European study of the performance of various pipe systems, respectively pipe materials for municipal sewage systems under special consideration of the ecological range of effects during the service life

S & P Consult GmbH
Konrad-Zuse-Str. 6, 44801 Bochum
Germany

Final Report
Summary

Bochum, September 2006

Preface

The study on “the performance of various pipe systems, respectively pipe materials for municipal sewage systems under special consideration of the ecological range of effects during the service life” presented here was carried out by Prof. Dr.-Ing. Stein & Partner GmbH, Germany. An external European expert panel contributed significantly to the project by bringing in their specific viewpoints on the sewer network situation of their countries, ensuring a holistic European view of the project. Their specific knowledge eased the adjustment of the analytic process rules of the used “STATUS Sewer” framework to the specific needs of the project. With their proofing review of the analytical approach used within the project, they ensured representative results.

The involved experts of the panel were:

- *Nick Orman* - WRc, Swindon, U.K.;
- *Hans von der Jagt* - Kiwa Water Research, Nieuwegein, Netherlands;
- *Gilbert Sevensson* - Chalmers University, Göteborg, Sweden.

Bochum, August 2005

Table of content

1 Introduction

Drains and sewer systems have been built systematically in Germany since 1842. For more than one century, accessible sewers were almost exclusively made from hard burned bricks. From the beginning of the 20th century, in-situ-concrete sewers became popular for economic reasons. The greater part of our drain and sewer systems is not accessible and consists of prefabricated pipes of different materials. Only in the past 50 years have plastic pipes (PVC, PVC-U, PP, PE, GRP) as well as pipes made from ductile cast iron, reinforced concrete and PRC been used.

A number of studies have identified that vitrified clay, concrete and reinforced concrete pipes are dominating in public sewers within Germany with a length portion of approx. 45% in each case. This is historically based and is confirmed for countries like England, which also began very early with the building of drains. In countries like the Scandinavian countries and Australia, which started later with the regular sewer construction due to large distances and high costs, the proportion of pipes in each pipe material shifts very clearly to plastic pipes. In the private domain (laterals), plastic pipes are now almost solely used.

For some years, an increasing acceptation of plastic pipes have also been observed for the early-canalized countries like England and Germany, which is already noticeable in the network stock. The manufacturers give the following reasons for this increase:

- Low weight (transport, handling without heavy equipment) example DN 300: Concrete 137 kg/m, vitrified clay 72 kg/m, plastic 8 to 10 kg/m
- Favourable characteristics to resist aggressive waste water and waste water constituents (corrosion resistance)
- Flexible deformation behaviour (without cracks)
- Hydraulic smooth materials and closer dimensional tolerances at joints (fewer deposits, less cleaning expenditure, small nominal sizes)
- Cutting to length and adaptation to local situation possible
- Machine installation technology possible
- Recycling/down cycling ability
- High secured service life
- Installation on curves possible, i.e. saving of manholes
- Material-homogeneous sewer systems (uniform materials for pipes, shaped parts, manholes)

Even if all plastic pipe systems are standardized or certified, some uncertainties still exist in the long-term evaluation of plastic pipes under practical conditions. Past investigations of the sewer conditions and piping materials were always limited to concrete/reinforced concrete and vitrified clay due to their predominant length portions.

This induced the German Federal Ministry of Education and Research (BMBF) to found a research project, which, by the evaluation of national inspection data, could give valuable information on defect and defect frequency in plastic drain and sewer systems.

These investigations form the basis for this European project for the evaluation of the ecological impact spectrum of the defects found. Additional inspection data for the investigation of concrete and vitrified clay pipe sections and their installation conditions were integrated in the project.

2 Objectives

The object of the work is a far-ranging analysis of the results of condition assessment and its environmental effects. Apart from the difference of the various materials (concrete and reinforced concrete, vitrified clay and plastics) to their types and frequencies of defect, the differences of environmental effects are defined. Environmental effects are understood to be leaks with the result of water exchange between aquifer and sewer in the form of exfiltration or infiltration depending on the position of the sewer with regard to groundwater level. The focus on infiltration and exfiltration is due to the fact that the majority of environmental impacts of a sewer network during service life is caused directly or indirectly by infiltration and exfiltration. Within this project, the overflow of the sewer systems are accounted as exfiltration as long as the capacity overload is caused by defects such as incrustation or sedimentation. Overflow caused by poor planning is not relevant for this study and left out here.

The analysis is carried out in different steps:

- Determination and comparison of the number and frequency of leaking defects
- Modelling of risk and environmental impact of leaking defects
- Definition of scenarios with different ancillary conditions
- Modelling the environmental impact of different sewer systems within different scenarios

3 Approach and Model

3.1 Introduction

In general, an exact calculation of environmental impacts of any kind is almost impossible. The model used is based on two main principles:

- Environmental effects of sewer defects are understood as impacts caused by infiltration or exfiltration. Therefore, all further considerations only aim at local effects based on local ancillary conditions.
- All modelling uses relative and descriptive scaling without units to avoid conversion problems and prevent comparisons between different impacts, which cannot and should not be set into an absolute context.

An appropriate way to meet the request for calculation using variables of different scaling systems (descriptive, numerical) and units is fuzzy logic.

3.2 Data basis and analysis

Inspection data from different European countries was included for analysis:

Table1: Available Data Stock

Country/Region	All pipes	Rigid pipes	Flexible pipes	Share of flexible pipes
Germany	1731.72 km	1640.83 km	90.89 km	5.25 %
Netherlands	46.69 km	30.27 km	16.42 km	35.17 %
Sweden	12.43 km	3.07 km	9.36 km	75.30 %

The data of the Netherlands and Sweden is analyzed with respect to the existing defect groups and compared with the German figures, which form the basis of the study. The reason for the different data situation outside Germany is the fact that only in Germany routine inspections are required by law. In all other countries inspections are mostly carried out on utilities request or on municipality initiative.

Three main viewpoints on the data of the sewer networks have been defined: 1st, frequency of defective sewer sections in relation to the total network; 2nd, frequency of defects per kilometre within the network and 3rd, frequency of defects per 100 m within the defective sections.

