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Global sewerage rehabilitation strategy with short-time selective sewerage inspection

1. Shortened version of the explanation report

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1. Explanation report

1.2 Aim of the examination and procedure

The aim of the examination on hand is to estimate the medium-term requirement of rehabilitation and repair financially to ensure a medium-term investment budgeting.

The necessary basis of this prognosis is a reliable knowledge of the present sewer condition as well as its further development into the future (deterioration of the condition by ageing).

The first of the planning basises can be made by means of a complete registration of the network condition or by means of a selective partial registration with a representative computer projection.

A complete registration of the network condition takes about 5 to 10 years because of the logistic facts to maintain the production and is over and above that very costly. More or less reliable assessments of the condition of the entire sewer system are with this procedure at the earliest possible after an inspection of 70% of the entire sewer system, that is about 5 to 7 years after beginning with the first inspection. Furthermore become the inspection results at this point of time partly already obsolete again. The condition deterioration is with the conventional inspection planning and analysis in the course of the time at the earliest at the beginning of the second inspection cycle assessable that is about 12 to 15 years after beginning with the first inspection.

The self-monitoring and self-control regulations of the federal states (e.g. Bavaria, Baden-Württemberg, Nordrhein-Westfalen, Hessen etc.) have usually an across-the-board first inspection of the entire network with following repetition inspections in fixed time intervals. Such a procedure is costly and supplies only insufficient condition datas for a foresighted rehabilitation planning.

Alternatively are selective inspection strategies after the euro standard DIN-EN 752/ part 5 considered with a statistical and prognostic analysis. They save at least half of the inspection expense. The condition results are faster available. They are more extensive and more topical.

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DIN-EN 752 (design), 6.5.1 Preparation of the inspection programs
„It is of special importance that the inspection of the sewer system is made purposeful to avoid double work. The structural examinations can either cover a complete examination of the drainage system or a selective methodology."

This means concretely that it is possible to assess the topical rehabilitation delay with a selective
methodology by means of a condition examination of a layered sample to the extend of approx. 10% of the entire network already very precisely.
Via the sampleful first registration of the network condition and its representative analysis reliable planning basises with a fraction of the expenses are at least five years earlier at one's disposal than with a complete registration without analysis.

The selective first inspection occurs effectively for a layered sample. The division of the complete network in so-called „layers" is made after available reach characteristics so that the differences
of the network condition is relatively small within the layers. As segmenting characteristics are considered for instance:

- soil conditions
- drainage system (M/R/S)
- material/ way of laying
- waste water quality (domestic/commercial/industrial)
- age
- other regional peculiarities (e.g. earlier maintenance deficits in sub sewer systems etc.)

From each of the layers made only a few parts of the network, so-called „lumps" are examined completely. Inspection results already on hand can be used without any loss of representativity of the total result.
For the security of the transmissibility of the network condition of the „lumps" on their layer, completing chosen sections of the network are inspected as single samples.

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After the appropriate computer projection of the condition results refering to the total stock of the network is it possible to devide its total length – subdiveded into construction costs relevant features (e.g. nominal sizes) – into condition classes. The two worst condition classes describe quantitatively the current replacement delay and the medium-term additionally developing need for replacement. Later completing and repeating inspections change the projected network condition in annual periods only gradually. Surprising modifications of the ascertained rehabilitation requirement do not occur.

The second planning basis, the future development of the network condition is determined in combination with the years of construction by means of modelling of the sewer system-specific ageing process. The prognosis result of the ageing process is the forecast of the remaining service-life of the examined network elements and so the regulation of their failure and rehabilitation time.

The financial need for rehabilitation results from the topical replacement delay and the expected further condition deterioration in the long-range planning period .

1.5 Selective TV examination

1.5.2 Basis of the sample

1.5.2.1 Layering of the network

The selective inspection occurs for a layered sample. „Layers“ are defined here as groups of reaches which are characterized by certain combinations of influential features (segmenting features). Aim of the division of the entire network into layers is to make a layering formation so that the differences of the network condition are expected relatively small within a layer.

