APUSS

Assessing Infiltration and Exfiltration on the Performance of Urban Sewer Systems

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DELIVERABLE 11.3

Summarisation of "Economic valuation"

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1 Introduction

This report describes the work of work package (WP) 11 “Economic valuation” of the APUSS project (Assessing Infiltration and Exfiltration on the Performance of Urban Sewer Systems). The main task of WP 11 was to evaluate the cost and benefit of the replacement/rehabilitation of sewer systems considering different circumstances. Therefore a cost-structure for a sewer system was created to determine all relevant cost factors with respect to in- and exfiltration.

The working process of WP 11 was expressed in three deliverables which had been published:

- D11.1 Cost-structure of sewer systems
  (May 2004, restricted for EU commission)
- D11.2 Cost-benefit analysis
  (October 2004, restricted for EU commission)
- D11.3 Summarisation of “Economic valuation”
  (December 2004, unrestricted, now on hand)

Between the difficult working phases some special circumstances and new results of the project partners made it necessary to modify the WP. The main problem was the data availability especially detailed operating cost information. Therefore some light modifications had been adjust with the project partners and were written down in the minutes of meetings of the different management meetings. In the following the main points of work are listed.

Description of work

- Development of a cost-structure for a sewer system to determine all costs corresponding to infiltration and exfiltration
- Elaborate the main influencing factors of the cost-structure
- Investigating the costs to make the cost-structure applicable to standard circumstances of a rehabilitation of a sewer system
- Defining and if possible estimating the external effects such as further ecological consequences
- Establish a cost-benefit analysis with respect to in- and exfiltration
- Prepare a matrix of the economical interdependency and cost effects of the different influences
- Assemble the cost information for the new developed methods in the APUSS project

2 Development of a cost-structure of sewer systems with respect to in- and exfiltration

One objective of WP 11 is to develop a cost-structure for a typical sewer system to determine all costs corresponding to infiltration and exfiltration. Basis for this work was a system definition and a detailed process model for a sewer system. Therefore a commercial data entry form was developed, which symbolized the cost-structure of a sewer system.

2.1 System definition

The first step for development of a cost-structure for a sewer system is to define the system boundaries. The whole urban drainage system is shown in Figure 2-1 with the components urban and natural catchment area, sewer system, CSO structure, waste water treatment plant and receiving water. For the APUSS project the main focus for the evaluation of a cost-structure is placed on the component sewer system that includes all the pipes, the CSO structure as well as the pumping stations. System boundaries are on the one hand the house connections (see WP 3) and on the other hand the last sewer to waste water treatment plant (see Figure 2-1). Therefore all relevant costs for operations must be specified for these components.

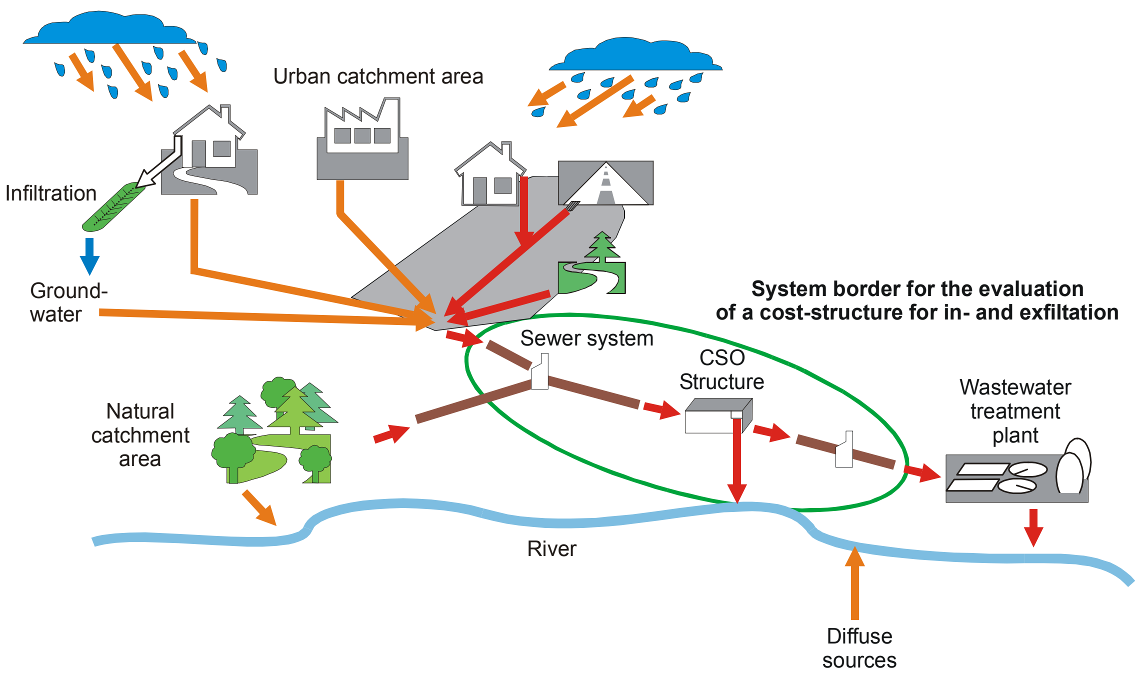


Figure 2-1: System border for the evaluation of cost-structure for in- and exfiltration

2.2 Process model of sewer systems

Crucial requirements for an examination of a sewer system are the allocation of costs to the different tasks which a sewer system has to fulfil. For this allocation the individual processes have been defined and described in detail (Figure 2-2).

In total four individual processes for a sewer system could be identified. These are:

- Private sewerage system
- Sewerage collection
- Stormwater treatment
- Miscellaneous

All this four individual process are divided in sub-processes. E.g. for the process “sewerage collection” are this the sub-processes gravity sewers, pressure main, inverted siphon, pumping station stormwater storage tank.

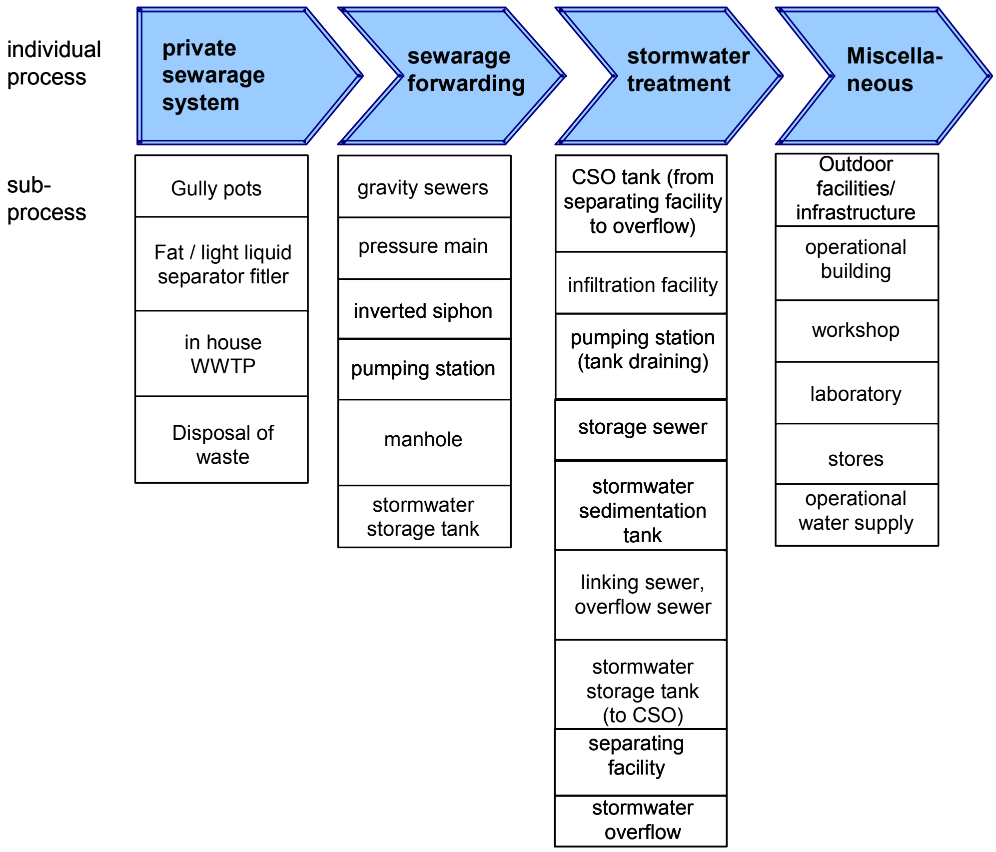


Figure 2-2: Process model of a sewer system (modified from EG/LV, 2003)

2.3 Cost-structure of sewer systems

For the development of a cost-structure of sewer systems it is necessary to divide all arising costs in subgroups. Therefore a commercial data entry form of sewer system as basis of economical indexing system was created (Table 2-1 and for detail see appendix on page 32). Therefore, the costs are divided into six groups. These are:

- Costs for material
- Wages and salaries
- Miscellaneous operational costs
- Disposal of waste
- Depreciation
- Calculated interest

Table 2-1: Reduced commercial data entry form of a sewer system (for detail see complete form in appendix)

No.	Indices (Total costs for the year:_____in €)	Unit	Overall sewer system	Private sewerage system			Sewerage collection					Stormwater treatment				Miscellaneous
			Tofal for cost group	Gully pots	Fat/light liquid separator	in house wwtp	gravity sewer	pressure main	inverted siphon	pumping station	manhole	CSO	storage tank	infiltration facility	storage sewer	
54	**Materials**	€														
540	Power, water, natural gas, TP gas, transmitted heat	€														
541	other fuels (for motor-vehicles)	€														
544	Auxiliary and operational utilities	€														
547	Cost for purchases (service and material)	€														
5471	***of which*** *maintenance services*	€														
5472	***of which*** *maintenance materials*	€														
549	Miscellaneous	€														
55	**Wages and salaries**	€														
551	***of which*** *maintenance and servicing*	€														
552	***of which*** *cleaning and inspection*	€														
59	**Miscellaneous operational cost**	€														
90	**Disposal of waste**	€														
57	**Depreciation (standadized)**	€														
58	**Calculated interest**	€														
Total amount																

The individual costs of the sewer system both for investment and operation of the sewer system were allocated to the respective individual processes.

This classification into six groups had been successfully tested in different benchmarking projects for wastewater treatment plants in Germany (e.g. SCHULZ et al., 2002 and SCHULZ, 2001).