3.3 Generating model data by a “Monte-Carlo-Simulation”

In the analysis of environmental impacts there is mostly no link between the specific sewer defect characteristics obtained from inspection data and the local ancillary condition. As these links are necessary for modelling the environmental effects, they have to be created in a way that promises decent analysis results, e.g. by the “Monte-Carlo-Simulation”-method. Three main groups of variables account for the environmental impacts:

- Specific sewer defect characteristics gained from inspection data (e.g. extent and position of the defect)
- Specific sewer defect characteristics gained from expert knowledge and hydraulic calculation (e.g. average leaking potential of the defect)
- Local ancillary conditions (e.g. soil permeability) defined in the different scenarios

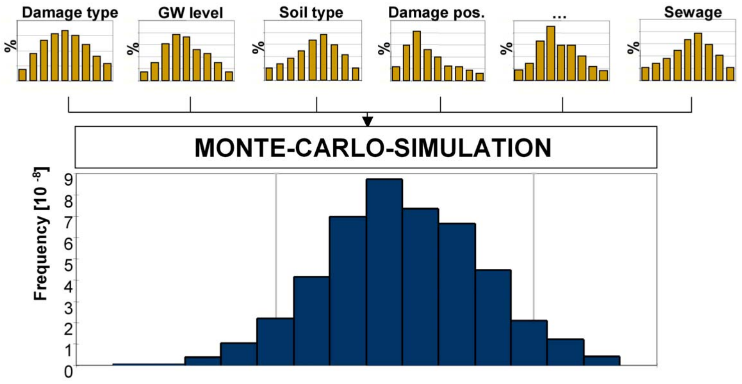


Figure 1: Monte-Carlo-Simulation

The result of the simulation is the establishment of the links between the local ancillary conditions and the specific sewer defect characteristics.

Determination of leaking defects

Average leaking potentials have been assigned separately to flexible and rigid pipes to determine the parameters for the Monte-Carlo-Simulation if these parameters cannot be determined from inspection data. The defect types, e.g. BAB-fissure (Table 2), are assigned to certain leakage groups to describe their leakage behaviour.

Table 2: Determination of leakage behaviour of fissure

Defect Type	Leakage Type	Leaking Potential Borders		Leaking Potential Average	
Code		Min	Max	Flexible	Rigid
BAB-Fissure					
A	Never				
B	Likely	Very small	Very big	Very small	Small
C	Always	Small	Very big	Big	Very big

Definition of scenarios

The different scenarios show the absolute environmental impact of different leaking pipe types on an ordinal scale. The sewage type is set to ordinary domestic wastewater, the net is within normal dense urban areas and the infiltrate is normal groundwater.

3.4 Risk and impact modelling by “logical trees” and “fuzzy logic”

In the fuzzy inference system of the study, the following factors are the data of the model and/or are model outputs/intermediate data:

- sewage level
- defect position
- leakage potential
- soil permeability
- groundwater level
- infiltration potential
- exfiltration potential
- soil type
- sewage type
- type of infiltrate
- distance of objects
- objects
- impact on groundwater level
- impact on sewer stability
- impact on receiving water
- impact on treatment plant
- groundwater pollution
- soil pollution
- objects threat

Risk and Impact trees

Appropriate ways to model any multilateral linked factors in order to determine endangerment potentials are logical trees which link cause and effect of single factors.

The fault tree describes all possible causes, their values, relations and link types and combines them into the resulting top cause (infiltration/exfiltration potential). The event tree identifies all possible consequences resulting from the defined top cause.

As all link types and relations can be expressed by process rules and the links are in most cases non binary, the cause-consequence-chart as a combination of the fault tree and the event tree can be simplified by a multi-dimensional system.

Linkage of variables via fuzzy logic

The fuzzy processing always follows the same path.

1. Fuzzification of the input variables according to the vectors and membership functions for the specific variable.
2. The related variables are linked by a fuzzy-inference-matrix that is the expression of the rule sets which link those variables.
3. The two input variables for this fuzzy-inference-matrix with their individual membership to the vector select the rules used for further processing.
4. Using the algebraic product and the centroid method, a resulting vector is determined which is finally defuzzificated to the resulting value on the target scale.

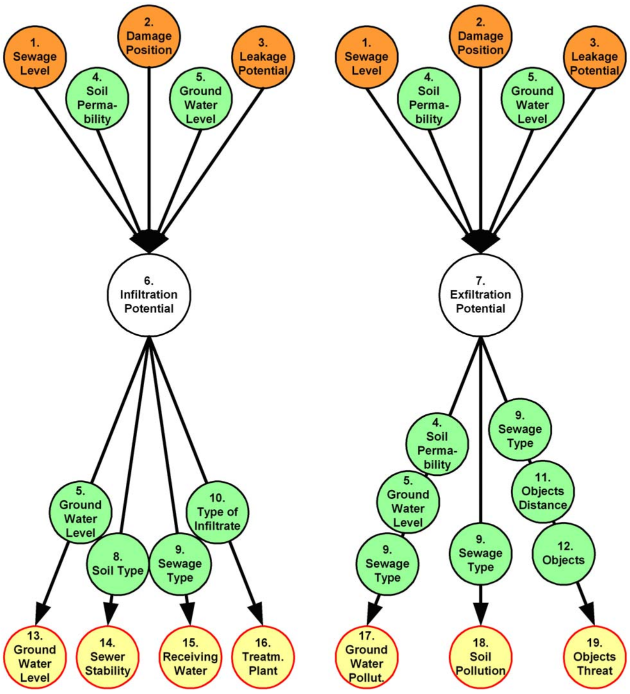


Figure 2: Cause-consequence-chart

This procedure is carried out for each data set created by the Monte-Carlo-simulation and for each node within the tree. The extensive multidimensional rule sets have been determined from two-dimensional matrices and sum up to a few hundred true rules.

3.5 Further aspects of modelling environmental impacts

Service life

As the absolute environmental impact of the analysed issues depend on the exposure time, they scale according to the service life of the sewer sections. Therefore, the ratio between these impacts and other environmental issues of the life cycle changes accordingly. The average service life has been set to 80 years for all materials in German regulations. For this reason these scaling effects are neglected here.

Data quality

Up to 20 % of the quality of the network data (inspection data and basic data) is imperfect in many ways, e.g. imperfect coding systems, subjective assessment, logical failures etc. Many of these inaccuracies will remain undetected unless a review of the TV-inspection tapes will take place, which is, however, costly or insufficient due to bad video quality or other reasons. Therefore, a direct comparison with results from other studies or models can only be successful if the relative scaling is kept.

Defect development and prognosis

All of the samples are from different age, some of the inspections were older than 10 years. Within this time span, the defects recorded by the inspector may have worsened and new defects may have arisen as the network deteriorates. To eliminate these data failures, all inspection data need to be scaled with regard to the same time span using a decent aging model. Other failures arise from the unfamiliarity with the inspection strategy of the utilities. If operators only select old pipes for inspection instead of random samples, the networks may appear in a worse condition than they may be in reality. Both issues are neglected in this study.

