Selective Inspection Strategy and Statistically Prognostic Rehabilitation Models

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1. Problem and objective

The method commonly used at present for determining the structural condition of sewer systems is inspecting the sewer by means of sewer TV. In addition, leak tests are often carried out. Information on the condition is required essentially for two planning purposes:

- To determine the condition of certain system elements (sewer reaches) as the basis for concrete, developed rehabilitation planning.
- To obtain an across-the-board view of the condition as the basis for analyzing the condition and cost trend as well as the extent of rehabilitation required as a whole for the sewer system or partial systems.

An up-to-date TV inspection is on all accounts necessary for developed rehabilitation planning according to point 1. Rehabilitation measures that are planned on the basis of findings gathered in inspections made several years before often prove to be unfeasible, no longer adequate or uneconomical when implemented because the condition of the sewer has meanwhile deteriorated considerably.

To obtain an across-the-board view of the condition according to point 2, the structural condition can be determined by making a full survey of the sewer system's condition or by carrying out a selective partial survey with representative extrapolation. The problem of the immense amount of time required and the high costs incurred for an across-the-board TV inspection have already been mentioned in [2].

Following the primary survey of the entire sewer system, an across-the-board repeat inspection is made. This involves re-examining reaches on a regular basis, independent of their condition and aging.

If the average useful life of sewers (50 – 100 years) [7] is taken as a basis, rehabilitation measures are carried out annually on approximately 1 – 2 % of the sewer system length. With an inspection volume amounting to 10 % of the system length per year, only 10 – 20 % of the findings gathered in the inspection lead directly to rehabilitation measures being implemented, while no measures ensue, for the time being, from the remaining 80 – 90 % of inspection findings because of their low priority. As a result, the repeated, across-the-board examination of the condition of sewer systems leads to the fact that every reach is inspected around five times before rehabilitation measures become necessary. On the strength of this problem it is worth developing more efficient strategies for primary and repeat inspections within the scope of self-monitoring.

One possibility is to determine the condition by using a selective strategy for sewer inspection with statistical and prognostic evaluation [1, 2, 10]. As only parts of the sewer system are at first examined, inspection expenditure is reduced considerably, information on the condition is available more quickly and is more up to date. By means of the selective inspection method, also taking into account repeat inspections, the costs of sewer inspections can be cut by two thirds within 25 years (Diagram 1).

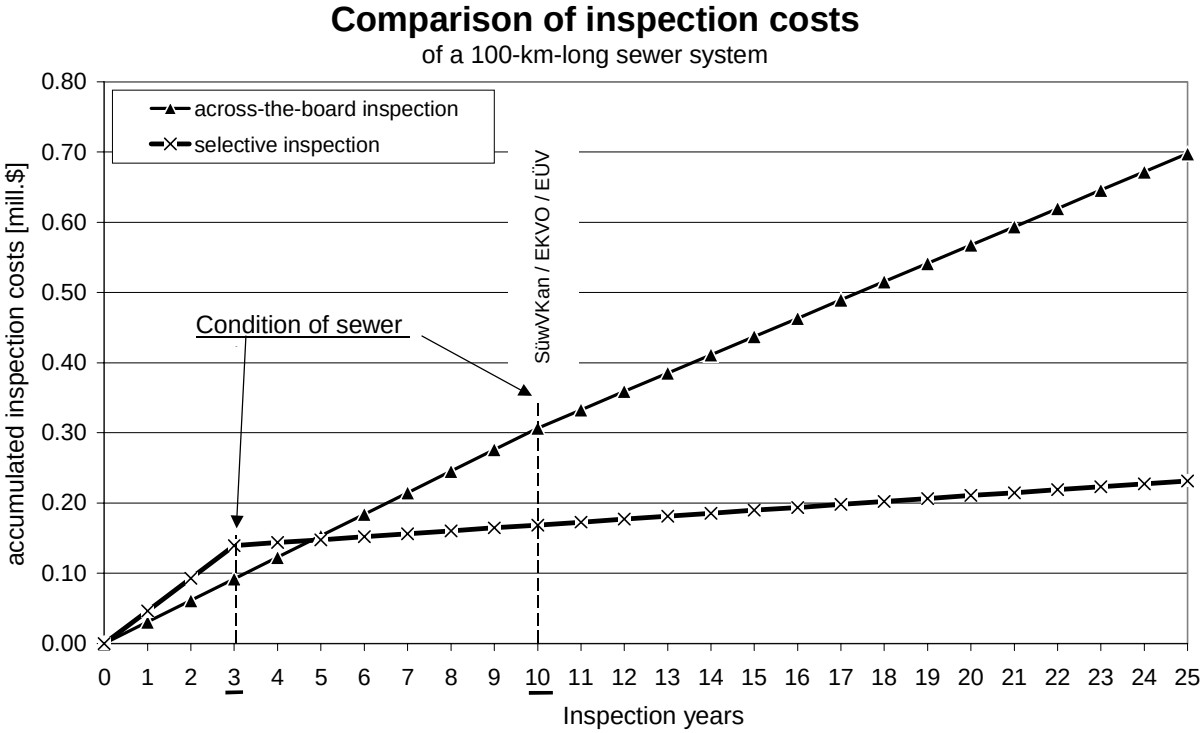


Diagram 1: Comparison of the costs of across-the-board and selective inspection of a 100-km-long sewer system