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Influences on the condition of the sewer system have especially following parameters which are always considered as segmenting features

- age
- drainage system and waste water quality (rain water, waste water, combined water, domestic/ industrial)
- pipe material and way of laying
- dimension of the pipe
- soil conditions
- ground water conditions and if necessary ground water chemistry
- position and degree of the traffic load
- other local or periodical caused peculiarities if not already mentioned in the features above

The number of parameters (segments) within a segmenting feature is
different. The feature drainage system for instance has 3 parameters (MW,RW,SW), the number of parameters concerning the feature soil conditions can - depending on the local conditions – vary strongly between 1 (same soil conditions in the entire area) and 5 (e.g. gravelly soils, rocky soils, depositions, loamy soils, soils not able to take a load in river meadows etc.)

It is necessary to pay attention to the fact that the number of layers with each additional segmenting feature increases by the factor of the number of segments. If there are 5 segmenting features à 5 segments for instance the theoretical number of layers can be 3125. Since however often not every segment of a feature is combined with every segment of another feature, the number of layers is virtually considerable smaller. Nevertheless is it necessary to proof critically whether a segmenting feature is virtually relevant to keep the number of layers as small as possible. Furthermore it has to be taken into consideration for which of the segmenting features which seem to be relevant in principle, the data basis can be determined with a justifiable expense.

A listing of all groups of these theoretical layers - sorted according to group numbers with a specification of the trimming of the reaches as well as the finally made scope of the sample contains the system 3.1.2.1.

There are representing from 167 layers more than half of it – that means 97 layers – a trimming with less than 10 reaches per layer, i.e. these layers are of secondary importance.

For further examinations: definition of the scope of the sample and analysis of the sample, these smallest groups are mostly assigned to a higher group.
Higher groups are groups with one or more segmenting features missing because of not having the appropriate information.

1.5.2.2 Definition of the sample

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First of all we proceed from the assumption of a scope of at least 10% per layer or rather at least 4 reaches per layer to define the scope of the sample.

At first was examined for which layers the scope of the sample needed is already totally or partly covered by means of the availableTV inspection .
The result for some layers was an already inspected share of the network of substantially more than 10-20%, smallest layers were partly 100% inspected.

1.5.6 Damage evaluation of the sample

1.5.6.1 General

So far the evaluation of damages took exclusively place because of the urgency of repairing the damages (structural priority). Both, the condition examination and all usual EDP programmes for classification and the work with ATV working groups which is manifested in the (withdrawn) design of the paper A149 „condition classification and evaluation of sewer systems and pipes" are aligned with a damage evaluation concerning the structural priority.
This type of classification is constituting a condition class exclusively or in particular because of the biggest single damage. This means that e.g. if a reach which is locally limited shows a burst pipe, the remaining reach however is completely intact is classified into the highest priority because of the necessity to repair the damage.

The entire technical condition or value of a sewer reach however is not described exactely then. This is comparable with the analogy that a motor vehicle with a damaged brake (single damage) requires an immediate repair (structural priority), but the value of the vehicle however depends on ist general state.

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For the prognosis of the ageing process of the network is therefore
a condition classification necessary that is considering the stages of the technical reduction in value as a result of ageing, lack of building and structural damages (9)

In the project on hand both classification types were used and compared in
their results

- condition classification according to the urgency of the damage repairing (structural priority)
- condition classification to describe the technical reduction in value

1.5.6.2 Condition classification concerning structural priority

The condition evaluation occured with the evaluation program KAIN which is part of the data base S&K-Tiffany

1.5.6.3 Condition classification concerning technical reduction in value

With the evaluation of the technical reduction in value is a classification made according to the total condition of a reach

The total condition is influenced – next to the extend of the damage and the
importance of single damages – especially by the density of damages.
Herewith are multiple damages in one reach appropriately considered.