All six groups are divided into sub-groups if necessary. E.g. the group “Materials” (no. 54) is divided into eleven sub-groups, like

- Power, water, natural gas, transmitted heat
- Other fuel (for motor-vehicles)
- Material for internal maintenance
- Material for internal cleaning and inspection
- Auxiliary and operational utilities
- Costs for purchases (service an material) – divided into four subgroups (see appendix)
- Miscellaneous

An extensive point is that costs for purchases were split into the parts maintenance services, maintenance materials as well as cleaning/inspection services and cleaning/inspection materials. In daily practice most of the costs are not collected in such a detail. This means that before the benchmarking processes starts the cost-structure in the accounting department of the operator has to change and the employees have to be instructed in the new system. This process needs time and often it works not very well in the beginning.

The group “wages and salaries” (no. 55) is only divided in two sub-groups. First one is the wages and salaries which are a result of maintenance and servicing and the second one of cleaning and inspection. It means that in practice the employees of the operator have to write down directly after finishing their work (at least daily) their working hours and allocate them to the two sub-groups.

The group “Miscellaneous operational costs” (no. 59) combines all costs which are not directly associated to special working processes. This group has to be divided into eight sub-groups:

- Licence fee
- Rent, lease, charge fee
- Assurance
- Office supply
- Post, transportation charge
- Travelling expenses
- Other and external services
- Miscellaneous

“Disposal of waste” (no. 90) is also one major point. This means e.g. all costs for disposal of sediments from the sewer system or leavings from sewer cleaning.

The last two points are “depreciation” (no. 57) and “calculated interest” (no. 58). Depreciation means the costs which are a result of the depreciation of a current replacement value or the investment cost e.g. for the sewer system or the one special sewer pipe. Calculated interest means the costs which have to rise to repay the credit from bank.

All these costs of the different groups must be allocated to the individual processes which had been defined in Figure 2-2. The four individual processes are:

- Private sewerage system
- Sewerage collection
- Stormwater treatment
- Miscellaneous

The four individual processes have three to five sub-processes which are also mentioned in Figure 2-2 and in the appendix. The main cost potential for in- and exfiltration is included in the process "sewerage collection" with the sub-processes

- Gravity sewers
- Pressure main
- Inverted siphon
- Pumping station
- Manhole

The main focus for the cost-structure and the cost/benfit analysis is on these points.

The field tests and measurements in the sewer system are the basis for the ascertainment of in- an exfiltration rates. With the measured rates the in- and exfiltration volume during the assessment period and some special performance indicators (see also Table 2-3 and Table 2-4) can be calculated. Among others the knowledge of the yearly total dry weather flow (DWF) and the proportion of in- and exfiltration on total DWF are input parameters for an up scaling on a complete sewer system (WP 5). Volume and proportion of in- and exfiltration are the input for a cost/benefit-analysis.

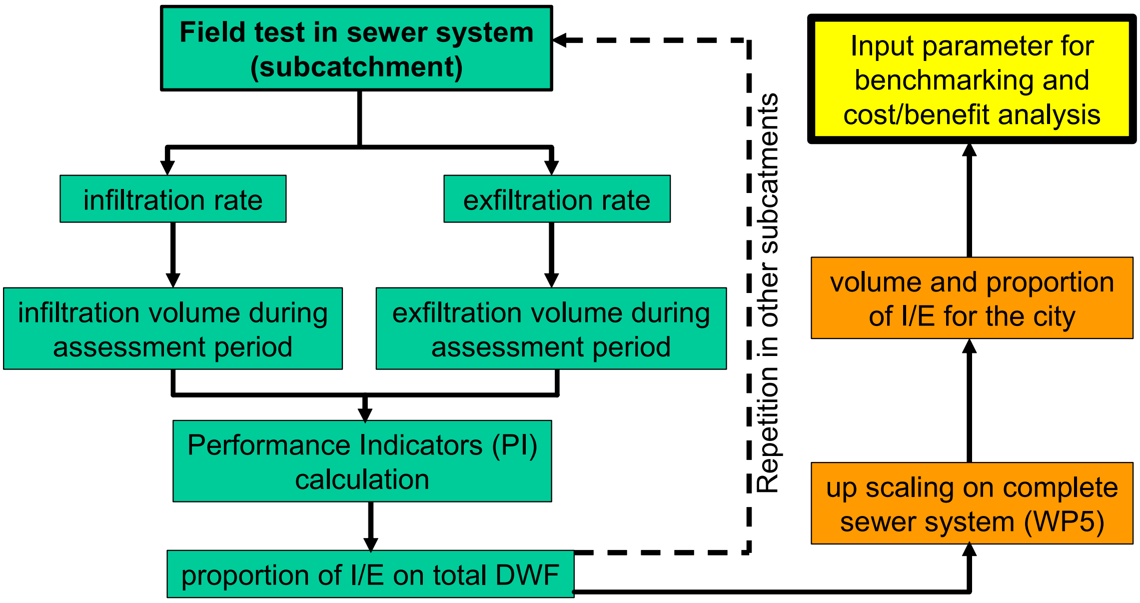


Figure 2-3: Procedure for determination (calculation) of in- and exfiltration rate as basis for the cost/benefit analysis

The main problem is that all the cost information and economical indices were not ascertained regarding the process in- and exfiltration. Instead of this all indices were ascertained for the special requirements of the sewer system operator. A classification of the accumulating costs for in- and exfiltration for two simple examples had been tried in chapter 2.4.

2.4 Simple example for an application of the developed cost-structure: Matrix of the economical interdependency

The costs of operation for a sewer system with respect to in- and exfiltration are hardly quantifiable and if possible at all a time-consuming work. In the following two simple examples of different groundwater situations (on the one hand infiltration and on the other hand exfiltration processes) are mentioned to introduce the complexity of this subject.

Figure 2-4 shows an example of a pumping station. With increasing groundwater infiltrates into the sewer system, more water flows to the pumping station. Consequently the costs of operation increase, because of a higher consumption of energy which is necessary to pump the water amount. With more pump capacity the costs for maintenance also increase. In this case the additional costs for infiltration can be calculated easily (see Table 2-2)

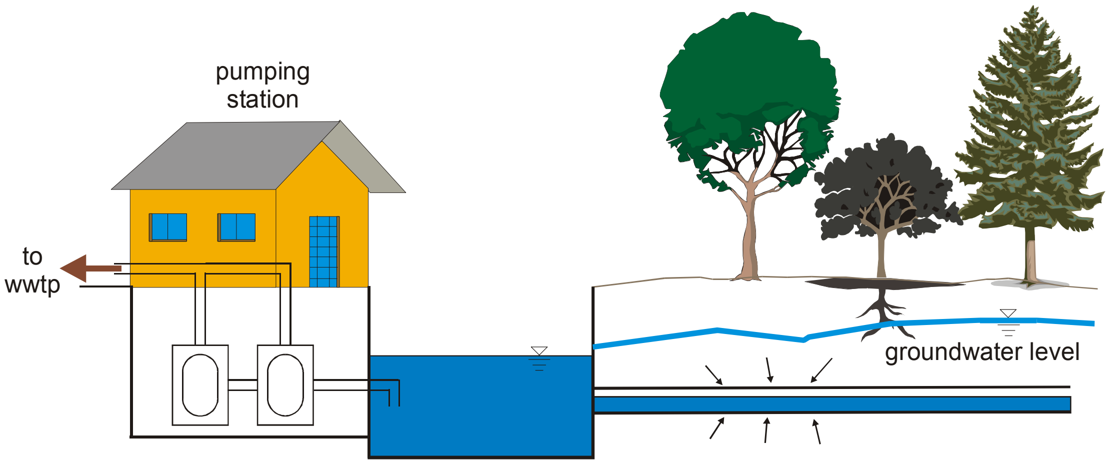


Figure 2-4: Simple example of a pumping station and increasing costs aroused by infiltration

The example in Figure 2-5 gives an impression of apparently decreasing costs for operation when wastewater exfiltrates into the ground. One possible changing in respect to exfiltration is a contamination of the ground and the groundwater with organic matter. Under special circumstances this contamination leads to higher concentrations in groundwater and receiving water and maybe to higher costs for treatment in the drinking water purification. Defining and estimating the external effects such as further ecological consequences was one point of WP 11, but after discussions with the other project partners at the London meeting, it was a decision by consensus that the analysis would be limited to sewer systems and infrastructure costs. The complexity of this point and the lack of reliable cost data make it impossible to manage this in detail.

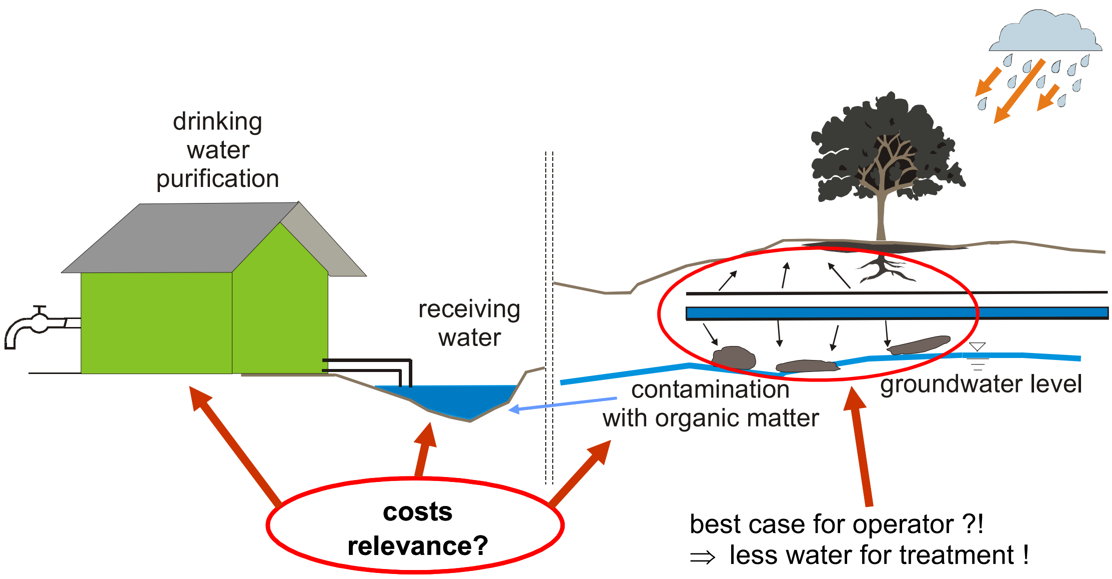


Figure 2-5: Example for exfiltration and apparently decreasing costs for operation

In Table 2-2 a first appraisal for the influence of in- and exfiltration and the development of costs is shown. Green arrows symbolises the exfiltration process and red ones the infiltration process. Nearly in all sub-process the costs for in- and exfiltration increase with higher in- or exfiltration rates. But e.g. for the sub-process "pumping station" the costs for power increase with higher infiltration rates and decrease with higher exfiltration rates (see Figure 2-4).