* SüwVKan ≙ Self-monitoring regulations of North Rhine-Westphalia / self-monitoring ordinance / self-monitoring regulations

The method has already been employed to examine the condition and cost trend of the sewer systems at the Volkswagen plants in Wolfsburg [2], Brunswick and Emden.

However, research is still required for it to be applied generally. The fundamentals for a method that can be applied generally and for detailed verification of the forecasted condition values are to be drawn up in a research project sponsored by the Federal Ministry of Education and Research (BMBF) in cooperation with the Rhenish-Westphalian Technical University in Aachen for the sewer systems of the city of Brunswick, the Entsorgungsverband Saar (waste disposal association), the city of Ingolstadt and the municipality of Marpingen (Saarland).

2. Selective inspection strategy method

With the selective inspection strategy method representative samples are examined and the results extrapolated for the entire sewer system. The characteristic features of the respective system are taken into account by the fact that sampling and extrapolation of the results are carried out each time for separate types of systems (layers) with similar feature formation (layered sample, Diagram 2).

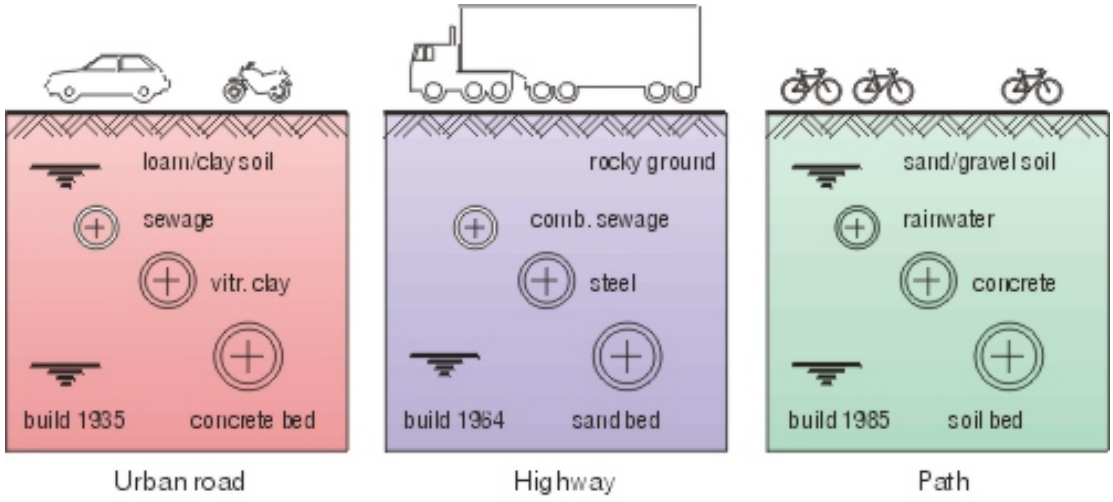


Diagram 2: Layer formation with representative features

As a result of the selective inspection strategy, the statistical information on the condition then available for the basic whole (all sewers) is

- the forecasted condition distribution in the entire sewer system, in individual layers (system parts) or differentiated according to individual features (Diagrams 3 and 4). In particular, the condition distribution according to individual features shows whether the initial assumption that the condition of the sewer system is dependent on certain features is indeed the case.