Empirical knowledge

It is widely known that correctly installed sewers have negligible defects and do not cause any trouble. Nevertheless improper installations happen all days for several reasons so the question "What happens if…" needs to be answered. Moreover, defects tend to occur more often and to be more serious in permeable soil than in less permeable soil. However, there is no method to establish this link as this experience is not recorded, which is the general problem of empirical knowledge. A way for integrating empirical data is by integrating it into an aging and forecasting model.

4 Results explanation and interpretation

4.1 Model results

The model itself is fed with several thousand data sets from the Monte-Carlo-simulation. These input variables are processed by the fuzzy model and lead to the numerical model output. This output dataset represents the various combinations of defects and ancillary conditions according to their probability of occurrence, which is defined by the scenarios and the analyzed inspection data.

Generating the arithmetic mean for all these variables gives the **average environmental impacts caused by the average defect of a specific pipe type within the given scenario considering the bandwidth of possible influences**. Generating the arithmetic mean for all input factors and processing these values within the model would shrink the effort for modelling.

The ancillary conditions defined in the scenario and the leakage rates determined by the defect characteristics of the inspection lead to a moderate impact on the environment for all pipe types. However, the impact is just moderate because of the bandwidth of possible impact severity. Ancillary conditions with their influence on the model results in fact limit the possible impact maximum of a certain scenario. The best example for the majority of the ancillary conditions is the total absence of infiltration and thus environmental impacts caused by infiltration. The ground water level defined in the example scenario is always below the sewer sections, which simply prevents infiltration. The defect grades and characteristics of the sewers are always subordinate to the ancillary condition, which decides on the magnitude of the environmental impact.

Another way to visualize the model results is to normalize the single variables to the maximum within the category. For each category (e.g. exfiltration risk) the maximum value is set to 1 and all the other members of the category scaled accordingly.

This form of data presentation clarifies the difference between the various pipe types. As these differences are only determined by the defect grades and characteristics of the sewers, the ancillary conditions do not affect the differences between the pipe types. As a logical consequence, the offset between the categories are (and need to be) almost the same. If there is no impact (by infiltration), the difference between the pipe types does not matter and therefore vanishes.

For some local situations, the model output may not reflect the true weight of the different category variables. Situations like the dominating importance of one or more factors cannot be taken into account by a general model but must be handled by transforming the model results on an individual weighing scale, which needs to be determined by local authorities, utilities and experts.

5 German results

5.1 Data analysis

The following data and figures result from the analysis of the provided network data (1732 km altogether after exclusions) and represent a symptomatic overview of today's situation with regard to pipe material groups. The German as well as all European inspection data have been translated to the EN 13508 code system using the translation standard set by the German association DWA (formerly ATV-DVWK).

The average is 6.8 years for flexible and 11.5 years for rigid sewer sections. Nevertheless the existing differences can be neglected as the majority of defects that are time-dependent like corrosion or abrasion are of minor relevance for this study.

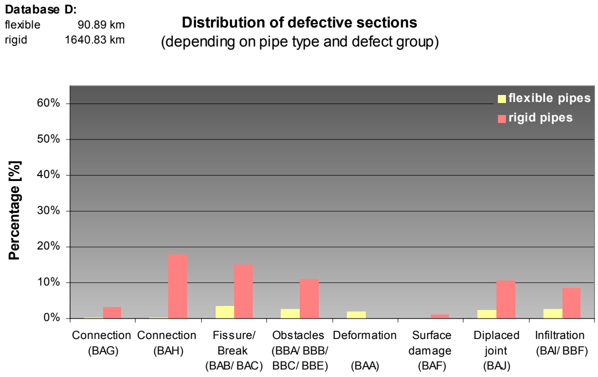


Figure3: Distribution of defective sections according to the defect type

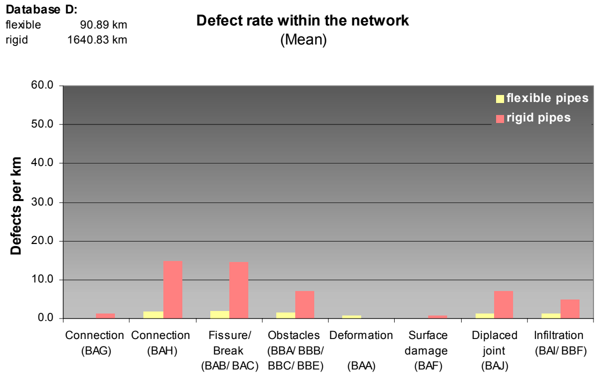


Figure 4: Defect rate within the Network - Mean of the Network

Fehler! Verweisquelle konnte nicht gefunden werden. shows the percentage of the defective sections according to the type of defect. As a sewer section can have different defect types, the accumulation of all shares of one material group may be more than 100 %.

The data is calculated by $\frac{\sum \text{Length of all sewers with defects}}{\sum \text{Length of all sewers}}$.

Flexible pipes at almost all defect types relevant for infiltration and exfiltration have a significantly lower share of defective sections within the network than rigid pipes.

The number of defects are put in relation to the length of the defective part of the network:

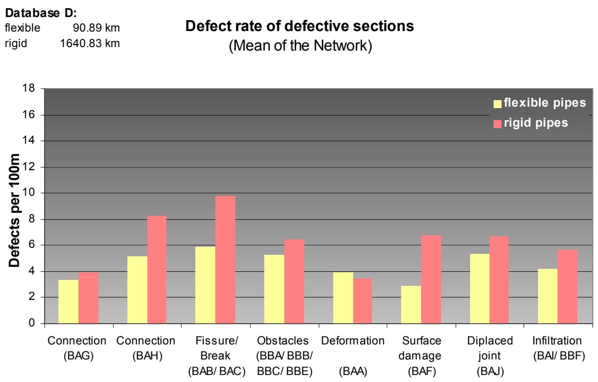


Figure 5: Mean Defect rate in Defective Sections

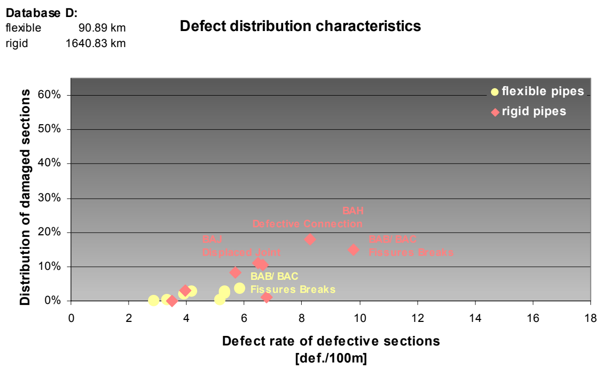


Figure 6: Relation between defect distribution and defect rate

The true difference between the material groups is the difference in failure frequency within the total network. The main factor in judging the environmental impact of a certain pipe material group can therefore only be the individual defect behaviour with regard to leakage in combination with the network defect rates.