1.6 Condition prognosis of the entire network

1.6.1 Correction of the layering

The theoretical layering of the network was corrected again after finishing the TV inspection and analysis of the received datas on the basis of practical point of views.
For many of the smallest groups wasn't it possible to take samples for every group because the expenditure is out of a reasonable proportion to the importance of the group and the result. Furthermore wasn't it possible to examine with the TV inspection, as already explained, the intended scope of the sample for every layer completely.

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The scope of the sample at our disposal was usually sufficient for these higher groups because all samples from the appropriate subordinated groups constitute partial quantities of the superordinated group of the sample.

1.6.2 Ascertainment of the prognostic condition distribution in the entire network

The group specific transfer factor is formed by the length of the sample and the section length taken into consideration (length of the reaches in the group where the inspection result is supposed to be transfered).
With this factor the results of the condition distribution of the sample are projected as statistic condition distribution to the totality of the reaches of one group.

With the received result of the sewer system condition for the entire network,
the fundamental basis for the prognosis of the future deterioration of the network condition and the worked out strategy of maintaining is available.

1.6.3 Statistical future predictions for individual reaches

While the diagram of the middle network condition documents more the entire scope and the main emphasises of the rehabilitation activity, the diagram of the expected minimum condition shows in particular the main emphasises and the order with scope for a detail program necessary first inspection to find the urgent necessary maintaining measures concretely- which is only a low share in proportion to the entire scope- and to start the planning.

1.7 Ageing prognosis of the entire network

1.7.1 Modelling of the ageing and replacement

The process of the individual ageing of a pipe section is shown by the respective deterioration of its structural condition as time goes by. This means practically that the pipe sections go through the condition classes from 6 (without damage) to 1 (immediate rehabilitation necessary) one after another according to their individual ageing speed. This process can be described mathematically as age-dependent probability of the transition in worse conditions. These transition rates change in the course of the age depending on material and use and are functionally linked with survival probabilities and life expectancy, or more general – with the probability to be in a certain condition and to achieve a corresponding age with it.

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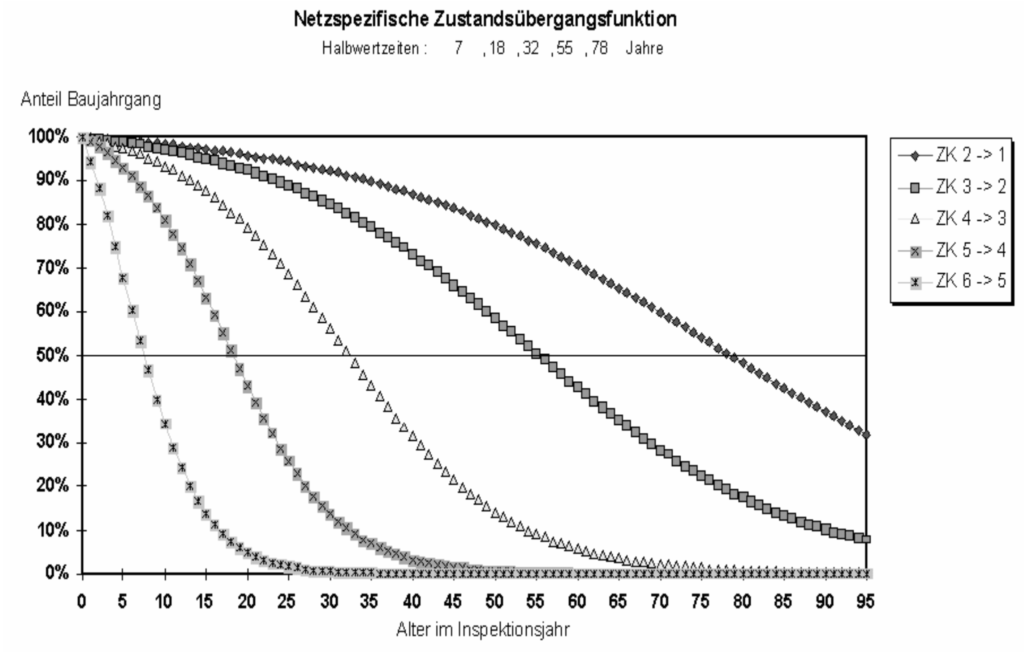