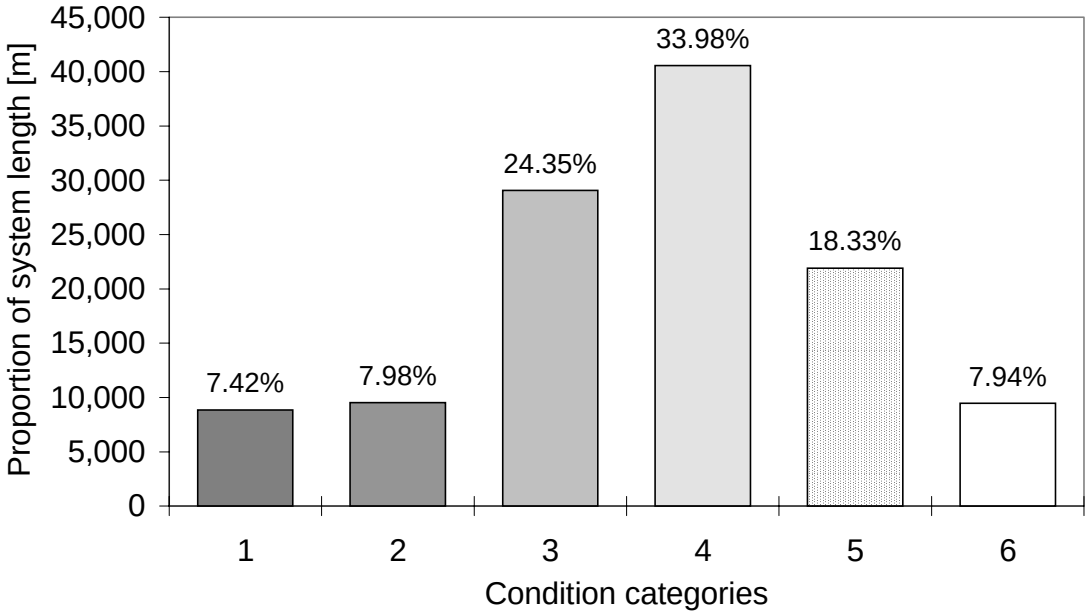
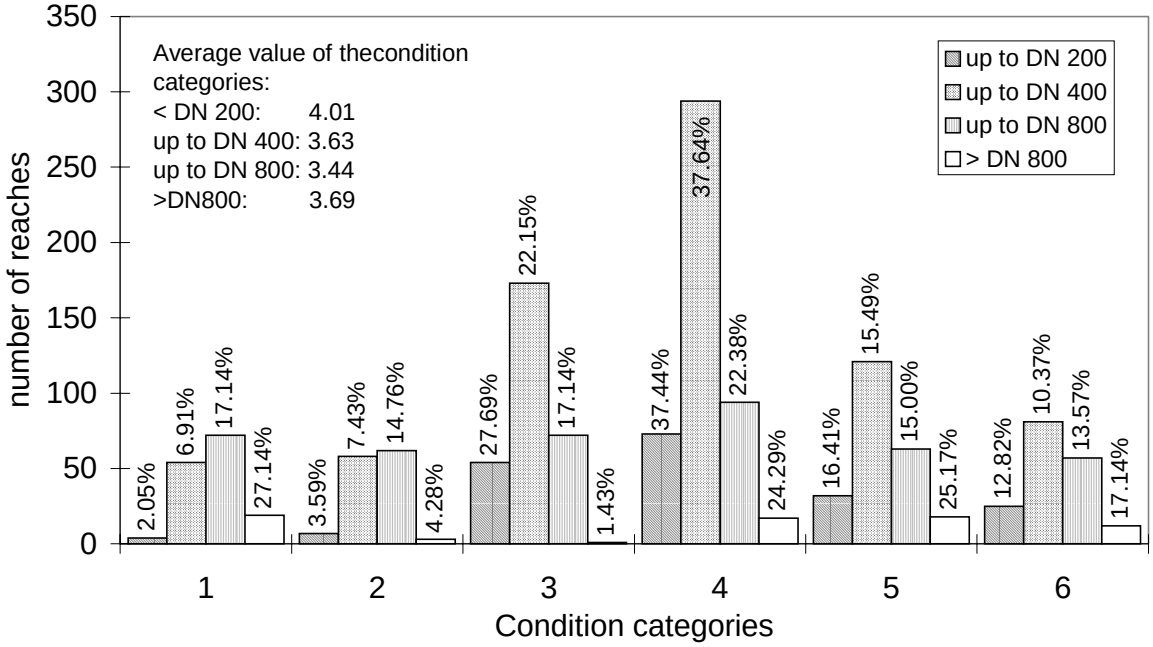