Especially for rigid pipes, the defect types most relevant for leakage show a high occurrence probability throughout the network and a high frequency of occurrence within the defective sections. The defect frequency and occurrence probability is clearly lower for flexible pipes, which makes them perform significantly better with regard to leakage.

5.2 Scenario definition

The following Table 3 lists the differences between the various scenarios:

Table 3: Scenario definitions

Scenario	**Sewage level**		**Soil permeability**		**GW – level**	
1 Coastal region Separated Sewage	MODE SPAN	1/3 ¼ - ½	MODE SPAN	Medium Low – high	MODE SPAN	Axis B. invert – a. crown
2 Northern lowlands Separated Sewage	MODE SPAN	1/3 ¼ - ½	MODE SPAN	High Low – very high	MODE SPAN	Axis B. invert – a. crown
3 Low mountain range Separated Sewage	MODE SPAN	1/3 ¼ - ½	MODE SPAN	Medium Very low – very high	MODE SPAN	Invert F. b. invert – a. crown
4 Northern lowlands Combined Sewage	MODE SPAN	1/3 1/3 - 2/3	MODE SPAN	High Low – very high	MODE SPAN	Axis B. invert – a. crown
5 Southern lowlands Combined Sewage	MODE SPAN	1/3 1/3 - 2/3	MODE SPAN	High Very low – very high	MODE SPAN	Invert B. invert – a. crown
6 Low mountain range Combined Sewage	MODE SPAN	1/3 1/3 - 2/3	MODE SPAN	Medium Very low – very high	MODE SPAN	B. invert F. b. invert – a. crown
7 Low mountain range Combined Sewage	MODE SPAN	1/3 1/3 - 2/3	MODE SPAN	Medium Very low - high	MODE SPAN	B. invert F. b. invert – a. crown

The seven German scenarios listed cover the German situation in a representative way being defined by grouping areas according to the hydro-geological situation, the population density and the sewer system.

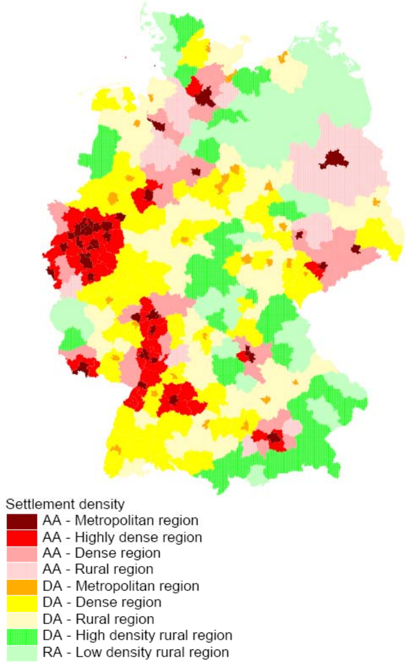


Figure 7: Settlement density within Germany

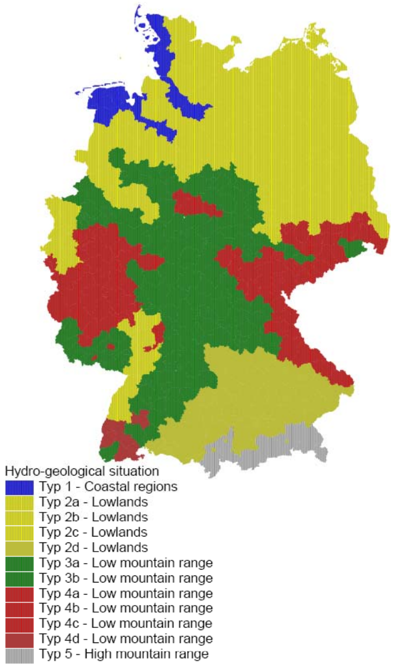


Figure 8: Hydro-geological situation within Germany

The figures show the geographic data used for scenario definitions. In Figure 7, the population density is used as one indicator for the share of the total network length of the different regions. The hydro-geological map of Figure 8 provides information on the ancillary conditions in the different regions. Here, the ground water level and soil type can be determined for the different scenarios.

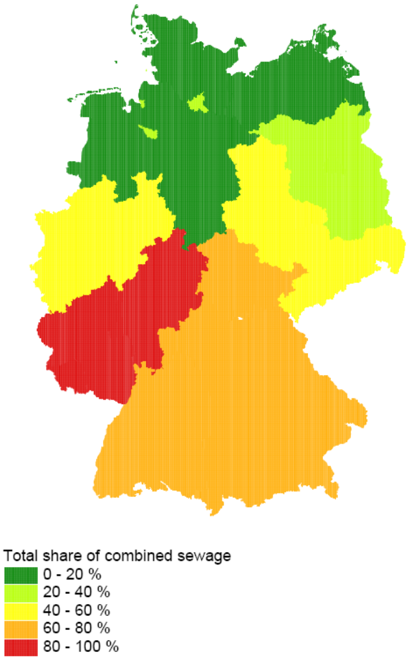


Figure 9: Share of combined sewage within Germany

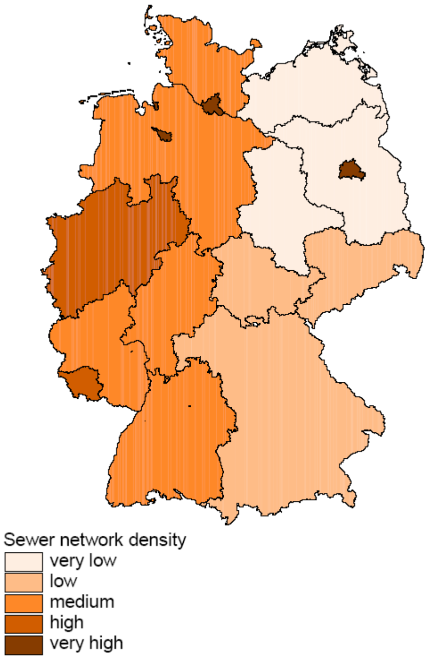


Figure 10: Sewer network density within Germany

All this geographical referenced data has been compiled into a geographical information system to determine the German scenarios as well as the average environmental impact of flexible/ rigid pipe systems caused by ex-/infiltration within Germany:

Table 4: Total share of the defined scenarios on the German sewer networks

Scenario		Total share
1	Coastal region - Separated Sewage	3.69%
2	Northern lowlands - Separated Sewage	25.91%
3	Low mountain range - Separated Sewage	11.40%
4	Northern lowlands - Combined Sewage	7.99%
5	Southern lowlands - Combined Sewage	13.85%
6	Low mountain range - Combined Sewage	18.56%
7	Low mountain range - Combined Sewage	18.60%

5.3 Model results

The various scenarios have lead to different results, which makes it necessary to consider the various ancillary conditions. To determine the true differences of the environmental impact of a network of rigid or flexible pipes, it is necessary to relate the model results, which are based on the average defect of the material group, to the average network defect rates by scaling them with the normalized defect rates, which causes the impacts to drop dramatically for the flexible pipes.