Table 2-2: First appraisal for influence of in- and exfiltration and the development of costs (matrix of the economical interdependency)

No.	Indices (Total costs for the year:_____in €)	Sewerage collection						Stormwater treatment			
		gravity sewer	pressure main	inverted siphon	pumping station	manhole	stormwater storage tank	CSO tank	stormwater storage tank	infiltration facility	storage sewer
54	**Materials**										
540	Power, water, natural gas, TP gas, transmitted heat	-	-	-	⇑ ⇓	-	-	-	-	-	-
541	Other fuels (for motor-vehicles)	S	S	S	S	S	S	S	S	S	S
542	Material for internal maintenance	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
543	Material for internal cleaning and inspection	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
544	Auxiliary and operational utilities	S	S	S	⇓ ⇓	S	S	S	S	S	S
547	Cost for purchases (service and material)										
5471	***of which*** *maintenance services*	⇑ ⇓	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
5472	***of which*** *maintenance materials*	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
5473	***of which*** *cleaning/inspection services*	⇑ ⇓	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
5474	***of which*** *cleaning/inspection*	⇑ ⇓	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
549	Miscellaneous	S	S	S	S	S	S	S	S	S	S
55	**Wages and salaries**										
551	***of which*** *maintenance and servicing*	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
552	***of which*** *cleaning and inspection*	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
59	**Miscellaneous operational cost**										
590	Licence fee	-	-	-	-	-	-	-	-	-	-
591	Rent, lease, charge fee	-	-	-	-	-	-	-	-	-	-
592	Assurance	-	-	-	-	-	-	-	-	-	-
593	Office supply	-	-	-	-	-	-	-	-	-	-
594	Post, transportation charge	-	-	-	-	-	-	-	-	-	-
596	Travelling expenses	-	-	-	-	-	-	-	-	-	-
597	Other and external services	-	-	-	-	-	-	-	-	-	-
599	Miscellaneous	-	-	-	-	-	-	-	-	-	-
90	**Disposal of waste**	⇑ ⇓	S	S	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
57	**Depreciation (standadized)**	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑	⇑ ⇑
58	**Calculated interest**	-	-	-	-	-	-	-	-	-	-
Total amount											

Legend:
⇑ Decreasing cost for exfiltration
⇓ Increasing cost for exfiltration
⇑ Decreasing cost for infiltration
⇓ Increasing cost for infiltration
S Secondary costs
- No influence

2.5 Application in benchmarking studies

Benchmarking is a well-established business practice that has yielded large improvements in different areas ranging from manufacturing to human resource management and from customer satisfaction to product design. The aim of benchmarking is to identify and learn from best practice. The first step is to realise whether there is a difference in performance between similar types of (in this case) sewer systems or not.

In Figure 2-6 the five work steps and 13 activities of a Benchmarking process are shown as described by ATV-DVWK (2000). The fist step is the “preparation and planning”, with a specification of the participants and the benchmarking object. Water associations, cities administration or operators could be participants of a benchmarking project. The next activity is the definition of a benchmarking object like a sewer system, waste water treatment plant (wwtp), receiving water or e.g. a special process inside the wwtp like carbon removal. A definition of different indices for the benchmarking process is the last activity in step one (e.g. Figure 2-7). The second working step is “data collection” with the activities data ascertainment and preparation and last but not least a check of data plausibility. Working step three is called “Benchmarking determination” and comprised the comparison of the different selected indices and the determination of benchmarks. The working steps four and five describe the practical site of the benchmarking process. In step four “Analyses” a critical reflection on the different parameters and benchmarks has to be done in detail. Different courses why the results are in this way and not better would be analysed, followed up by a calculation of achievement potential and the planning of action in future. The last step “Integration” is a transfer of the results to practice. A benchmarking process is only effective when a recapitulation of data ascertainment (working step two to five) can be implemented.

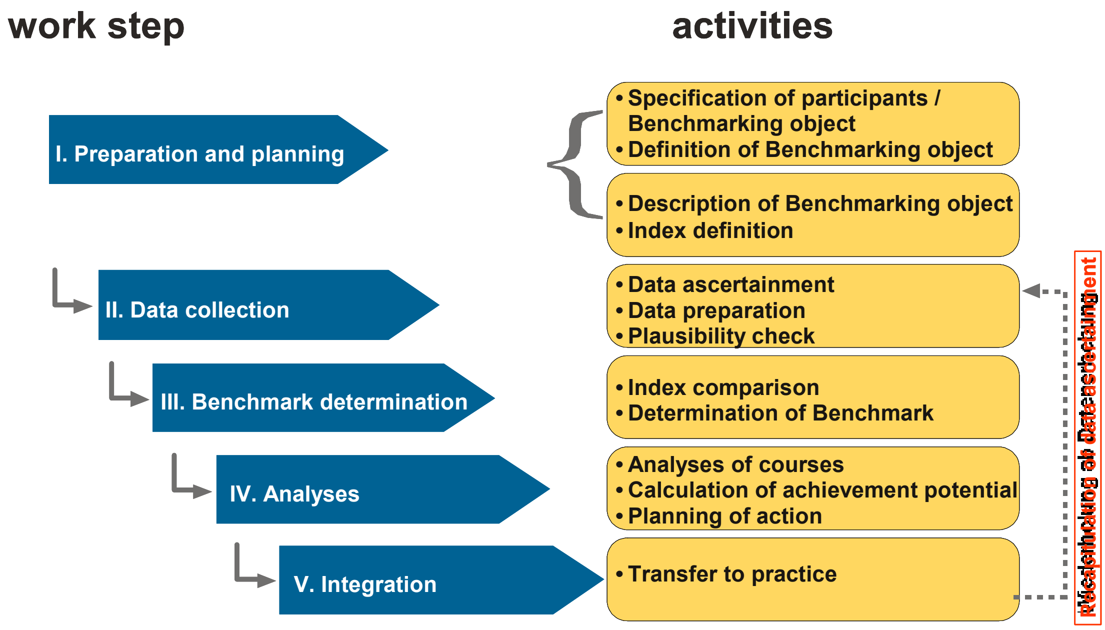


Figure 2-6: Work step / activities for a Benchmarking process (from ATV-DVWK, 2000)

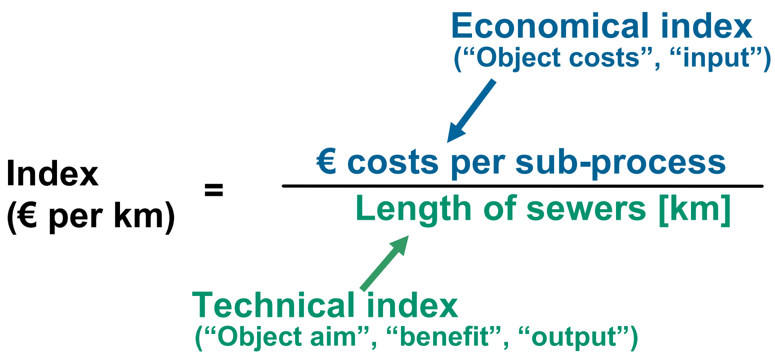


Figure 2-7: Example for an index development

An example for a simple index is shown in Figure 2-7 with the total length of sewers as reference value (technical index) and the operation costs as object costs (commercial index). The IWA Task Force on "Performance Indicators for Wastewater Services" (MATOS et al., 2004) presented in total 182 performance indicators (PI) which can be used a as basis for building different benchmarking indices. This report and the work of WP 9 was basis for the cost-structure. The 182 Performance Indicators (PI) presented in this manual are intended to provide a global set that should cover all types of undertaking and objectives for using a PI system. But it is not the intention that undertakings should necessarily use all of the 182 PIs, and it is unlikely that each of the PIs would be important for any undertaking. Hence, users should carry out a PI selection process. For APUSS only the four PIs from the subgroup "Inflow / Infiltration / Exfiltration (I/I/E)" are interesting.

Table 2-3: Performance Indicator (PI) the subgroup "Inflow / Infiltration / Exfiltration (I/I/E)" (MATOS et al., 2004)

Code	**Indicator**	**Unit**	**Concept** ***Processing rule*** **Comments**
wOP30	Inflow / Infiltration / Exfiltration (I/I/E)	%	Volume of water entering sewers, from groundwater and wrong connections less the leakage from sewers into the ground / (collected sewage + inflow + infiltration – exfiltration) x 100, during the assessment period *wOp30=(wD35+wD36-wD37) /(wF1+wD35+wD36-wD37)x100* This indicator may be assessed for periods shorter than one year, but special consideration is required when used for comparisons, either internal or external to the undertaking.
wOP31	Inflow	m³/km/ year	(Volume of water entering sewers from wrong connections during the assessment period x 365 / assessment period) / total sewer length at the reference date *wOp31 = (wD35 x 365 / wH1) / wC1* *Note that " x 365 / assessment period" is a unit conversion expression and is not intended to be considered as extrapolation.* *This indicator may be assessed for periods shorter than one year, but special consideration is required when used for comparisons, either internal or external to the undertaking.*

wOP32	Infiltration	m³/km/ year	(Volume of water entering sewers from groundwater during the assessment period x 365 / assessment period) / total sewer length at the reference date *wOp32 = (wD36 x 365 / wH1) / wC1* *Note that " x 365 / assessment period" is a unit conversion expression and is not intended to be considered as extrapolation.* *This indicator may be assessed for periods shorter than one year, but special consideration is required when used for comparisons, either internal or external to the undertaking.*
wOP33	Exfiltration	m³/km/ year	(Volume of leakage from sewers into the ground during the assessment period x 365 / assessment period) / total sewer length at the reference date *wOp33 = (wD37 x 365 / wH1) / wC1* *Note that " x 365 / assessment period" is a unit conversion expression and is not intended to be considered as extrapolation.* *This indicator may be assessed for periods shorter than one year, but special consideration is required when used for comparisons, either internal or external to the undertaking*

Table 2-4 contains the variables definition according to the subgroup “Inflow / Infiltration / Exfiltration (I/I/E)”, included all necessary operational indicators, physical assets data and time data.