Diagram 3: Condition category distribution (forecast) in the entire sewer system



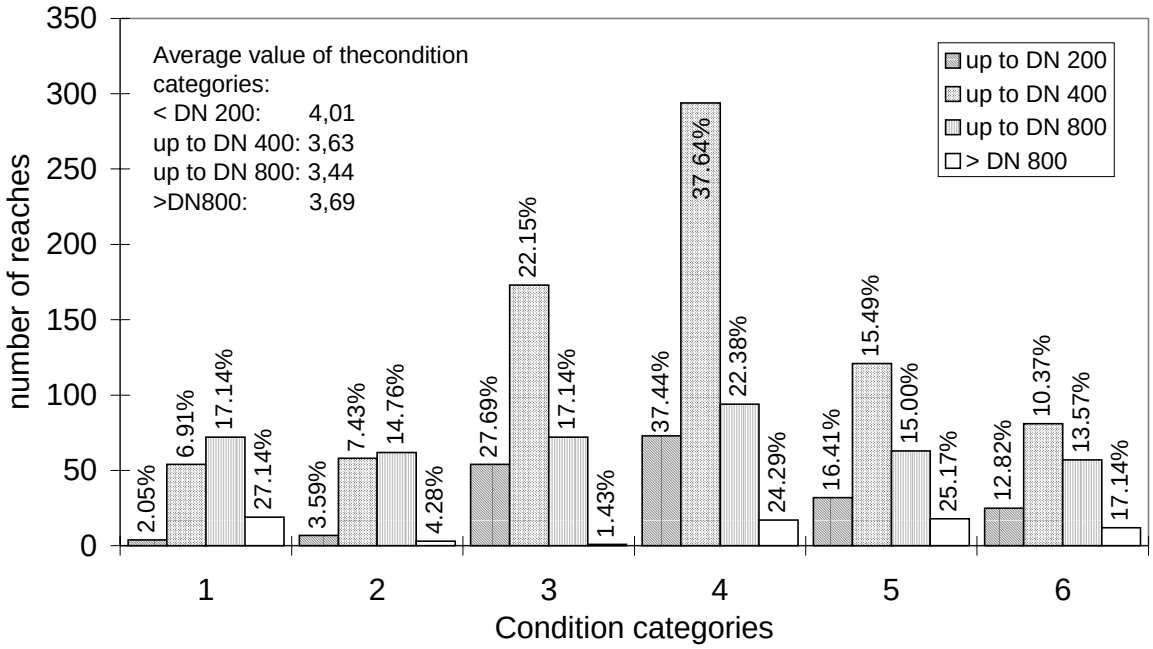


Diagram 4: Condition distribution (forecast) in the entire sewer system according to diameter groups

- estimated values related to reaches with regard to condition

  - An arithmetical average of the condition category, specific to the layer. There is a confidence belt for this average which indicates the permissible dispersion of the actual average around the forecasted average, dependent on the sample volume.

  - In addition, the median can be calculated for skew condition distributions. It gives the condition category that has been fallen below or exceeded by exactly 50 % of the reaches. If distribution is very skew, it might give a more correct picture than the arithmetic average used below.

  - A minimum condition for each reach which, with a certainty to be defined, is not fallen below. This is determined on the basis of the observed dispersion of the condition categories around the average.

Example:

The reaches in layer y show a medium condition category of x = 3.5. The confidence belt (95 % certainty) of the average is μ = 0.3. The minimum condition of the reaches which will not be fallen below with 95 % certainty is CCmin = 2.1.

Diagram 5 (available on request from AQUA Ingenieure GmbH) shows a chart of the system proportions in certain condition category ranges for a certainty of 95 %. All condition categories from 1 to 6 can be represented in 33 % of the sewer system that has not been inspected. In the case on hand this proportion is relatively high and, due to the age structure, was also to be expected. It focuses above all, but not exclusively, on the old parts of the system, which make up around a third of the sewer system.

Approximately 51 % of the system is in condition category range 2 to 6. That any serious damage exists in this part of the sewer system, damage that would lead to classification in condition category 1, can be ruled out with 95 % certainty.

Around 13.4 % and 1.7 % are in condition category range 3 to 6 and 4 to 6 respectively. Serious damage that would mean classification in condition categories 1 and 2 or 1 to 3 is not to be expected in these areas of the system. There is no need here for monitoring and rehabilitation at short notice.