The remaining-time of a reach in the condition classes can be described with condition transition functions (survival functions) concerning a defined condition. The diagram above shows these condition transition functions for the sewer system network of a city district with 100.000 inhabitants. The diagram shows the expectancy value of the remaining-times of a reach in the condition classes on the 50% line:

condition class	remaining-time (expectancy value)	
6	7	years
6+5	18	years
6+5+4	32	years
6+5+4+3	55	years
6+5+4+3+2	78	years

Because the ageing is a stochastic process, i.e. a process depending on chance, the ageing speed is spread upwards and downwards around the line of 50% i.e. there are more long-lasting and more short-lasting reaches.

The prognosis whether a reach is long-lasting or short-lasting can be determined with the above mentioned functional connections from the present condition and age .
For the modelling of the network specific ageing process general transition functions are adapted by fixing of curve specific parameters to the ageing structure and to the condition distribution available on a qualifying date. This
process is called calibration of the arithmetic ageing process.

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Practically the calibration is made via a backwards calculation of the historical network development from the stock and condition datas and an iterative correction of the parameter as long as the backwards calculated network
development is corresponding with the actual, historical network lengths.

The backwards calculation is only corresponding to reality if the based transition function was estimated correctly. The other way round the historical correct determining of the development of the network length proofs that the calibration for the transition functions is correct.

This calibration is part of the used simulation program AQUA-WertMin.

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1.7.2 Prognosis of the undisturbed ageing process

After the network specific calibration of the condition transition functions is it possible to calculate for every reach and drain of the sewer the expected transition and failure point of times as well as the service-life and residual service-life on the basis of the individual age and condition.

At the same time result from these transition point of times the distribution of the proportionate lengths of the sewer system or rather the number of pieces of the drains for the single condition classes in each prognosis year. A continuous forecast of the network condition development on condition „pure aging“ is herewith made, i.e. there are no alternate measures taken for failed network elements.

1.8 Strategies for the maintenance of the sewer network

1.8.1 General basises

- **aim definition**

  Financial and technical optimized maintenance strategies result from the network condition development demonstrated via the ageing prognosis. Aim of the sewer maintenance in technical regard (debit condition):

  - maintenance of the operability and stability
  - operation of a permanent close sewer network that
    - endangerings of the environment by ground water and soil pollution via exfiltration are excluded.

  According to DIN EN 752 „sewer systems outside from buildings“have to be constantly close and safe in functioning

  - previous infiltration of water from outside

  To reach the above mentioned technical aims in financial and economic regard the costs need to be minimized in medium-term view and the development of the costs constant and foreseeable.

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1.8.2 Costs of the damage removal procedures

The costs for carrying out the single damage removal procedures are calculated on the basis of parameter depending cost functions which consider the local cost level.

1.8.3 Examined strategies

In coordination with the purchaser the three following strategies to maintain the sewer network were examined:

a) repair strategy

The repair strategy intends no replacement or renovation of reaches as alternate procedure. The removal of the damages to get to the above defined debit condition occurs exclusively via constantly repeating measures of repair. Herewith the ageing process and the progressive technical reduction in value is not delayed. Merely the evaluation of the structural condition improves.

b) substantial value maintenance strategy

Paying attention to the aim - reaching and keeping the technical debit condition intensive measures – replacement and renovation - are taken that

- the condition class 1 is wilted till the year 2000
- the at present available substantial value (the technical value) of the sewer network is kept in future. This means that the relation between the single condition classes in the network is not changing from time to time.

The further necessary damage removal measures in the condition class 2 to guaranty a permanent close network are made via routine repair measures - the annual costs of it are calculated.