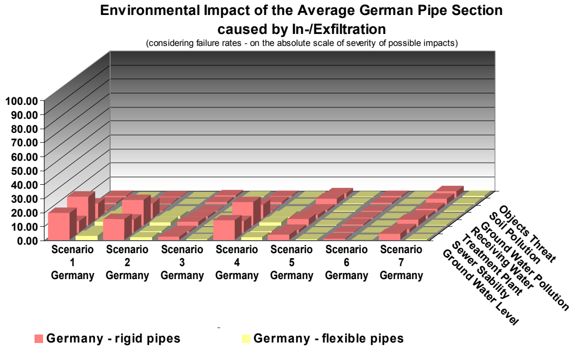


Figure 11: Environmental Impact of the average German failure causing in-/exfiltration within the total scope of possible impact severity - considering failure rates

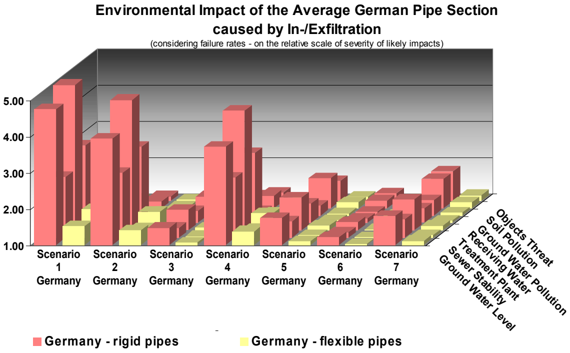


Figure 12: Environmental Impact of the average German failure causing in-/exfiltration within the relative scope of likely impact severity - considering failure rates

In Figure 11, this is shown on the absolute scale and in Figure 12 it is shown on the relative scale of environmental impacts caused by in-/ exfiltration.

Flexible pipes have a better performance with regard to their environmental impacts by in-/ exfiltration. The average defect is less leaky and the frequency of occurrence is lower.

Table 5: Result scaling

Pipe type	Average defect rates	Normalized defect rates
Flexible pipes	8.45 defects per km	0.17
Rigid pipes	50.26 defects per km	1

With the ancillary conditions as dominating factor, the relation of the difference between flexible and rigid pipe systems within the single scenarios remains almost equal. Having determined the net share of the single scenarios, it is now possible to cumulate the average environmental impacts for Germany (Figure 13). Impacts on the treatment plant, sewer stability and the receiving water are the most critical of all the impacts according to network operators. Impacts on the ground water level are ambivalent (tight systems may increase the groundwater level and cause damage to objects) and thus the dominating impacts caused by in/exfiltration.

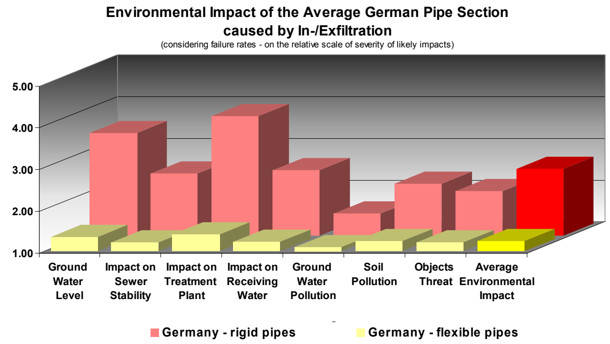


Figure 13: Environmental impact of the average German failure causing in-/exfiltration within the relative scope of impact severity - considering failure rates and aggregating scenario results according to net share

6 Dutch results

6.1 Data analysis

The Dutch inspection data has been additionally revised to determine the difference in defect assessment. There is a significant level of congruence, the differences in indications by the engineers were caused by minor interpretation distinctions or missing defect descriptions, e.g. the code for defective connections is not recorded in the protocols although it is stated on the TV-tape (Figure 19).

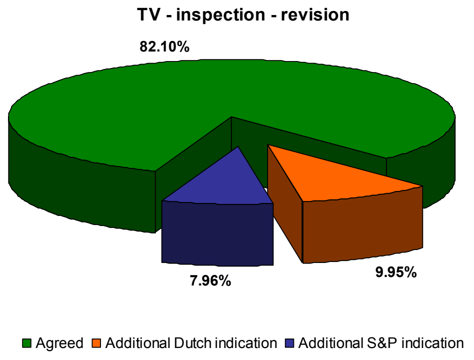
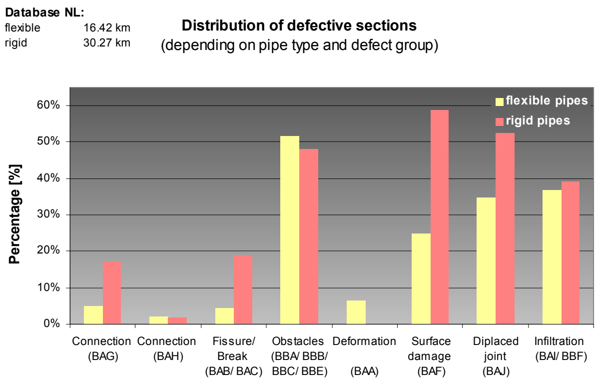


Figure 14: Result of the revision of the Dutch TV-inspections

Figure 15: NL BBF (Infiltration) S&P: BAH (Defective connection) additionally

According to the Dutch expert Mr. van der Jagt, the high share of infiltration defects (BBF) are due to incorrect defect assessment by the inspectors as most of these indications should have been assessed as defective connection (BAH), a defect which comes from massive installation problems due to missing supervision. Another defect problem resulting from the quality issue is the problem of displaced joints.