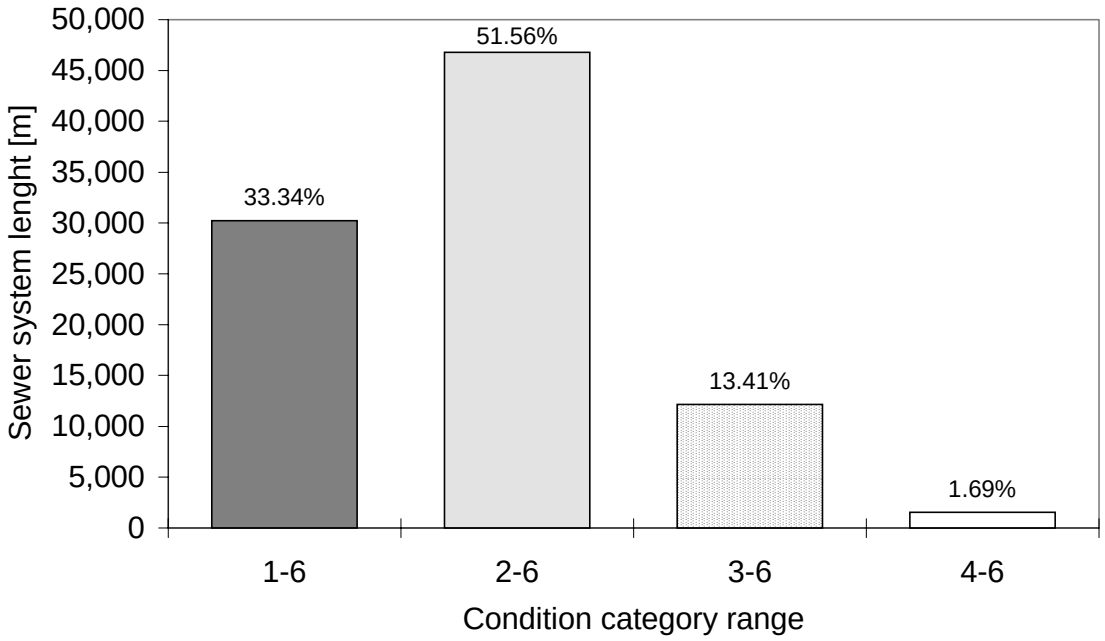


Diagram 5: Forecasted minimum condition of the sewers not inspected

3. Planning on the basis of the results of the selective inspection strategy and further course of action

For short and medium-term budgetary planning the extent of rehabilitation currently required, with details of costs for the entire sewer system and partial system, can now be established on the basis of the differentiated condition distributions with specific features (dependence of condition on age, type and size of section, pipe material and sewer location) for appropriate technical and financial marginal conditions

- proportion of different rehabilitation methods, dependent on, for example, condition, age, size and location of the sewers

- specific cost functions for the rehabilitation methods used, dependent on, for example, the above-mentioned parameters.

A condition assessment and classification with regard to the technical loss of usefulness, for which category classification is determined by the total damage volume of a reach and not by the most serious - and possibly only – piece of damage, is appropriately taken as the basis for this planning. The development of the extent of rehabilitation required and the development of costs in the future can also be shown on the mentioned data pool by means of aging models [3, 6].

In addition, overall views of the sewer system can be created, which document the average condition of the reaches for each layer. This presentation shows, in particular, the scope and priority of the need for rehabilitation.

On the basis of the minimum condition, which can be indicated for every reach, the priority, extent as well as the distribution in terms of time and location of the TV inspections to be carried out in the coming years for concrete rehabilitation planning (inspection plan) can be compiled. In this connection, the reaches to be inspected first are those in which damage belonging to condition category 1 (constructional priority) is not ruled out (95 % expected value < CC 2) (top inspection priority) and which have the worst average condition category (technical loss of usefulness) ($\rightarrow$ in greatest need of rehabilitation). Inspection priority is to be ordered accordingly. Thus, in the long term there is no need to inspect reaches with a minimum condition of 3 or 4 and a correspondingly good average condition category of 4 or 5.

Not only the average condition of a reach, but also the expected minimum condition of every reach can be presented in an overall view of the sewer system, thereby illustrating again the local priorities of the rehabilitation requirements.

4. How reliable is the forecasted information from the selective TV inspection?

After the selective inspection that was carried out in 1997 for the VW plant in Wolfsburg, parts of the sewer system have meanwhile been inspected completely, on the one hand to carry out concrete rehabilitation and on the other to check the reliability of the results from the selective inspection. In the main, adherence to the forecasted statistical condition values was verified.

Prerequisite for a comparison is that the same assessment criteria were taken for the current examinations of the condition, the TV inspection for sampling and the classification. An assessment of the condition according to the worksheet ATV-M 143, part 2 (sewage technology association) was stipulated. The examinations were carried out by various companies, the damage response tested by spot-checking the video films and records and a general elimination of defects demanded.

A total of 34 reaches that had already been inspected as a sample in 1997 were inspected again. This allows a direct comparison of the inspections and classification results to be made. Surprisingly, the more recent inspection often produces a better condition category than that of 1997. As a whole, a condition that is better by 0.5 condition categories is obtained. The difference is essentially the result of different damage dimensions being given (numeric addition to the damage grammalog), dimensions that are only estimated and which present a necessary but, depending on the size of the sewer, the camera and its angle of view, and the operator, fairly subjective statement. The keener assessment of the damage with the sample is naturally reflected in the forecast. This systematically different assessment and the better sewer system condition resulting from the current inspections of 0.5 condition categories are to be considered when making a verification.