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c) minimum condition strategy

Aim is to examine the scope of the necessary investments via replacement and renovation as well as the development of costs with the specification to reduce the condition classes 1 and 2 completely within the next 10 years (that means till the year 2008) and to keep the sewer network in the long-term. That is why the condition class 3 is defined as minimum condition in the sewer network.

The primary observation period for the condition maintenance strategies is planned for the medium-term by the purchaser approximately till the year 2030. That's why the longer-term observation till the year 2080, like executed by the program, is for the decision-making process of minor importance.

Processing technical the elaboration of the strategies is an iterative process by varying the annual investment budget as long as the desired aim of strategiy is achieved. To avoid immense brief fluctuations in the necessary budget small brief fallings below or exceeding of the aim of the strategy are also accepted.

1.8.5 Valuation of the strategies

Due to the cost comparison shown above, the minimum condition strategy should be given preference - despite the stronger fluctuations in the development of costs and the investment subsidizes (keeping to it at least condition class 3) - hence a technical high-quality maintenance strategy in comparison to other strategies.

Even though a strategy which is only aiming at the preservation of the substantial value leads to continuous investment budgets it is however longer-term more expensive because of the high share of necessary repair costs compared to the first mentioned minimum condition strategy.

A repair strategy cannot be recommended as well because of the extremly rising costs in the future as because of the decreasing security of sewage and refuse disposal.

For the favored version „minimum condition strategy" the technical relevant and financial values are arranged as follows:

period of time	necessary annual				annual overall costs [Mio. DM/a]
	rehabilitation work	investment budget	repair costs	mainten-ance costs ZK 3-5*	

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	[km]	**[Mio. DM/a]**	**ZK1 u. 2 Mio. DM/a]**	**[Mio. DM/a]**	
1998 - 2007	4,0	3,5	2,0 - 0	2,3	7,8 - 5,8
2008 - 2019	2,0	1,8	≈ 0	2,3	4,1
2020 - 2030	4,5	4,0	≈ 0	2,3	6,3

*) The additional annual maintenance costs for ZK 3-5 reduce to 0,8 mio. DM if there are occuring only for waste water appropriate additional maintenances.

1.8.6 Practical realization

The successful practical realization of the maintenance strategy requires in the main following single steps:

- detailed planning in sections and execution of rehabilitation measures via renovation, replacement and maintenance, first on the basis of the given TV-inspection. Annually require approximately 4 km of sewer network a rehabilitation via replacement or renovation. Additionally there is a need of maintenance in reaches of the condition class 1 and 2 not redeveloped yet of approximately 3,0 km in the first year (decreasing in the subsequent years). Further damage removal measures and leak tests in the condition classes 3 to 5 have to be considered as well. Every year about has to be worked concretely on about 8 – 8,5 km as well as examined.

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- Constant continuation of the TV-inspection for direct damage assessment within the next years. The sewers with the worst prognostically established minimum condition have to be inspected first. In addition approximately 50 km of sewer network have to be inspected in the following 5 years as well as further 40 km within the next 5 years.

- The present digital database of the stock of sewers is due to the missing planning documents for some network areas, missing or inconsistent details in the based plans in some parts still incomplete or rough. Via a supplementing stocktaking or examination and measurement within the next years this database has to be improved continuously and be updated after network extensions, changes, replacements and renovations.

1.9 Summary

The sewer network in the factory premises of the city X covers approximately 350 km. About 120 km are main sewers (collective sewers), the rest of it small dimensioned connecting sewers.

Aim of the executed examination was to number the medium-term need of rehabilitation and repair for the 120 km of the main sewer network in the factory premises of the city X to make a medium-term investment planning till the year 2030 possible. Aim of the medium-term investment and maintenance is to achieve and keep a technical debit value of the sewer network which ensures a maintenance of functioning and stability as well as a no damages and
leaks of the sewer network that endangering the environment and if necessary criminal responsibilities are avoided.

