AQUA-WertMin
V 5.0

Value Conservation and Funding of Sewer Systems by means of Preventive Maintenance

Description of Method

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1. Introduction

It is widely known that the poor maintenance condition of sewer systems leads to exfiltration and infiltration of the groundwater, impairs safe disposal, and calls for immediate measures, which entail disproportionately high costs, to be taken to repair damage. The immense rehabilitation backlog that currently exists is not restricted to the requirements of replacing antiquated parts of the system. Reaches and shafts that are not so old are also in need of rehabilitation well before their calculated useful life due to structural failings and damage. This misjudgment of the useful life expectancy calls for the introduction of preventive maintenance planning with an analysis of the weak points and a prognostic inspection strategy. The experience gained by the energy supply companies and the processing industry can be evaluated to develop a modern sewer management system.

A particular challenge in sewer management is to reconcile maintenance of the existing network with liquidity constraints, i.e. to harmonize the erratically incurred expenses of rehabilitation with the steady receipts from sewage charges. The increasing steadiness necessary for the financial requirements is achieved by optimizing the times and methods of rehabilitation.

2. Depreciation and preventive maintenance for comparable capital goods

The useful life of buildings is limited by their depreciation during the course of time. This is also applicable to sewer reaches and shafts. According to the asset valuation guidelines of 1991 a distinction is made between technical and economic depreciation [1]. The causes of depreciation are age, structural failings, structural damage and changed requirements (see Diagram 1).

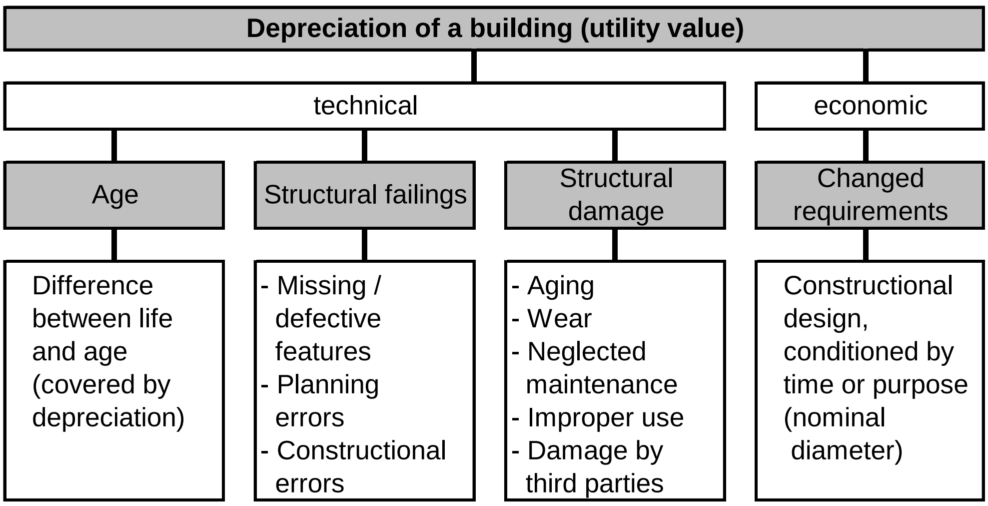

Diagram 1: Depreciation of a building [1]

Maintenance is carried out to preserve the utility value. In accordance with DIN 31051 this comprises the following measures [2]: inspection, maintenance and overhauling. The term overhauling corresponds to the term in sewer management of structural rehabilitation, which is divided into repair, renovation and replacement [3].

In addition to the maintenance measures in accordance with DIN 31051, preventive measures are taken in practice to increase the operational safety of technical systems. The institute for internal auditing coined the term of preventive maintenance for this in 1989 [4].

"Preventive maintenance is to be generally understood as measures to find ways and means of avoiding to a large extent any damage to be expected and of keeping the future costs of maintenance, inspection and repair as low as possible, and to do this as early as during the planning, construction or even erection of plants."

Measures for preventive maintenance serve to preserve the planned condition of a system's technical components at minimal cost, and are oriented to the following criteria [4]:

- cost-minimizing inspection, maintenance and preventive overhauling
- selection of equipment constructions that are resistant to damage
- maintainability
- procurability
- technical reliability
- value stability

Traditional strategies within the scope of preventive maintenance are [4]:

- the preventive strategy (periodical overhaul of components without inspection)
- the inspection strategy (periodical inspection, overhaul dependent on condition)
- the operative strategy (stockkeeping, quick replacement in the case of operational failure)

In contrast to the traditional strategies, forward-looking maintenance is based on forecasting the depreciation and the costs of operational failure. The purpose of this forecast is to optimize the operational reliability of the system at low cost. To be specific, economic assessments and evaluations of alternative rehabilitation strategies (preventive repair/renovation/replacement) and alternative rehabilitation methods are carried out. A checklist for the following individual decisions is then drawn up from the forward-looking maintenance strategy that has been developed:

- different intervals between inspections or special inspections
- different maintenance measures
- preventive repairs
- change in the calculated remaining useful life
- different materials or laying methods
- replacement of pipe sections

Forward-looking maintenance is standard practice in the electricity, gas and water supply sectors. In these industries sections of the supply line are replaced as a precaution once their useful life expectancy has expired, in order to minimize the risk of operational disturbance. By means of systematically analyzing the weak points, structural failings and damage (e.g. insufficient corrosion protection and corrosion damage that has been observed) are taken account of when determining the calculated useful life [5].