The evaluation with regard to the expected minimum system condition (95 % certainty) being fallen below showed, without taking account of the above-mentioned variances, that of 985 inspected reaches, for which the expected minimum system condition is equal to, or better than, condition category 2, 33 reaches were in a worse condition – that corresponds to a fall-below rate of 3.4 %. When adjusting the current inspection by the systematic difference (adjusting the assessment by 0.5 condition categories), 58 reaches fall below the expected minimum condition (fall-below rate of 5.9 %). The error rate therefore is within the range of the expected rate of 5 %. At the same time, the actual condition was a maximum of one category worse than the expected minimum condition. There were no cases where the condition was worse by two or more categories. Thus, it can practically be ruled out that there are indeed reaches of condition category 1 or 2 in sewer system areas that have an expected minimum condition of 3 or 4.

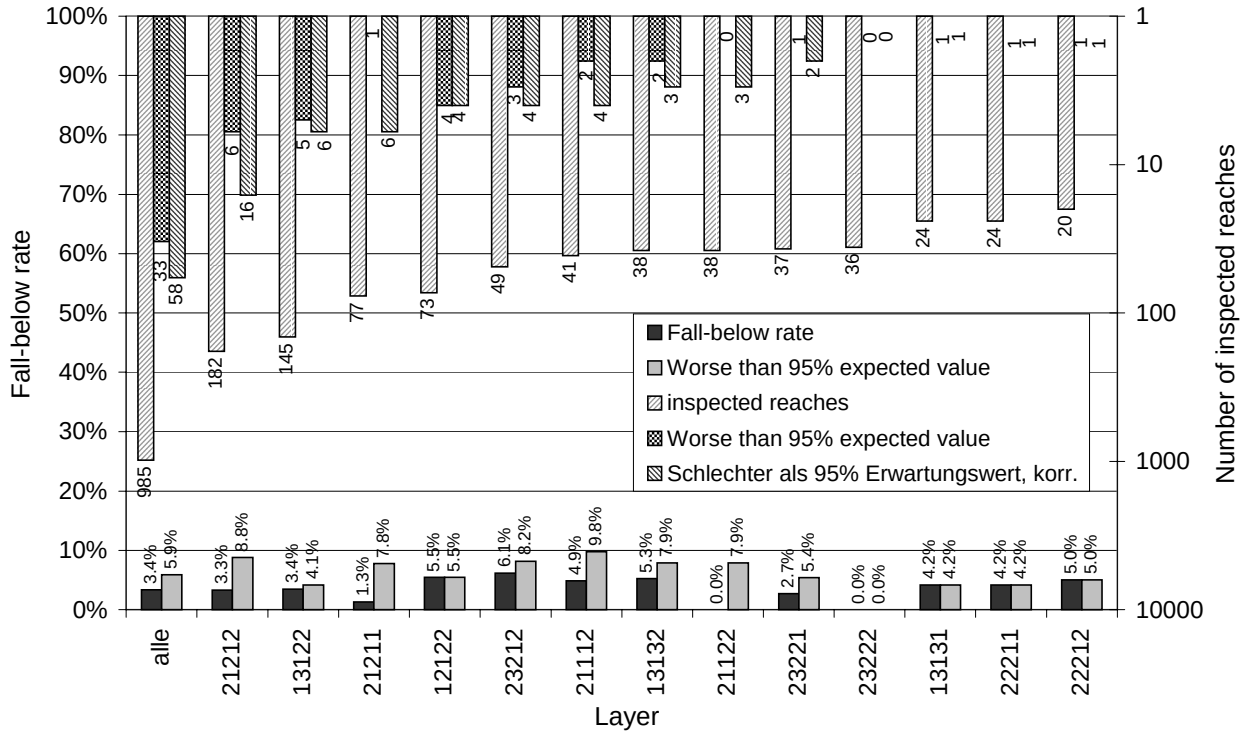


Diagram 6: Fall-below rate of the 95 % expected value

Diagram 6 shows the fall-below rate of the 95 % expected value, dependent on the number of inspected reaches per layer. An evaluation was only made for layers where at least 20 reaches were inspected as a statistical statement can no longer be made with a smaller inspection volume. Presented are the fall-below rates per layer with direct comparison and taking account of the systematic variance of the classification results. The fall-below proportion of the 95 % expected value (corrected assessment) varies from 0 % to 9.8 %. The 95 % expected value of the minimum condition is thus on average correct. The error rate of a single layer is below 10 % in every case. The extent to which exceeding the permissible error rate is favored by the overall correction of the condition categories cannot be proved in detail in this connection.