Table 2-4: Variables definitions according to the subgroup “Inflow / Infiltration / Exfiltration (I/I/E)” (MATOS et al., 2004)

wD35	inflow **VOLUME**	Unit: ***m***^{3} Valid values: ≥ 0
	Volume of water entering sewers from wrong connections during the assessment period. *Wrong connections include incorrect connections to the sewer system (e.g. direct surface runoff and entry through manhole covers to sanitary sewer).*	
wD36	infiltration **VOLUME**	Unit: ***m***^{3} Valid values: ≥ 0
	Volume of water entering sewers from ground water during the assessment period.	
wD37	exfiltration **VOLUME**	Unit: ***m***^{3} Valid values: ≥ 0
	Volume of leakage from sewers into the ground during the assessment period.	
wF1	**COLLECTED SEWAGE**	Unit: ***m***^{3} Valid values: ≥ 0
	collected sewage, corresponding to the volume of domestic, commercial and industrial inputs to the sewer system during the assessment period. *This data should be obtained from a measure of dry weahter flow subtracting infiltration, in dry weather conditions. In case there are no measurements of dry weather flow, collected sewage can be estimated based on a return factor, which is a percentage of water supplied that is discharged as wastewater.*	

wH1	**ASSESSMENT PERIOD**	Unit: ***days*** Valid values: Integer
	Period of time adopted for the assessment of data (variables, PI and CI). *The IWA PI system aims to be used annually and therefore it is highly recommended that the year is used as the reference assessment period. However, since the undertakings may need to track the evolution of their performance within the year, the PI system is prepared to accommodate other assessment periods for most indicators.* *In this case, and in order to ensure unit coherence and allow for PI comparison, all the PI expressed in terms of time are formulated in such a way that the values calculated for other assessment periods are converted into annual values.* *Attention is drawn to the fact that the behaviour of most variables is not uniform during the year, due to random or seasonal effects, or to activity planning. All comparisons based on PI assessed from non-annual data must take this fact into consideration, in order to avoid any bias.*	
wC1	**TOTAL SEWER LENGTH**	Unit: ***km*** Valid values: ≥ 0
	Total length of sewers managed by the undertaking at the reference date. *Service connections excluded.*	

The main problem for the use of the PI’s (Table 2-3) is the unknown volume of water entering sewers from groundwater (infiltration volume, wD36, Table 2-4) and the volume of leakage from sewers into the ground (exfiltration volume, wD37, Table 2-4): None of the asked sewer system operators has reliable information about this. So the only practicable way is to use information from the measurements of different sewer systems and the associated costs of these measuring campaigns.

3 Possible effects of sewer rehabilitation – drainage effect

Many sewer systems are not only a drainage system for waste water and stormwater. Because of leakage there also have often more or less randomly the function of a drainage system for groundwater (see Figure 3-1 and Figure 3-2). The drainage effect of the sewer system could be very high, especially by a low distance between groundwater level and surface e.g. in polder regions. Furthermore there is a high variability of infiltration with a maximum value at the end of winter half year, just when the groundwater level is on the highest stage (ATV-DVWK, 2003b).

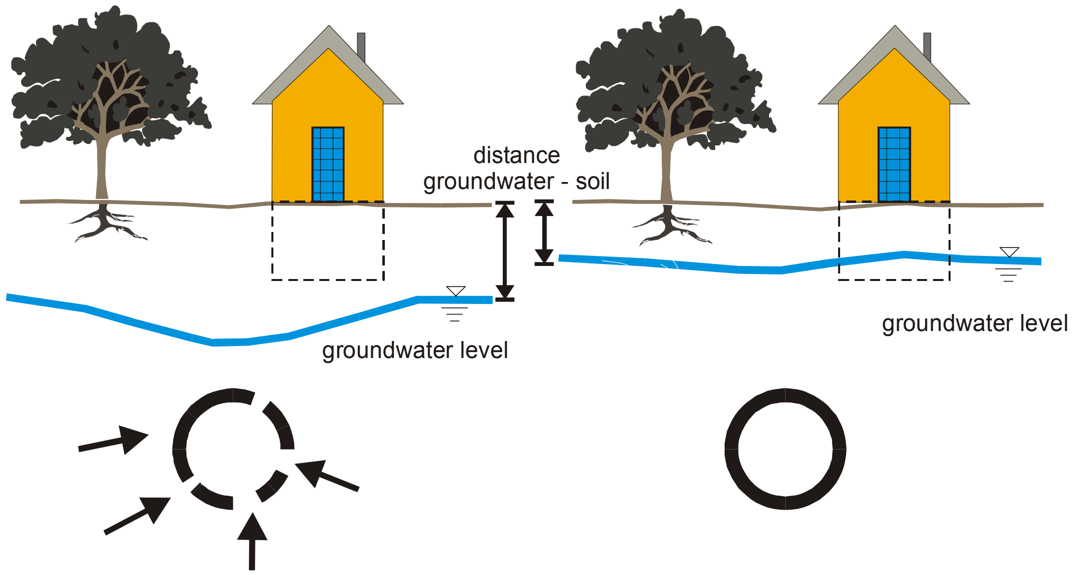


Figure 3-1: Possible change of groundwater situation after rehabilitation of sewer system

The drainage effect of sewer pipes is known for a long time. So BUESING had discussed this point in detail in his book “Handbuch der Hygiene” (only in German available) from 1894. He gives some examples how with different selective measures, e.g. the installation of a drainage pipe right under the normal sewer pipe with the result of a better construction possibility when a low distance between groundwater level and surface is predominate (see Figure 3-3). The lowering of the groundwater table by knowingly leakage (e.g. open joints) or unintended leakage (e.g. insufficient construction) with a permanent reception of groundwater into normal wastewater sewer has to be excluded clarifies BUESING already in the year 1894.

By a rehabilitation of the sewer system with sealing of leakage, infiltrated groundwater could not be drained in the sewer pipe as before. If no alternative drainage possibilities were made available, the sealing of leakage could be followed by a increasing of the groundwater level over a wide area. Beside the ecological advantages of the infiltration reduction also the disadvantageous effects have to keep in mind. But disadvantageous effects don’t excuse the operator of the sewer system from the responsibility of rehabilitation. Some possible effects of sewer rehabilitation after a listed below:

- water logging of not watertight cellars and basements (consequence: limited usability),
- damage to buildings as consequence of water logging of building components and base plate,
- change of the utilisation of garden and agriculturally used areas,
- flooding of areas,
- increasing of infiltrated water in drainage systems of developed real estate,
- remobilisation of pollution from abandoned polluted areas.

Figure 3-2: Infiltrated groundwater in an old sewer pipe

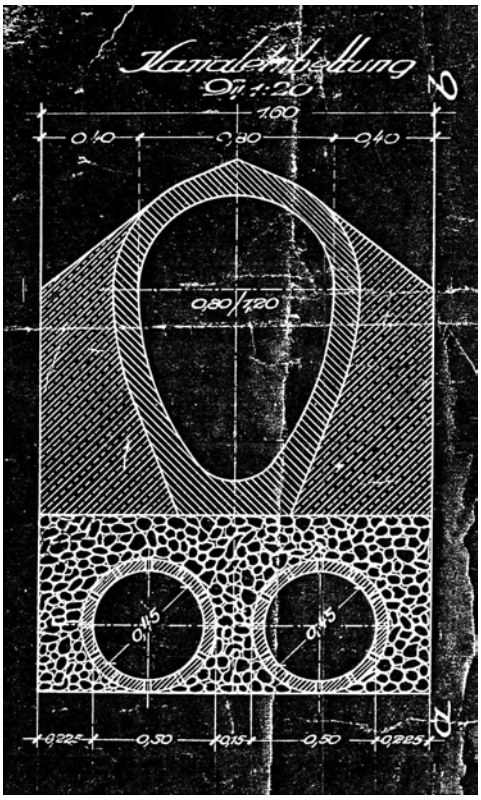


Figure 3-3: Sewer pipe in the City of Duisburg, year of construction 1921 with accompanying drainage (Getta et al., 2004)

4 Basics of cost-benefit analysis

Cost-benefit analysis (CBA) is an analytic framework for organizing purposes, listing the pros and cons of alternatives and determining values for all relevant factors so that the alternatives can be ranked (SCHMID, 1989).

The basic notation is relatively simple. If we have to decide whether to do *A* or not, the rule is: Do *A* if the benefits exceed those of the next best alternative course of action, and not otherwise. If we apply this rule to all possible choices, we shall generate the largest possible benefits, given the constraints within which we live (LAYARD and GLAISTER, 1994).

To guarantee that the choice of alternatives fulfil minimal requirements, it is necessary to define indispensable receivables regarding benefits and costs. In the cost-benefit-chart (see Figure 4-1) it is visible that alternatives have to be eliminated of the evaluation, if the indispensable receivables regarding benefit are not fulfilled or if the cost limit is exceeded. In the worst case it is possible that all alternatives are located in the double hatched area. That means the minimum requirements for costs and also for benefit are not fulfilled.