Forward-looking maintenance in the manufacturing industry is even more pronounced, in particular in assembly line production. There it is used to avoid losses of output caused by malfunctions. For example, the breakdown of a system component in the assembly line production of automobiles results, after a waiting time of 4 minutes, in a loss of output that involves losses in sales amounting to a two-digit figure in millions every day.

Reliable disposal is also guaranteed by forward-looking maintenance measures in modern sewer management. Moreover, financial planning is of particular importance here as the planning of measures in municipal sewage disposal is essentially determined by liquidity squeezes.

3. Modern sewer management system

Modern sewer management is based on a methodical model of action which, as a cyclic chain of activities, comprises the steps of inventory recording, recording the condition, evaluation, forecast, planning and execution [6, 7]. With regard to forward-looking maintenance and the financing of such, the systematic analysis and decision process between recording the condition and planning is particularly important.

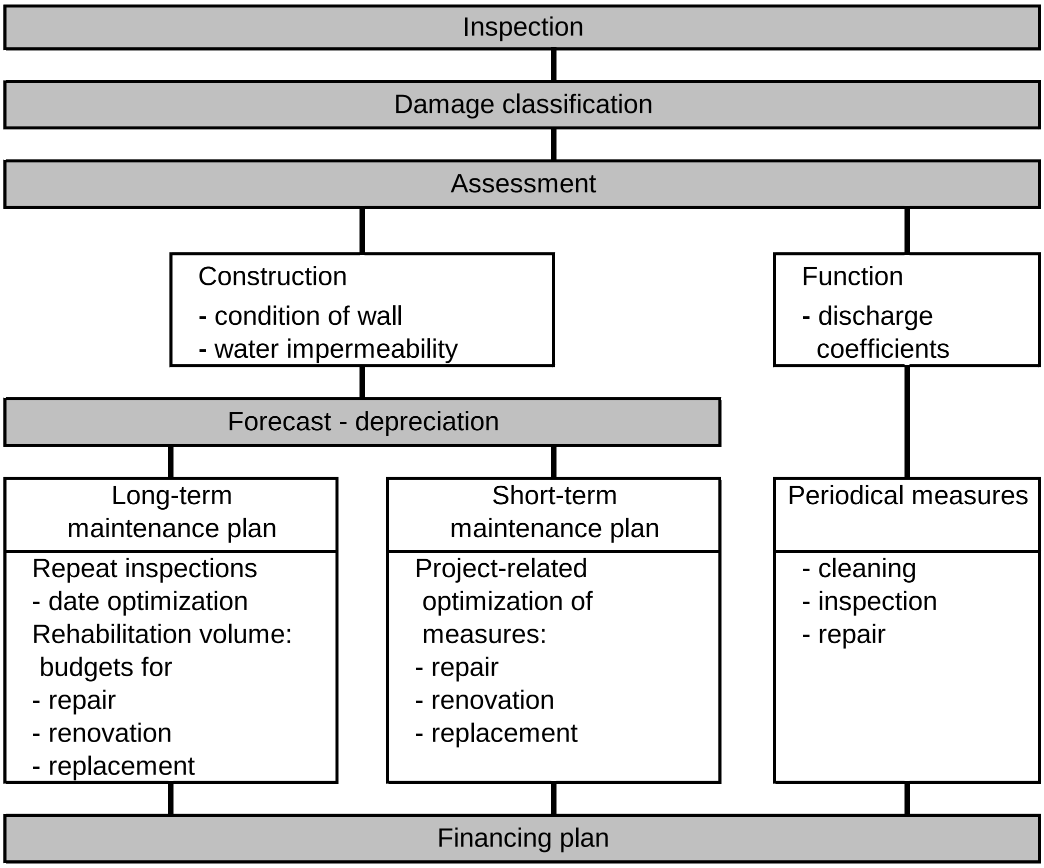

Diagram 2: Flow chart of a modern sewer management system according to [7]

Diagram 2 shows that inventory recording and condition evaluation in modern sewer management are called on to forecast the depreciation. The latter forms the basis of long-term maintenance and financial planning.

4. Determining the useful life expectancy

The methodical cornerstone of modern sewer management is the task of analyzing and forecasting the depreciation of sewer system components which involves the need for replacement. The analysis of the depreciation is directed at age, observed wear, structural failings, structural damage and insufficient dimensioning. In connection with the required minimum condition (determined by the risk potential with regard to water management) it allows the remaining useful life to be ascertained and thus rehabilitation requirements to be fixed in terms of time.