The second estimated value of the condition to be inspected is the average of the condition categories. Without adjustment according to the above-mentioned systematic variances as a result of the damage response, an average system condition of 4.2 is obtained on the basis of the current TV inspection, and of 3.7 when adjusted by the systematic variances. The average condition forecasted on the basis of the selective inspection for the corresponding reaches is 3.64. The variance between forecast and inspection result (corrected values) therefore amounts to around only 0.1 condition categories.

In Diagram 7 (can be purchased from AQUA Ingenieure GmbH) the variances of the condition category averages between inspection and forecast of the permissible variance (confidence belt of the forecasted average) are compared for the respective layer. The differences (value) are plotted on the primary axis (axes bottom left). The sample volume on which the forecast was based is presented on the secondary axis (axes top right).

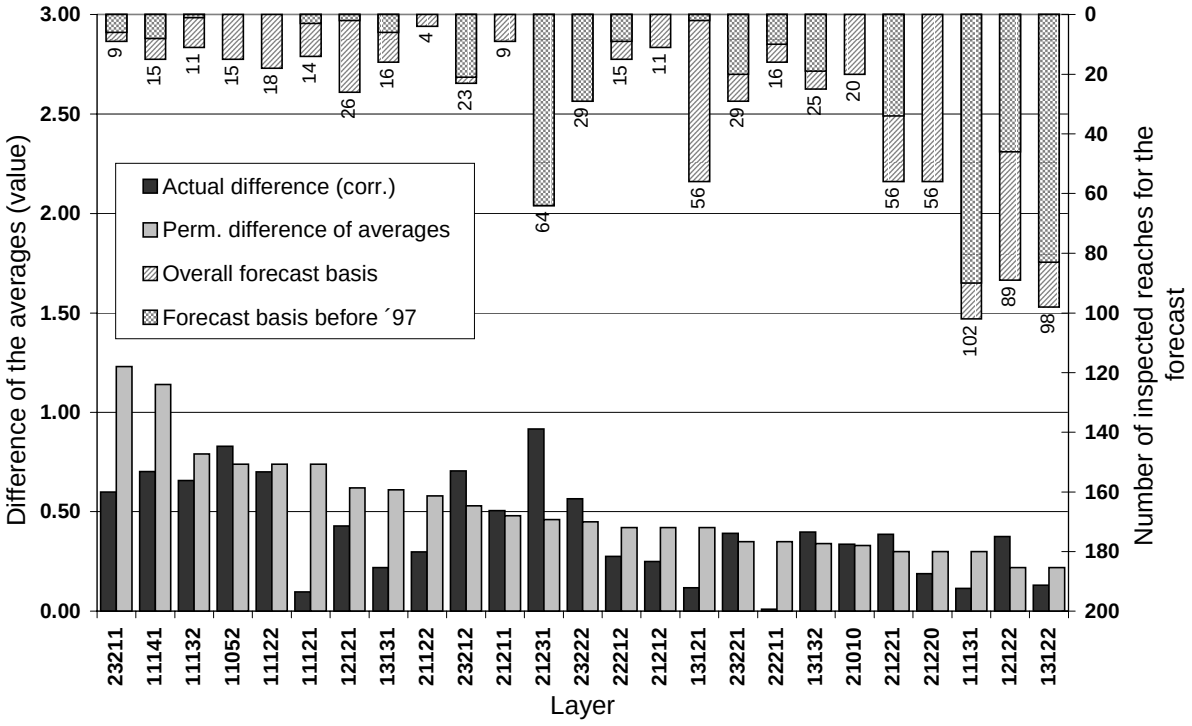


Diagram 7: Difference of the averages of the condition categories between inspection and forecast

The permissible variance of the averages (confidence belt) depends considerably on the volume of the sample for the forecast. 60 % of the actual variance value is within the calculated confidence belt. It is noticeable that in most of the cases where the actual variance of the average is outside the confidence belt, the sample on which the forecast was based contained a high proportion of inspections already existent.

In this connection it is to be assumed that the inspections of the samples already existent did not, however, have all the required randomness and stochastic independence of the result (sewer condition). A good example of this can be demonstrated by the condition distributions of the layers 21231 (Diagram 8). Noticeable is the high proportion of CC 1, which was forecast but did not occur. If we trace the origins of the sample, we find that all reaches come from the same inspection contract from 1991 for the locally limited area of the main link road in the plant. Similarly, this applies to layers 23212, 23222, 23221, 13132 and 12122, the samples of which contain a high proportion of old inspections.