Basis of the prognosis is the knowledge of the sewer stock, age and of the sewer condition as well as its further development in the future.
Therefor the complete digital registration of the sewer stock into a database was necessary. The necessary data capture was made from approximately 230 available single diagrammes. Data inconsistencies between the different plan documents were cleared up as far as possible. The age of the single sewer sections was traced due to the plan documents as well as matching with the purchaser, department building management.

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The made out database offers now the basis to make via gradual accurate registration of hitherto rough and incomplete data a complete digital sewer land register.

The sewer condition was recorded by a selective sewer inspection with computer projection of the results with regard to the entire network. Compared to a (so far usual) complete TV condition examination this methodology could save
considerable costs and bring the necessary dates concerning the sewer

condition for the short-term. Approximately 16 km of already available TV-inspections could be analysed that the additional necessary inspection was limited to about 12 km. Basis of the selective condition registration was a structure of the sewer system after characteristic features (age, material, drainage system, profile size and position) which were combined with each other in altogether 99 groups.

The TV-inspection occured as a representative sample for each group, from the result of it – **middle network condition, minimum network condition and distribution of the condition classes –** was made a total computer projection. The evaluation of the by TV-inspection recorded damages (condition classification) was made

- concerning the **structural priority** (urgency of elimination of discovered damages)
- as well concerning the **technical reduction in value** of the network as result of the entire condition from age, wear and tear, building lacks and building damages.

The gradation of the condition is made in 6 classes, from **class 1: most serious damages, to class 6: without any damages.** After the classification result concerning the technical reduction in value approximately 5 km of the sewer network are in condition class 1 and further approximately 23 km in condition class 2, that is **with about 25 % of the sewer network the substantial value is to a large extend strongly worn out** and reduced because of age and damages.

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About 73 km (61 %) of the sewer network are in the condition classes 3 and 4 and show a middle damage or a technical reduction in value. **Only approximately 20 km of the sewerage system show no or only a low damage (condition class 5 and 6).** This sewer condition will be deteriorated increasingly within the next years without any measures of rehabilitation.

By sewer specific modelling of this ageing process via statistic condition transition functions, so-called „survival functions“, this condition deterioration was reconstructed as well as the respective expected residual service-life of the examined network elements and so their moment of failure and rehabilitation was calculated. The financial need for rehabilitation results from the topical replacement tailback and the condition deterioration expected within the planning period.

The present about 27 km containing share of sewers in the condition classes 1 and 2 (danger of burst pipe and collapse) will increase without any countermeasures within the next 10 years by 56 % to approx. 42 km.

On the basis of this expected development three different strategies concerning a maintenance of the sewer network were examined:

- **repair strategy**
  The technical debit condition is restored only by local repairs without an improvement in value replacement of the structural substance especially of the pipe statics.

- **substantial value maintenance strategy**
  Investments for replacement or renovation of the structural substance with restoration of the pipe statics are made to an extend that the present network condition (concerning the technical reduction in value) is maintained. For additional necessary damage repairs are to a certain extend repair costs due for annual necessary maintenance expenses.

- **minimum condition strategy**
  Aim is to reach via intensified investments within the next 10 years a minimum condition of the sewer network so that no sewer reaches are incondition class 1 or 2 anymore (danger of burst pipe and collapse).

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Due to the economical **cost comparison the minimum condition strategy comes off best** and is therefor to be favored for the medium-term sewer maintenance. The worst strategy is in comparison to it the repair strategy which has consequences of enormous increasing costs in the medium-term and is not able to ensure the security of waste management like the two other methodologies.

The annual necessary financial amount to achieve the technical debit condition for the favored variant:

period	**financial amount [Mio. DM/a]**
1998 - 2007	7,8 - 5,8
2008 - 2019	4,1
2020 - 2030	6,3

The concrete realization of the worked out minimum condition strategy needs in the following years a continuous damage removal via replacement, renovation and repair in the already inspected sewer network areas and a match between TV-inspection and demand for a purposeful damage removal. Furthermore the digital database of the sewer network has to be improved systematically via supplementing stocktakings and measurements.

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