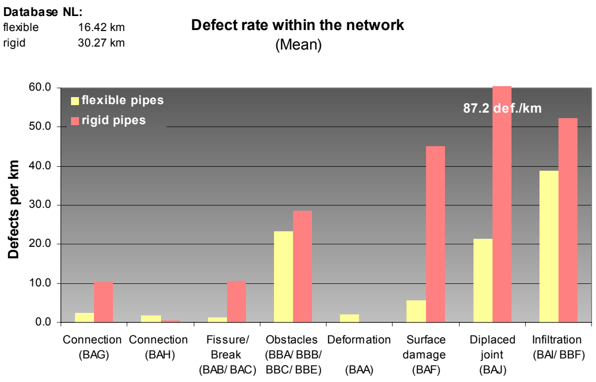
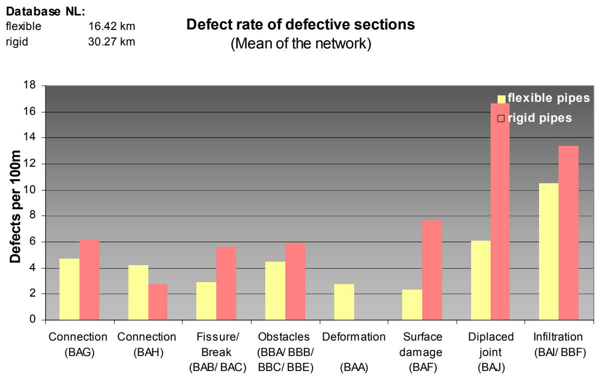


Figure 16: Distribution of defective sections according to the defect type

Figure 17: Defect Rate within the Network - Mean of the Network



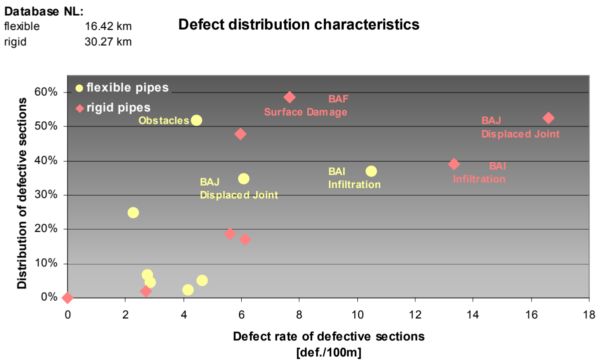


Figure 18: Mean Defect Rate of Defective Sections

Figure 19: Relation between defect distribution and defect rate

Figure 16 to Figure 19 show the results of the analyses that have been carried out on the lines of the German investigations.

6.2 Model results

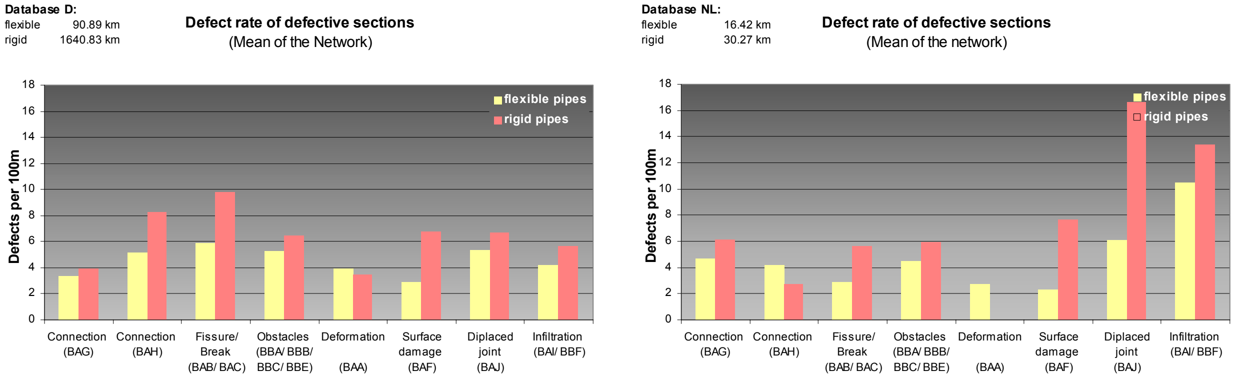
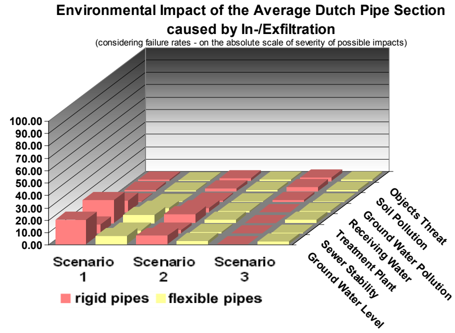


Figure 20: Comparison of German and Dutch defect rates

As the Dutch database for the modelling was too small, the German data was adapted for the Netherlands. Comparing the data analysis figures of Germany and the Netherlands, it becomes obvious that defect rates of defective sections are similar apart from the displaced joint (BAJ) and the infiltration issue. The last problem results mostly from incorrect indications or installation problems due to missing supervision. Assuming similar supervision, maintenance and rehabilitation behaviour as in Germany, the differences in defect characteristics would significantly change and move towards German figures. Therefore, the adaptation of the German data was feasible. Thus, a direct comparison of the sensitivity of the ancillary conditions for the three Dutch scenarios with the other European scenarios became possible.

Table 6: Scenario definitions for the Netherlands

Scenario	Sewage level		Soil permeability		GW – level	
Nr. 1	MODE SPAN	Closer to axis Invert – axis	MODE SPAN	Medium low - medium	MODE SPAN	Axis b.invert – a.crown
Nr. 2	MODE SPAN	Closer to axis Invert – axis	MODE SPAN	Low Low – medium	MODE SPAN	Invert a.crown (15%)
Nr. 3	MODE SPAN	Closer to axis Invert – axis	MODE SPAN	Closer to low v.low – low	MODE SPAN	Far below pipe invert



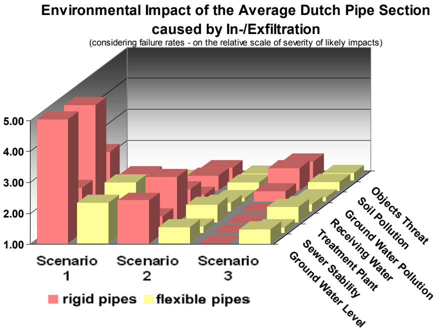


Figure 21: Environmental Impact of the average failure causing in-/exfiltration within the total scope of possible impact severity - considering failure rates

Figure 22: Environmental Impact of the average failure causing in-/exfiltration within the relative scope of likely impact severity - considering failure rates

The Dutch analysis reveals the same results with regard to flexible pipes as the German investigation.