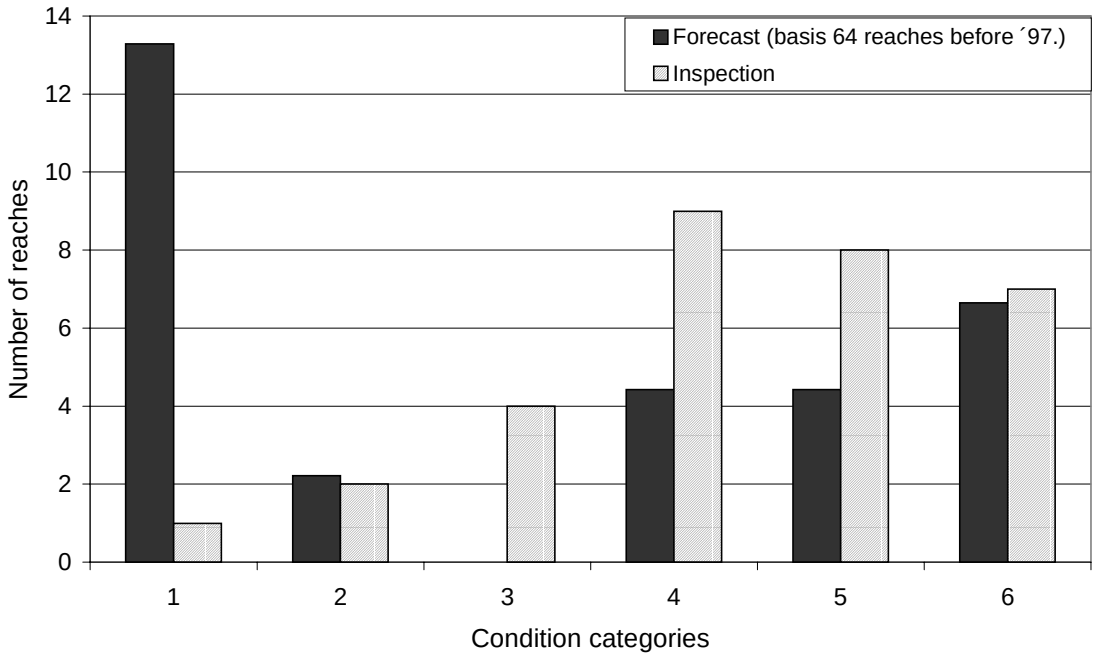


Diagram 8: Comparison of condition category distribution according to forecast and after inspection for layer 21231

The use of old inspections, which were not stochastically independent of the assumed condition, leads to clearly recognizable variances between the forecast and actual condition of the sewer. More care is required here when checking randomness. The proportion should possibly be limited.

Aside from these freak values, the range of variation between the actual averages and forecasted value is between + 0.83 and – 0.60, and thus for the most part within the statistically permitted range.

Although the data basis for verification was not ideal due to systematic variances and, as was discovered, the data basis of the sample was partly full of errors, the examination shows that the reliability of the selective inspection strategy is within the limits required.

Literature

[1] DIN EN 752:
Drainage systems outside buildings, part 5, Nov. 1997

[2] Hartwig, E.; Krug, R.:
Funding and maintenance of sewers – selective sewer inspection at the VW plant in Wolfsburg. Korrespondenz Abwasser 1998 (45), no. 8, pp. 1483 – 1488

[3] Hochstrate, K.; Jansen, K.:
Maintenance and funding of sewer systems by means of preventive maintenance. Korrespondenz Abwasser 1996 (43), no. 2, pp. 284 – 291

[4] Hochstrate, K.; Jansen, K.; Schönborn, F.:
Funding and maintenance of sewers. Quality control of selective inspection strategies in accordance with DIN EN 752-5 by approving authorities. Korrespondenz Abwasser 1997 (44), no. 11, pp. 1971 – 1974

[5] Hochstrate, K.; Schönborn, F.:
Funding and maintenance of sewers – selective sewer inspection strategies. Umwelttechnik aktuell 1996, no. 3, pp. 249 – 252

[6] Krug, R.:
Dynamic rehabilitation strategies replace traditional rehabilitation concepts. Sewers, maintenance and funding. Technical Academy Wuppertal, further education seminar, Nuremberg 1996

[7] LAWA (association of federal states – water)
Guidelines for implementing cost comparison methods. LAWA working group cost-benefit investigations in the water industry, published by: Länderarbeitsgemeinschaft Wasser (LAWA), Munich 1993

[8] Reinhard, W.:
Environmental impact of defective sewers – administrative law regulations. Umwelttechnik aktuell, 1996, no. 2, pp. 118 – 122

[9] Sachs, L.:
Angewandte Statistik – Anwendung statistischer Methoden (applied statistics – application of statistical methods. Published by Springer-Verlag, Berlin Heidelberg, 8th edition 1997

[10] Snaterse, C.:
Determination, classification and repair of damage to sewers in the Netherlands. Lecture at the 2nd International Mains Construction Congress, Hamburg Oct. 1989