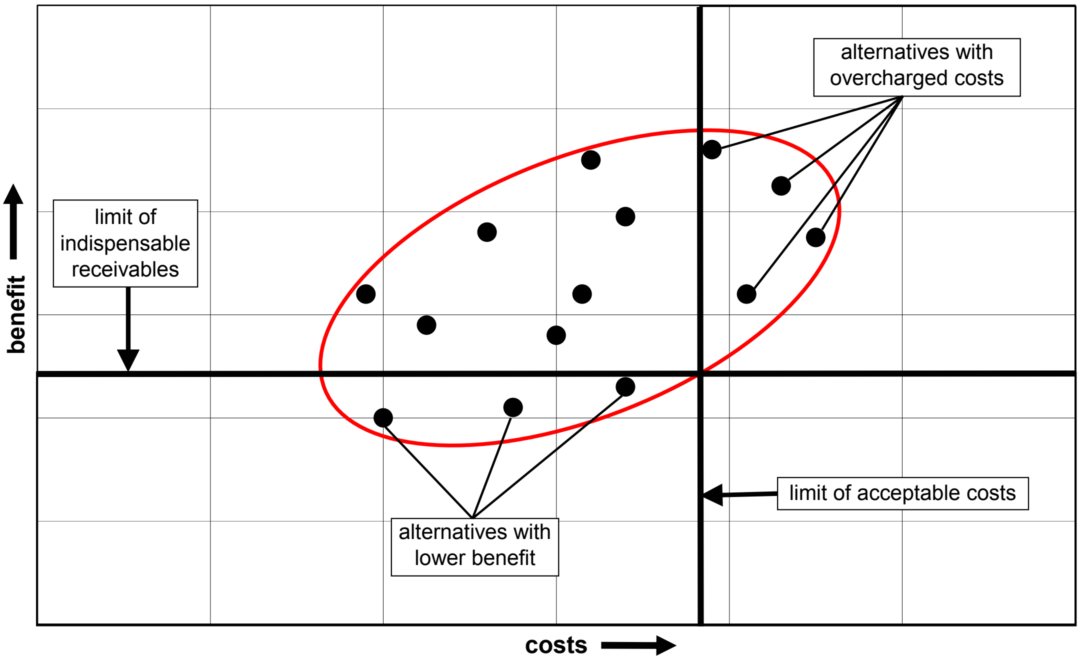


Figure 4-1: Example for the results of a cost-benefit analysis

RINZA and SCHMITZ (1992) suggest a procedure of five stages for a CBA (see Figure 4-2). The first stage is the definition and differentiation of the problem, which also includes a specification of indispensable requirements. The second stage is the benefit analysis. This stage could be divided in seven single steps. These are a definition of the project aims, weighting of the aims, preparation of value table and function, disclose and valuate of alternatives, calculation of the value of benefit and ranking order, a sensitivity analysis and the presentation of results (see Figure 4-2 grey box). Beside the benefit analysis, the cost analysis is part of stage three. With the results of the benefit analysis and the cost analysis the main CBA could be started. In this stage the range of convenient alternatives is also defined. Last point (stage five) is the presentation of results and in the most of the cases a choice of the best alternative.

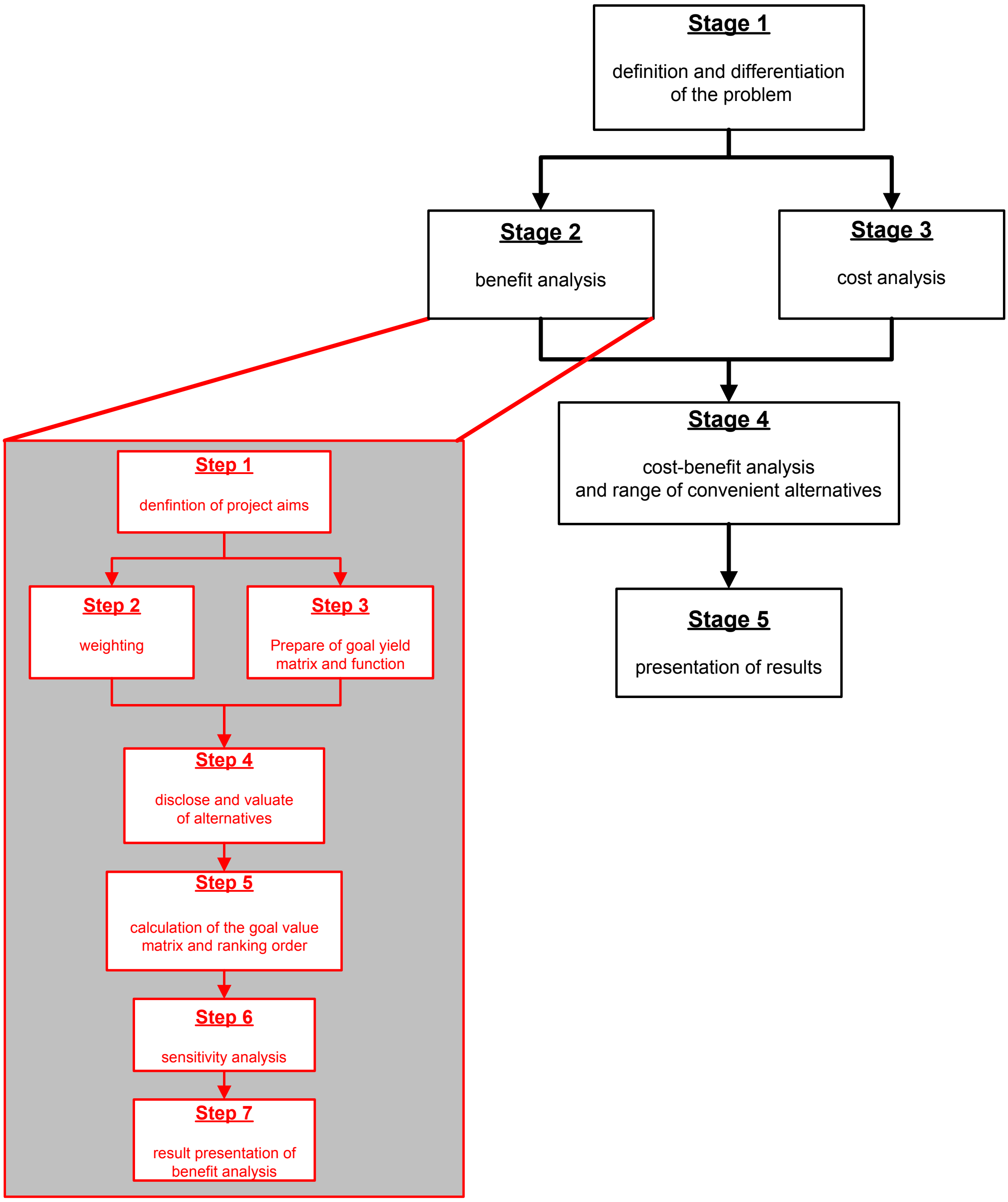


Figure 4-2: Sketch of the process of a cost-benefit analysis (modified from RINZA and SCHMITZ, 1992)

4.1 Benefit analysis

The Benefit analysis (BA), also referred to as multi-factor method, is a static evaluation procedure, used to prepare a selection between several alternatives. With the help of BA it is attempted to make transparent both the evaluation and the decision.

The individual options are evaluated with respect to the specified subgoals. Usually, a marking scale is used for the evaluation. Based on their different importance, the sub-goals are differently weighted. The benefit value (the overall goal performance) of an option is the sum of the weighted subgoal performances, i.e. a weighted average, and represents the decision criterion.

If the application criteria of the method are met and if no cost-related decision has to be made, the procedure is as follows:

1. Definition of knock-out criteria
2. Collection of suitable options (market analysis)
3. Rejection of alternatives not meeting one of the knock-out criteria
4. Defining and weighting goal criteria
5. Evaluating the subgoal performance per option (= goal yield matrix)
6. Calculating the weighted subgoal performance (= goal value matrix) and the overall goal performance (= total benefit) per alternative
7. Selection of the best alternative
8. In case of only minor differences: realization of sensibility analysis and thus backing up or possibly changes the decision. The sensibility analysis is to define how the result of the evaluation changes if within an acceptable range the allocation of weights or the evaluation of subgoals for the alternatives is varied.
9. Presentation of results

Points 1 to 3 are used to prepare the benefit analysis (points 4 to 9) as shown in the grey box in Figure 4-2.

4.2 Cost analysis

The cost analysis could be divided in two main parts:

- Calculation of the costs for sewer system operation and possible cost savings
- Calculation of the investment costs necessary to reduce in- or exfiltration

As mentioned before one objective of WP 11 was to develop a cost-structure for an average sewer system to determine all costs corresponding to infiltration and exfiltration. Therefore, a commercial data entry form was developed, which symbolized the cost-structure of a sewer system. With this commercial data entry form (see Table 2-1) it is possible to calculate all operational costs of a sewer system in detail.

4.3 Implementation of the cost-benefit analysis for sewer systems with respect to ex- and infiltration

A procedure for the evaluation of a cost-benefit analysis is shown in Figure 4-3. First it is necessary to make a cost calculation with help of the table of economic indices for the sewer system (commercial data entry form, see Table 2-1). The main focus for in- and exfiltration is on the individual process “sewerage collection”. The costs per m³ flow and the proportion of cost for in- and exfiltration from total yearly flow, as a result of measurement directly in the sewer system and of up scaling (WP 5) are input parameters for the cost-benefit analysis. Costs for field tests and costs for rehabilitation of the sewer system are the two main other input parameters for the cost- benefit analysis. It has to be admitted, that these evaluation would be only a theoretical study. After many discussions with our end-users it became clear that the cost data for investment and operation are too confidential to use in a research project. This was also discussed at the London meeting 2004.

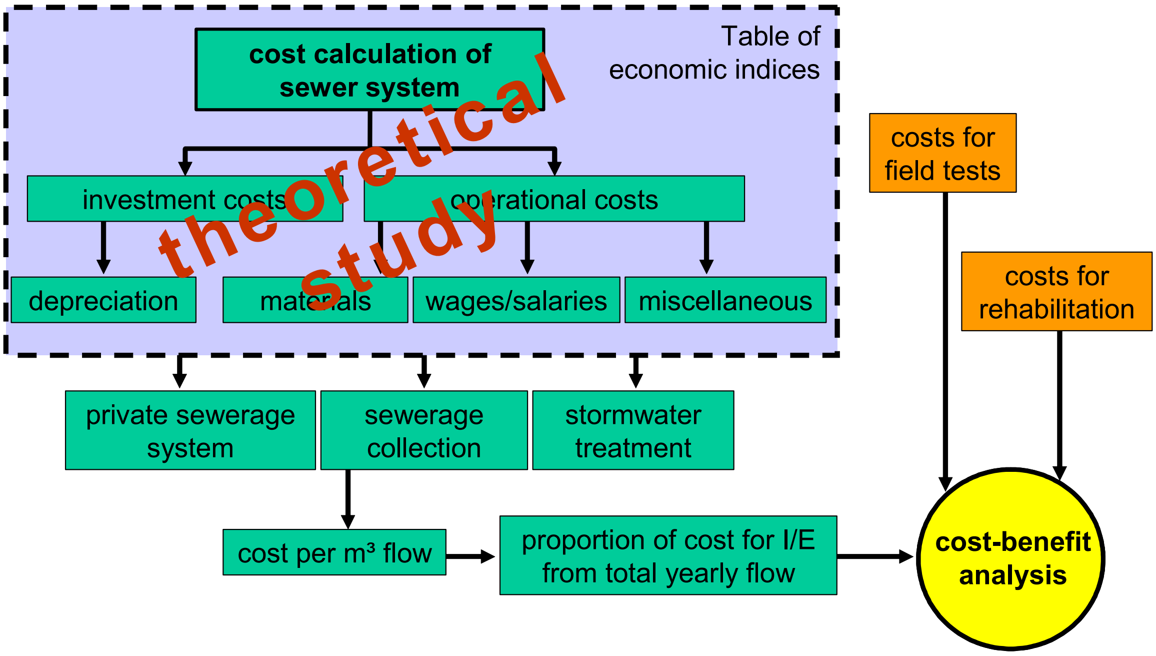


Figure 4-3: Procedure for the cost-benefit analysis

5 Example for a CBA for sewer rehabilitation with respect to in- and exfiltration

As described in chapter 2.4 nearly in all sub-processes the costs for in- and exfiltration increase with higher in- or exfiltration rates. But only for some sub-processes a clear influence could be transferred in real costs. E.g. for the sub-process “pumping station” the costs for power increase with higher infiltration rates and decrease with higher exfiltration rates.