Table 7: Result scaling

Pipe type	**Average defect rates**	**Normalized defect rates**
Flexible pipes	95.91 defects per km	0.41
Rigid pipes	234.56 defects per km	1

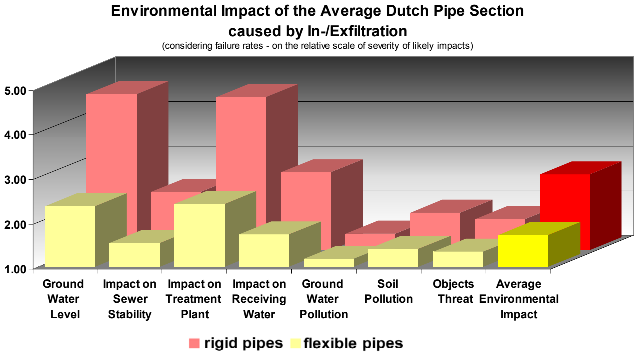


Figure 23: Environmental Impact of the average failure causing In-/Exfiltration within the relative scope of likely impact severity - considering failure rates and aggregating scenario results according to net share

7 Swedish results

7.1 Data analysis

The Swedish defect indications within the protocols were mainly plaintext descriptions instead of a code system, which eased the translation into the EN code.

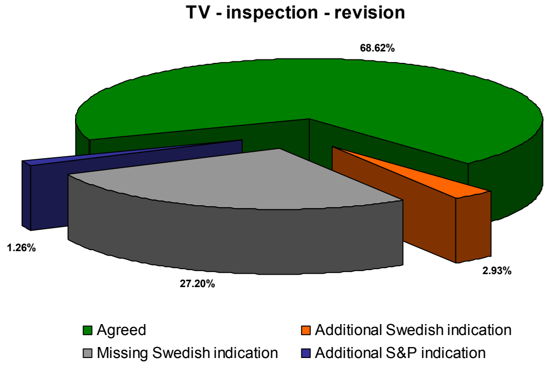


Figure 24: Result of the revision of the Swedish TV-inspections

The main indication differences come from missing indications in the protocols as many Swedish protocols are summaries that only state the number of failures found per section withoiut listing the defect indications in detail. These lacking protocols had to be completed by the TV-revision causing the high percentage of missing indications. With almost 3%, the true differences in defect assessment are rather small.

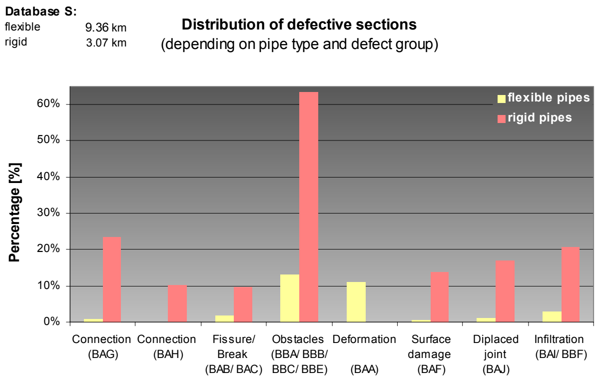


Figure 25: Distribution of defective sections according to the defect type

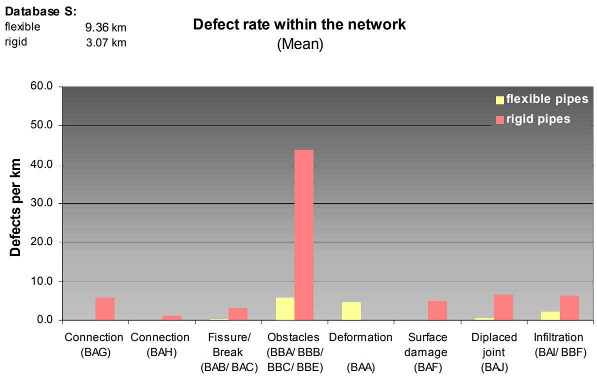


Figure 26: Defect Rate within the Network - Mean of the Network

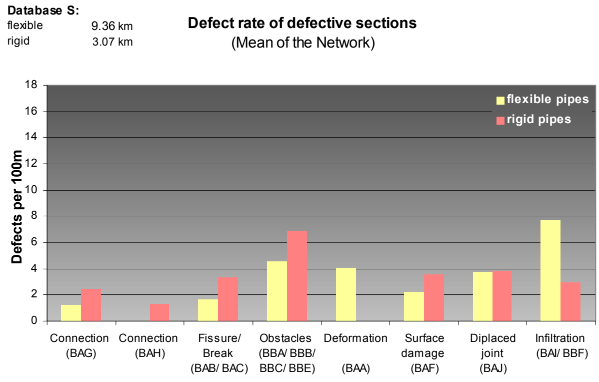


Figure 27: Mean Defect Rate of Defective Sections

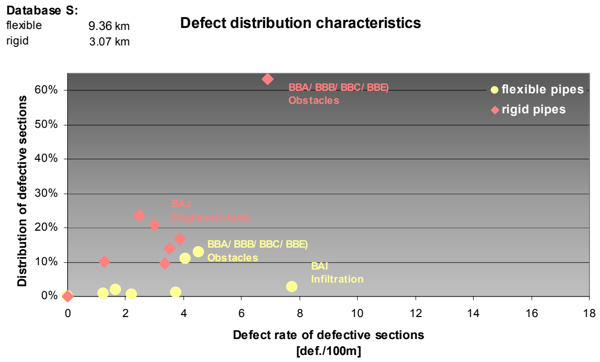


Figure 28: Relation between defect distribution and defect rate

According to the Swedish expert Mr. Sevensson, the high share of obstacles, which were mainly sedimentation problems from paper, are not typical of Swedish sewer systems.

7.2 Model results

As the Swedish data base for the modelling was too small, the German data was adapted for Sweden. Thus, a direct comparison of the sensitivity of the ancillary conditions for the three Swedish scenarios with the other European scenarios is possible.

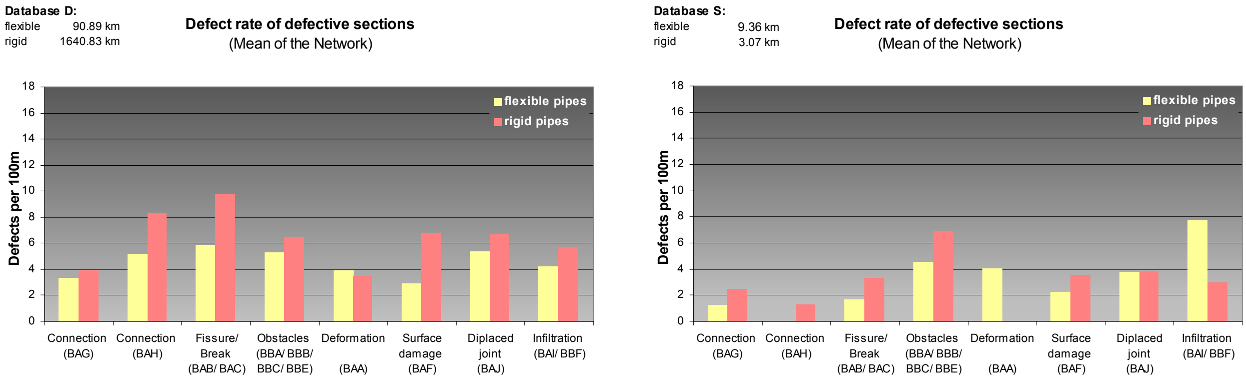


Figure 29: Comparison of German and Swedish defect rates

The detailed consideration with regard to the adaptation of German data was also carried out for the Swedish modelling.

Table 8: Scenario definitions for Sweden

Scenario	Sewage level		Soil permeability		GW – level	
Nr. 1	MODE SPAN	Closer to axis Invert – axis	MODE SPAN	Medium v.low – medium	MODE SPAN	Axis b.invert – a.crown
Nr. 2	MODE SPAN	Closer to axis Invert – axis	MODE SPAN	v.low	MODE SPAN	Invert a.crown (15%)
Nr. 3	MODE SPAN	Closer to axis Invert – axis	MODE SPAN	Closer to low Low – medium	MODE SPAN	Far below pipe invert

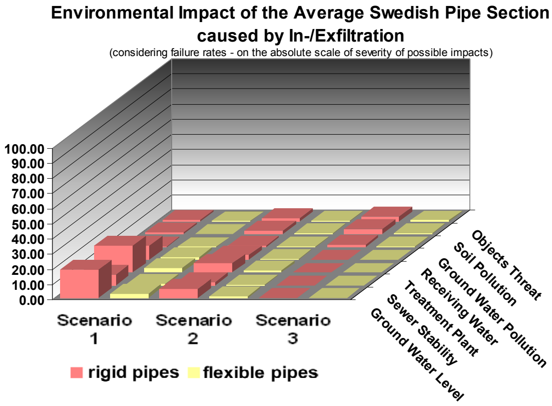


Figure 30: Environmental Impact of the average failure causing In-/Exfiltration within the total scope of possible impact severity - considering failure rates

Table 9: Result scaling

Pipe type	Average defect rates	Normalized defect rates

Flexible pipes	13.46 defects per km	0.19
Rigid pipes	71.74 defects per km	1

The Swedish analyses revealed similar results for flexible pipes as the German analyses.

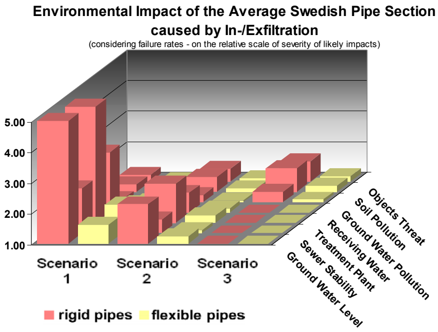


Figure 31: Environmental Impact of the average failure causing In-/Exfiltration within the relative scope of likely impact severity - considering failure rates

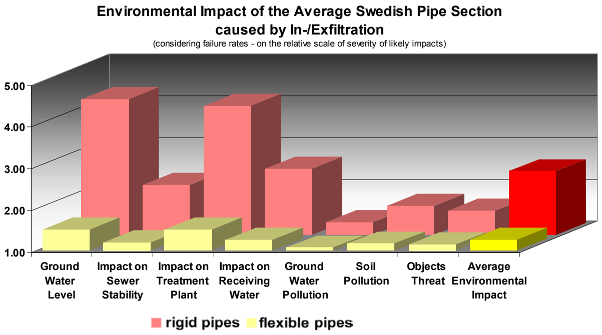


Figure 32: Average Swedish environmental impact caused by in-/exfiltration within the relative scope of likely impact severity - considering failure rates and aggregating scenario results according to net share

8 Conclusion

Although it is rather difficult to determine environmental impacts of drain and sewer systems in general, “STATUS Sewer” and its specific models for environmental issues of sewer systems give for the first time acceptable results to compare the environmental impact of flexible and rigid pipe systems caused by in-/ exfiltration.

Due to the general approach to draw a conclusion for the pipe systems in general, the results do not reflect the situation of a specific local sewer network, which would require to carry out this approach on the specific local data stock. The findings should be seen as an acceptable indicator for the environmental performance of the pipe systems analysed.

Accepting that all sewer systems leak, the question was which pipe systems promise a better performance with regard to the leakage problems. These problems are the main environmental issues during service life. As the analysis of the operational period was the aim of the project, it concentrated on the dominating issues of infiltration and exfiltration, causing the major environmental impact of such systems in this particular period. Moreover, almost all environmental effects caused during operation are local impacts, affecting directly the customers of the network operator.

As a result of this investigation, the following statements with regard to the analysis data restrictions (e.g. age limit 30 years, internal diameter not bigger than 800 mm etc.) can be summarized:

- The environmental impact of the average section caused by in- or exfiltration for flexible pipe systems is 15 % (less than one-sixth) of that for existing rigid pipe systems. Especially in scenarios with sensitive ancillary conditions, flexible pipes show a better environmental performance to rigid pipe systems.

- Considering the number of defects in reference to the installed length of all sewers of the material groups analysed in this study, flexible pipe systems have on average just 20 % (one fifth) of the defect rates of rigid pipe systems.
- When considering the number of defects in reference to the installed length of sewers of this particular material, defect rates of flexible pipe systems are on average by 25 % (one quarter) of the defect rates of rigid systems significantly lower for defect types that are the main causes for infiltration and exfiltration such as BAB (Fissures), BAC (Break/ Collapse) or BAH (Defective connection).

This study can deduce that sewer systems of flexible pipes show a significantly better environmental performance with regard to infiltration and exfiltration, due to lower defect rates and defect risks. Apart from this main research result, the study has shown that improper installation quality as well as impermanent monitoring and missing quality control lead to significantly higher defect indications, which multiplies the defect rates.

Additional country-specific conclusion

Although the Dutch and Swedish databases are relatively small and may not draw a perfect picture of the countries' sewage systems, they still give an acceptable overview on the country-specific situation. Nevertheless, the results from the data analysis clearly show the impact of different inspection strategies, which is for the Netherlands primarily driven by the request of the network operators and not – like in Germany – by laws and regulations. This finally causes significantly higher defect rates for the inspected sections, as only sections with defects that are serious enough to cause an inspection call by the operators are recorded. Additionally, the missing practice of TV-based acceptance protocols for the construction works encourages defects caused by deficient construction work and as a consequence higher defect rates.

The relatively small Swedish database consists of a large number of short sections from various conditions for both rigid and flexible pipes. This sample selection caused the data to be more representative for Swedish conditions than a selection from a limited number of sections.