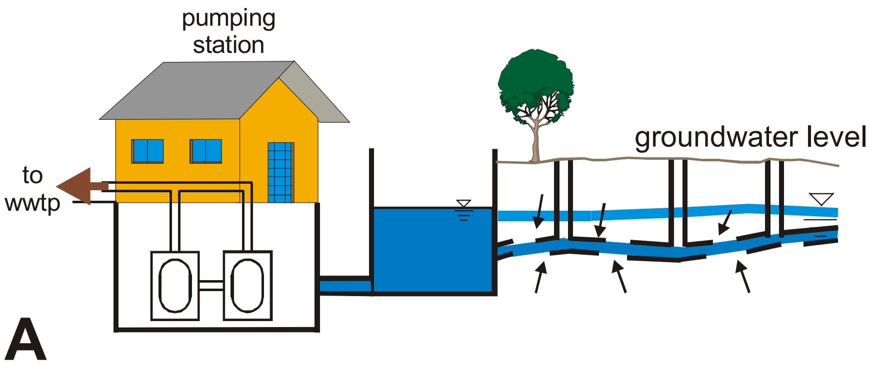
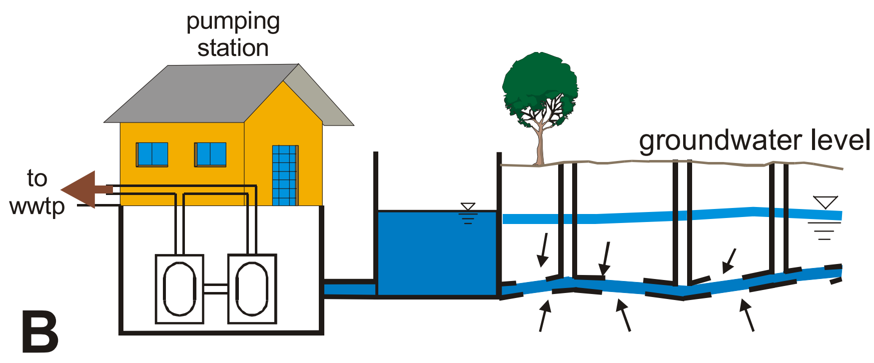
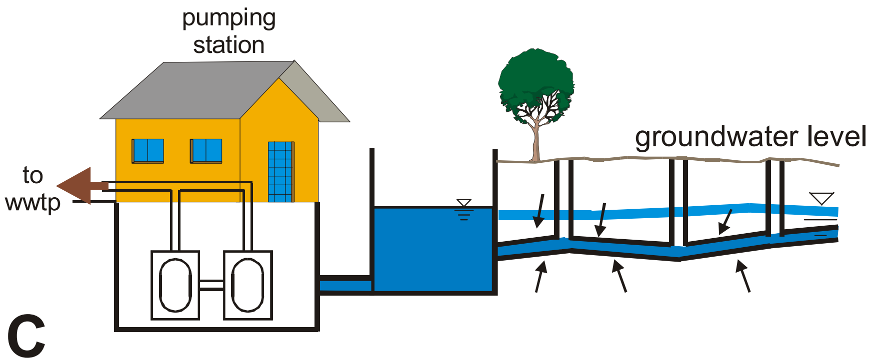
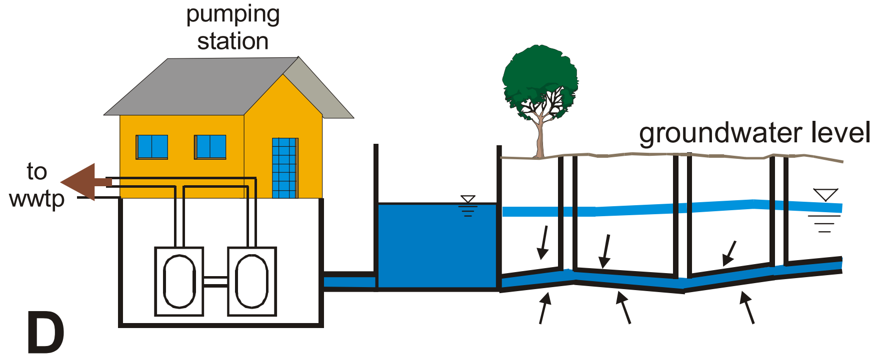
The influence of infiltration would be discussed on four special examples (see Table 5-1). In example A and B the damages in the sewer system are so serious, that a replacement of the sewer pipe is necessary. In example C and D there are only light damages, so a replacement is not necessary and a rehabilitation of the sewer pipe is possible. The difference between A and B as well as C and D are the different cover depth. In example A and C the cover depth is about 4 m and in example B and D about 10m. In all four examples a pumping station is located at the end of the sewer system, where the wastewater is pumped towards the wastewater treatment plant. The different cover depths (nearly equal to the delivery head of the pumping station) lead to varied energy costs for the pumping station.

5.1 Basics for cost-benefit analysis of the four special examples

Basics and boundary conditions for the cost calculation are listed in the following (see Table 5-1):

- Length of sewer: 40 m
- Diameter: 600 mm
- Cover depth: 4 m or 10 m
- Surface: Street with asphalt covering
- No. of manholes: 2
- No. of HC: 2
- DWF: 27 L/s
- Infiltration rate: 38 %
- Efficiency factor (pump): 55 %
- Price per kWh: 0.06 €/kWh

Table 5-1: Four Examples for a CBA with respect to infiltration

	cover depth H = 4 m	**cover depth** H = 10 m
Replacement **(serious damages)**		
Rehabilitation of sewer system **(light damages)**		

5.2 Cost data for the replacement and rehabilitation of sewer pipes

For the evaluation of the CBA it is necessary to collect and analyse different cost information for the replacement and rehabilitation of a sewer pipe. Source of cost information in Table 5-2 and Table 5-3 are data from different investment projects of the City of Gladbeck and Emschergenossenschaft, but also information from STEIN & PARTNER (Consulting Engineers for pipeline construction, pipeline maintenance and rehabilitation) and different literature.

In Table 5-2 cost data are listed for the replacement of a sewer pipe corresponding to the example A and C (Table 5-1) with a cover depth of 4 m for the sewer pipe. In Table 5-3 the cost data for a cover depth of 10 m is shown (example B and D in Table 5-1). A cover depth, which is nearly equal to the delivery head of 10 m or more, is not unusual in the Emscher region. At the moment Emschergenossenschaft is planning three pumping stations with a delivery head of more than 18 m.

The remaining costs for a replacement of a sewer pipe could be divided in subgroups. These are:

- sewer pipe (including delivery, installation and testing of leaks)
- trench coating
- ground excavation
- sump drainage
- drawdown
- upraise, recovery of surface
- house connection
- bottom part, upper part and cover of manhole

With these cost information it is possible to calculate the replacement costs of a single sewer pipe.

E.g. the costs for a sewer pipe including delivery, installation and testing of leaks (all earthworks like ground evacuation etc. are not included) for different diameters are shown in Figure 5-1 (basis for the cost calculation in Table 5-2 and Table 5-3). During the analysis of the different cost data, it became visible that the delivery costs vary in wide range. Therefore three classes had been defined to make the range available. The lower line is a minimum value and the upper one a maximum value for the delivery cost. In the middle is the expected value displayed which is located in the middle of minimum and maximum value.

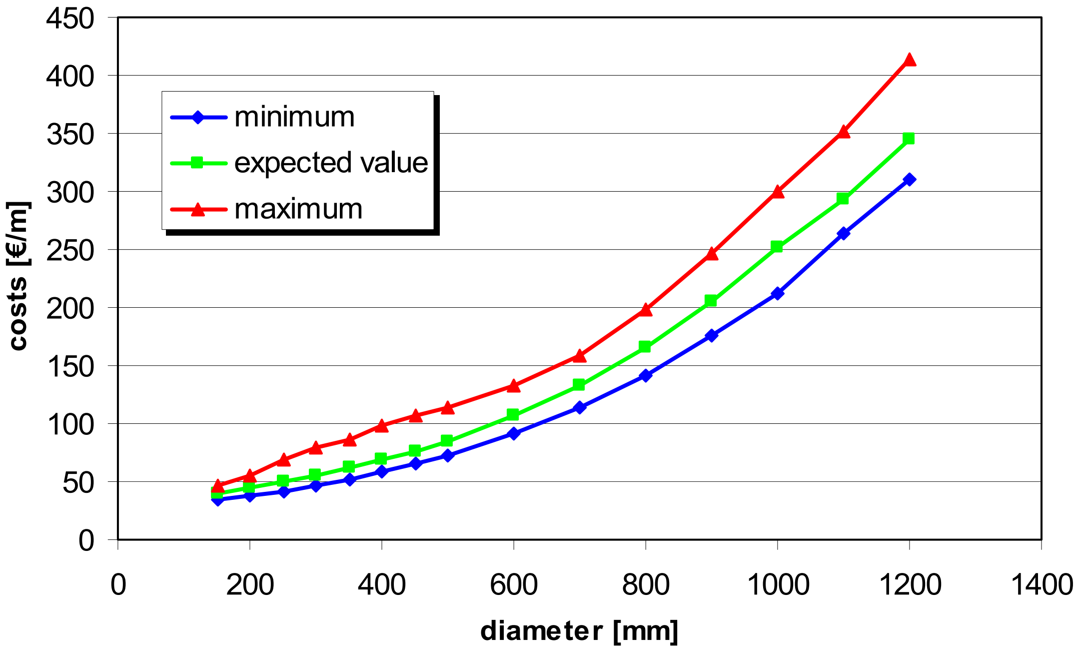


Figure 5-1: Costs for sewer pipe including delivery, installation and testing of leaks (all earthworks like ground evacuation etc. are not included)

Table 5-2: Cost information for the replacement of sewer pipes (cover depth 4 m)

		cover depth 4m		
	unit	**minimum**	**expected value**	**maximum**
sewer pipe (DN 600) *)	€/m	90.92	106.30	133.40
trench coating **)	€/m²	9.00	16.00	29.50
ground excavation ***)	€/m³	17.00	23.00	30.50
sump drainage +)	€/m	5.00	10.00	20.00
drawdown ++)	€/m	81.00	90.00	108.00
upraise, recovery of surface	€/m²	46.50	59.00	74.50
house connection	€/piece	130.00	180.00	225.00
bottom part of manhole	€/piece	972.72	1,189.10	1,556.27
upper part of manhole	€/m	130.00	200.00	720.00
cover of manhole	€/piece	133.00	440.00	651.00

*) including delivery, installation and testing of leaks (see Figure 5-1)
**) depth 4 m
***) soil class 3: easy removable soil (DIN 18300, 2002)
+) for 2 m
++) drawdown of 2 m

Table 5-3: Cost information for the replacement of sewer pipes (cover depth 10 m)

		cover depth 10 m		
	unit	minimum	expected value	maximum
sewer pipe (DN 600) *)	€/m	90.92	106.30	133.40
trench coating **)	€/m²	36.00	69.00	94.50
ground excavation ***)	€/m³	35.00	49.50	72.50
sump drainage +)	€/m	7.40	14.00	30.00
drawdown ++)	€/m	288.00	320.00	384.00
upraise, recovery of surface	€/m²	46.50	59.00	74.50
house connection	€/piece	130.00	180.00	225.00
bottom part of manhole	€/piece	972.72	1,189.10	1,556.27
upper part of manhole	€/m	130.00	200.00	720.00
cover of manhole	€/piece	133.00	440.00	651.00

*) including delivery, installation and testing of leaks (see Figure 5-1)
**) depth 4 m
***) soil class 3: easy removable soil (DIN 18300, 2002)
+) for 2 m
++) drawdown of 2 m

After a literature review and a collection of different cost data of rehabilitation methods, three different cost approaches for sewer relining could be identified:

- ~ 0.80 €/(mm diameter and m) for low depths of cover (< 5 m)
- ~ 1.00 €/(mm diameter and m) for depths of cover > 5 m
- “half diameter in mm = price in € per m sewer line” (empirical formula, ATV-DVWK, 2003a)

The costs for a rehabilitation of a house connection or manhole could be calculated with 1,500 € per house connection or manhole (ATV-DVWK, 2003a).

5.3 Cost-benefit analysis: example for infiltration

For the cost-benefit analysis it is necessary to calculate the amount of investment costs for the replacement of one sewer pipe (example A and B) and the rehabilitation (example C and D). Investment costs on the boundary conditions mentioned in chapter 5.1 and cost information for the replacement of sewer pipes (see chapter 5.2) for the different cover depths are displayed in Table 5-4. The cost for the replacement varies from € 17,500 to € 34,000 for a cover depth of 4 m and from € 63,000 to € 135,000 for a cover depth of 10 m. Rehabilitation of the sewer pipe is of course much cheaper. In these cases the range is from € 24,500 (cover depth of 4 m) to € 29,500 (cover depth of 10 m). The empirical cost approach (see chapter 5.2 “half diameter…”) provides investment costs of € 18,000 independent of the cover depth, which seems to be too little. According to the variation in Figure 5-1, Table 5-2 and Table 5-3 there are also strong variations in Table 5-4 (see also appendix on page 31).

Table 5-4: Investment costs of the four examples

		cover depth H = 4 m	**cover depth H = 10 m**
Replacement	minimum expected value maximum	€ 17,500 to € 23,500 to € 34,000	€ 63,000 to € 99,000 to € 135,000
Rehabilitation	minimum maximum	€ 18,000 to € 25,000 €	€ 18,000 to € 30,000

For all of the examples it is assumed that a pumping station is located at the end of the sewer system. Wastewater and infiltrated groundwater have to be pumped to the waste water treatment plant. After a replacement or rehabilitation of the sewer pipe subject to infiltration, a reduction of pumping costs is possible. Before it is possible to calculate these costs it is necessary to calculate the pump capacity and power supplied.

The power required at the operating point can be derived from the operating flow-rate and delivery head in conjunction with the pump’s efficiency. Power (energy per time) is the product of weight per time (ρgQ) and delivery head (energy per weight). So:

$$P = \rho \cdot g \cdot Q \cdot H \qquad (5\text{-}1)$$

P power (W)

ρ density (taken as 1000 kg/m³ for water)

g gravitational acceleration, (9.81 m/s²)

Q operating flow-rate (m³/s)

H delivery head (m)

A pump receives power (‘power supply’), usually in the form of electrical power. But the pump and motor are not 100 % efficient at converting the power supply into power given to water. Efficiency (power given to the water divided by power supplied to the pump) varies with flow-rate, and can be taken from the manufacturer’s plot (BUTLER and DAVID, 2000). Therefore:

$$Power\ \text{supplied} = \frac{\rho \cdot g \cdot Q \cdot H}{\eta} \qquad (5\text{-}2)$$

where

η efficiency (-)

With the information listed in chapter 5.1 (DWF = 27 L/s and Infiltration = 38%) and time of pumping over one year, the pumping cost and a possible reduction of the pumping costs could be calculated. The pumping costs per year are about 1015 € to 2530 € for a cover depth of 4 m to 10 m. Using the hypothesis that the pipe is water-tight after rehabilitation or replacement, a saving of about 385 € per year is possible for a delivery head of 4 m and a value of about 960 € per year for a delivery head of 10 m (see Table 5-5).

Table 5-5: Reduction of costs for pumping

	pumping costs per year	**cover depth H = 4 m**	**cover depth H = 10 m**
Replacement	1015 €/year	~ 385 €/year	~ 960 €/year
Rehabilitation	2530 €/year	~ 385 €/year	~ 960 €/year

Pumping costs are only calculated on basis of the energy costs

With the calculated investment cost for replacement or rehabilitation (Table 5-4) and with reduction of costs for pumping (Table 5-5) it is possible to calculate the amortisation time of the chosen measure. Therefore the investment costs have to be divided by the possible savings. The calculation is simplified without a cost increase over time and the interest calculation is unconsidered. In Table 5-6 the amortisation time is calculated on the basis of the cost analysis. The amortisation time of the replacement measure varies between 45 years and 88 years (H = 4 m) and 65 years and 141 years (H = 10 m). If these results were compared with the normal life cycle of a new sewer pipe, which is about 80 years to 100 years, a critical appraisal of results is necessary.

Table 5-6: Amortisation – life cycle of sewer pipes

	threshold value	**cover depth H = 4 m**	**cover depth H = 10 m**	
Replacement	80 to 100 years	45 years to 61 years to 88 years	65 years to 103 years to 141 years	minimum expected value maximum
Rehabilitation	50 to 60 years	47 years to 65 years	19 years to 31 years	minimum maximum

Interest calculation is unconsidered.

In most of the cases a rehabilitation of the sewer system or a single sewer pipe is cheaper than a replacement. But it has to be considered that a rehabilitation measure is not as long fully functional than a replacement of a sewer line. So all measures should be very critical reviewed with an amortisation time over 50 to 60 years, because the maximum expected useful life varies for a rehabilitation measure from 40 to 50 years. But of course not only economical reasons are taken into account in the decision making process, but also often political reasons. The decision if a replacement or a rehabilitation (e.g. with inliners) is the best solution, has to be check for every single case in detail. A general recommendation for one of these techniques is not possible. Moreover, due to new European directives, the consideration of environmental aspects will probably become more and more important in the future (see also WP10).

6 Cost information for experiment campaigns

One aim of WP 11 was to evaluate cost information of experiment campaigns for measurement of in- and exfiltration. Therefore all partners were asked to calculate the amount of the experiment campaigns they had been carried out.

In Table 6-1 are costs for "prototype" measurements of four methods QUEST-C, s::can, Isotopes and the measurement of house connections for in- and exfiltration (HC). Indeed there are procedural differences between the QUEST and QUEST-C methods, e.g. Lithium Chloride and Sodium Bromide as tracer instead of Sodium Chloride, but there are not so big differences between the costs of the two methods.

Table 6-1: Range of costs for experiment campaigns (estimation of each partner)

Methods developed within the APUSS project	**QUEST-C (exfiltration)**	**s::can (infiltration)**	**Isotopes (infiltration)**	**HC *) (in- and exfiltration)**
measuring equipment	~ € 10,700 to € 13,200	~ € 24,500 to € 28,300	~ € 17.200	~ € 300 +) to € 2,200
Including	Flow measuring unit Mixer	Flow measuring unit s::can probe	Flow measuring unit equipment for groundwater sampling	CCTV camera sealing balloons (only rental basis)
personnel cost	~ € 1,500 to € 2,000	~ € 1,500 to € 5,000	~ € 3,000	~ € 400 to € 800
Calculated hours	~ 70 h – 80 h	~ 60 h – 110 h	~ 120 h	~ 80 h – 160 h
Calculated Price per hour	€ 22 - € 27	€ 25 - € 45	€ 25	€ 5
Number of experiments/samples	1 / 4 - 10	1 / 20	1 / 44	2-3 / -
cost for consumption	~ € 300 to € 500	~ € 500 to € 1,000	~ € 2,700	~ € 100 to € 200
total cost	~ € 13,200 to € 15,000	~ € 27,500 to € 30,400	~ € 24,900	~ € 1,200 to € 2,800
cost per experiment	~ € 1,800 to € 2,200	~ € 2,000 to € 5,500	~ € 5,700	~ € 600 to € 900

Cost information from WP1, WP3, WP4, WP7 and WP11
*) HC: Measurement of house connection for in- and exfiltration
+) Price for the measuring equipment is only rental basis calculated

All partners assume that the costs could be reduced, if measurements would be applied on a routine basis. With regard to the planning phase, more experience would speed up preparatory analysis. With regard to the practical execution of the experiment, more experience leads to improved logistics and organizational aspects. This would reduce the overall personnel costs.

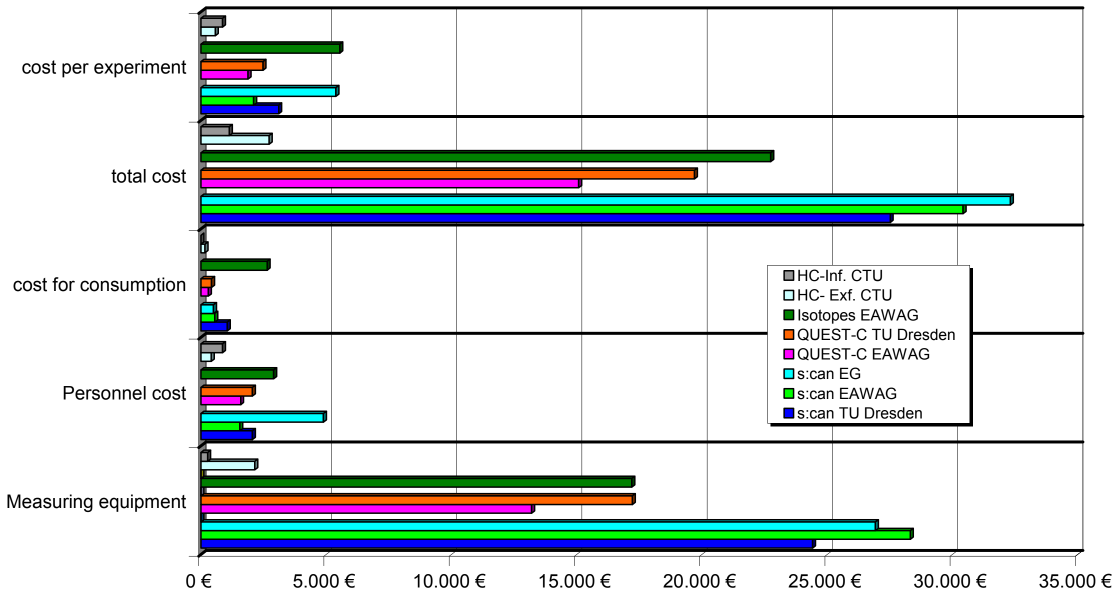


Figure 6-1: Cost information for experiment campaigns (information provided by the APUSS partners)

To classify the measurement cost of the new methods it would be necessary to compare these with a “classical” flow measurement campaign. For example with the aim to measure infiltration the night flow minima could be used in one test site in a sewer system, with following boundary conditions:

- 1 flow measuring unit
- Duration: 3 months
- Maintenance, read out and analyse of data every 14 days

A German company which is specialized on measurements in sewer systems provide on request the following cost information for a flow measurement as described before:

- Costs for installation and demounting: 525 €/per site
- Maintenance, read out and analyse of data: 850 €/month

Given this information, total cost of the measurement is equal to 3075 € (plus VAT). But it also have to be compare with a purchase of a flow measuring unit, personnel cost and the costs for consumption as listed in Table 6-1 for the new methods.

- Measuring equipment (flow unit including data logger): ~ 8,000 €

- Personnel cost (calculated hours: ~ 60, Price per hour 40 €, duration of measurement: 3 month): ~ 2,400 €
- Cost for consumption: ~ 250 €

Total cost: ~ 10,900 €/per site

Looking only at economical aspects, “classic” flow measurements appear more beneficial for the operator. However, the new measurement methods provide values of infiltration and exfiltration with better evaluation of uncertainty. The results obtained using these methods are more reliable than with the “classic” methods. In some special cases, e.g. were a measuring of flow is not possible or necessary, the new methods could be cheaper than a “classic” flow measurement (see DE BÉNÉDITTIS, 2004 for the Yzeron catchment).

As mentioned before all costs for the new methods are costs for a "prototype" measurement which could be reduced it measurements would be applied on a routine basis.

7 Conclusion

This deliverable D11.3 summarises the results of WP 11 “Economic valuation” of the APUSS project (Assessing Infiltration and Exfiltration on the Performance of Urban Sewer Systems).

As first step of WP 11 (see D 11.1) a questionnaire was developed and sent to selected end-users in 2003. The questionnaire was divided in two parts. Part 1 was about general aspects of in- and exfiltration and part 2 about technical information about the sewer systems and environment. As expected the technical data of the different sewer systems strew in a wide range, so a transfer of these information between different cities is not possible. An infiltration problem is in most of the cities already known and often also as normal accepted, but only in a few cases the operator takes measures to reduce this problem.

One objective of WP 11 was to develop a cost-structure for an average sewer system. The new developed cost-structure for sewer systems was presented in detail in chapter 2.3. Therefore the costs are divided into six groups (costs for material, wages and salaries, miscellaneous operational costs, disposal of waste, depreciation and calculated interest) which could be filled in the new created commercial data entry form for sewer systems. This cost-structure constitutes bases for a cost-benefit analysis, but could also be used for benchmark studies.

In chapter 3 the area of conflict between sewer rehabilitation and the drainage effect of a leakage sewer pipe is discussed. In some regions the drainage function of the sewer system (transport of groundwater) keeps basement of houses dry. This problem must be studied before the rehabilitation of the sewer system would be realised.

Basis for a cost-benefit analysis are detailed cost information, especially for the operation of a sewer system. After some general remarks about cost analysis and benefit analysis, four special examples (rehabilitation vs. replacement in different installation depths) of the application of a cost-benefit analysis is shown. The necessary detailed cost data for the replacement and rehabilitation of a sewer pipe came from different projects by Emschergenossenschaft and from literature. For the comparison the yearly operation cost and the investment cost for the example were calculated. The amortisation time of the planed measure was one of the main points for the decision making.

In the APUSS project a minimum of four different methods for the measurement of in- and exfiltration had been developed by the project partners (WP 1 and WP 3). For all of these methods detailed cost information (personal cost, cost for measuring equipment, and cost for consumption) had been requested by all partners who had worked with these new methods and the range of costs had been calculated. Therefore it must be considered that all of these costs are for a "prototype" measurement which could be reduced when measurements would be applied on a routine basis. Looking only at economical aspects, “classic” flow measurements appear more beneficial for the operator. However, the new measurement methods provide values of infiltration and exfiltration with better evaluation of uncertainty. The results obtained using these methods are more reliable than with the “classic” methods.

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9 Appendix

9.1 Costs for replacement of a sewer pipe

Cover depth of 4 m

	cover depth H= 4m			
	minimum	expected value	maximum	unit
sewer pipe *)	90,92	106,30	133,40	€/m
trench coating **)	9,00	16,00	29,50	€/m²
ground excavation ***)	17,00	23,00	30,50	€/m³
sump drainage +)	5,00	10,00	20,00	€/m
drawdown ++)	81,00	90,00	108,00	€/m
upraise, recovery of surface	46,50	59,00	74,50	€/m²
house conection	130,00	180,00	225,00	€/piece
bottom part of manhole	972,72	1.189,10	1.556,27	€/piece
upper part of manhole	130,00	200,00	720,00	€/m
cover of manhole	133,00	440,00	651,00	€/piece

*) Including delivery, installation and testing of leaks
**) depth 4 m
***) soil class 3: easy removable soil (DIN 18300, 2002)
+) For 2 m
++) drawdown of 2 m

Cover depth of 10 m

	cover depth H= 10m			
	minimum	expected value	maximum	unit
sewer pipe *)	90,92	106,30	133,40	€/m
trench coating **)	36,00	69,00	94,50	€/m²
ground excavation ***)	35,00	49,50	72,50	€/m³
sump drainage +)	7,40	14,00	30,00	€/m
drawdown ++)	288,00	320,00	384,00	€/m
upraise, recovery of surface	46,50	59,00	74,50	€/m²
house conection	130,00	180,00	225,00	€/piece
bottom part of manhole	972,72	1.189,10	1.556,27	€/piece
upper part of manhole	130,00	200,00	720,00	€/m
cover of manhole	133,00	440,00	651,00	€/piece

*) Including delivery, installation and testing of leaks
**) depth 10 m
***) soil class 3: easy removable soil (DIN 18300, 2002)
+) For 6 m
++) drawdown of 5 m

Source:
- Cost information from the city of Gladbeck
- Cost information from different projects of Emschergenossenschaft
- Cost information from Stein & Partner, Consulting Engineers, Bochum
- Cost information from Pecher (literature)

9.2 Commercial data entry form

Developed cost-structure for sewer systems (commercial data entry form)

	Indices		Overall sewer system	Private sewerage system				Sewerage collection						Stormwater treatment				Miscella-neous
No.	(Total costs for the year:_____in €)	Unit	Total for cost group	Gully pots	Fat/light liquid separator	in house wwtp	Disposal of waste	gravity sewer	pressure main	inverted siphon	pumping station	manhole	stormwater storage tank	CSO tank	stormwater storage tank	infiltration facility	storage sewer	
54	**Materials**																	
540	Power, water, natural gas, TP gas, transmitted heat	€																
541	Other fuels (for motor-vehicles)	€																
542	Material for internal maintenance	€																
543	Material for internal cleaning and inspection	€																
544	Auxiliary and operational utilities	€																
547	Cost for purchases (service and material)																	
5471	***of which*** *maintenance services*	€																
5472	***of which*** *maintenance materials*	€																
5473	***of which*** *cleaning/inspection services*	€																
5474	***of which*** *cleaning/inspection materials*	€																
549	Miscellaneous	€																
55	**Wages and salaries**																	
551	***of which*** *maintenance and servicing*	€																
552	***of which*** *cleaning and inspection*	€																
59	**Miscellaneous operational cost**																	
590	Licence fee	€																
591	Rent, lease, charge fee	€																
592	Assurance	€																
593	Office supply	€																
594	Post, transportation charge	€																
596	Travelling expenses	€																
597	Other and external services	€																
599	Miscellaneous	€																
90	**Disposal of waste**	**€**																
57	**Depreciation (standadized)**	**€**																
58	**Calculated interest**	**€**																
Total amount																		