The usual method formally used to calculate the remaining useful life from a useful life expectancy specific to the material and the age has proved to be unsuitable as pipes made of the same materials have reached very different lengths of useful life in different towns.

Material-related useful lives were originally recommended in the LAWA guideline of 1992 for writing-off accounting [81. Since the new publication of the LAWA guideline of 1994, only a range of useful life expectancies of between 50 and 100 years, independent of the material, is given [91. The remaining useful life is to be determined within this range, taking into account age, structural condition and the risk potential with regard to water management. No method is given for determining the remaining useful life from age and structural condition.

The thought that suggests itself of presenting the connection of age and structural condition by a trend is methodically inadmissible because the dwell times in the condition classes vary [10]. Nevertheless, the - methodically inadmissible – trend analysis shows that the condition of the reaches in an inspected sewer system is, as to be expected, better for the more recent pipes than for those of older construction. On the other hand, entire year-of-construction groups deviate considerably from this trend of the condition deteriorating due to age.

Negative deviations from the trend are caused by structural failings, damage or increased load (Diagram 3). The negative and positive deviations from the trend (e.g. year of construction 1967 and 1971 in Diagram 3) can, however, only be taken into account qualitatively for forecasting the remaining useful life because it is not to be expected that the trend deviations of these year-of-construction groups will remain constant (if the cause of damage goes unchanged, the entire aging process will be accelerated until failure occurs).

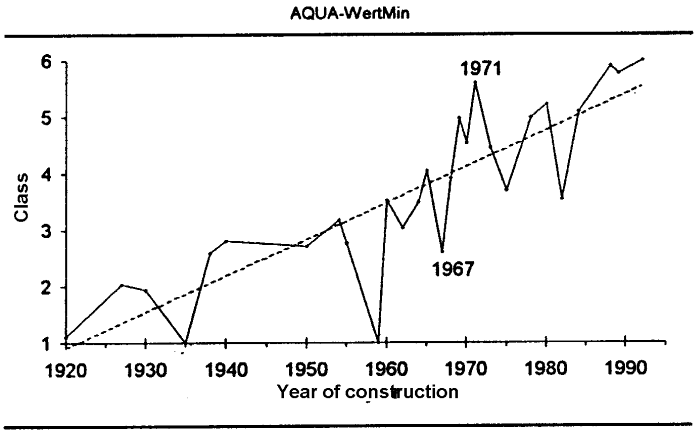

Diagram 3: Condition of reaches due to age – averages related to year-of-construction group

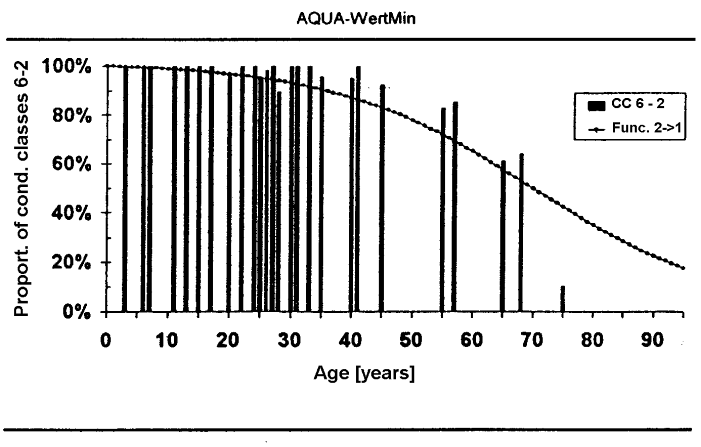

Diagram 4: Condition transition function from class 1 to class 2

In contrast to data classified by trend analysis, demographic forecast methods that describe the probability of survival as a function of age are methodically unproblematic. They have been used successfully in actuarial theory for decades. If the logic of actuarial theory is applied to the aging process of sewer pipes, condition class 1 (deformed reach with loss of function) corresponds to death, while condition classes 6 to 2 are within the survival period. The survival function is then determined empirically from the proportion of the condition classes 6 to 2 in the inventory's year-of-construction groups. Diagram 4 shows these proportions as columns. The survival function is then constructed as a compensation of error function by the upper corners of the columns. The sum of the signed errors (measured in m) between the upper column corners and the survival function is thus equal to zero. The useful life expectancy for the surveyed sewer system can be read directly from the survival function. In addition, it shows the probability of this useful life being fallen below or exceeded.

The condition transition function from condition class 2 to condition class 1 (cc2 -> cc1) thus allows the useful life expectancy of the reaches in a specific system to be determined in a reconstructable way. If the water management risk potential is higher (water protection area or similar), the accepted useful life is bound to increased condition requirements. In this case the accepted useful life ends on transition to condition class 2 (this intervention class can be selected freely in [11]). Diagram 5 shows that the accepted useful life for increased water management requirements is, as expected, shorter, amounting to 44 years.

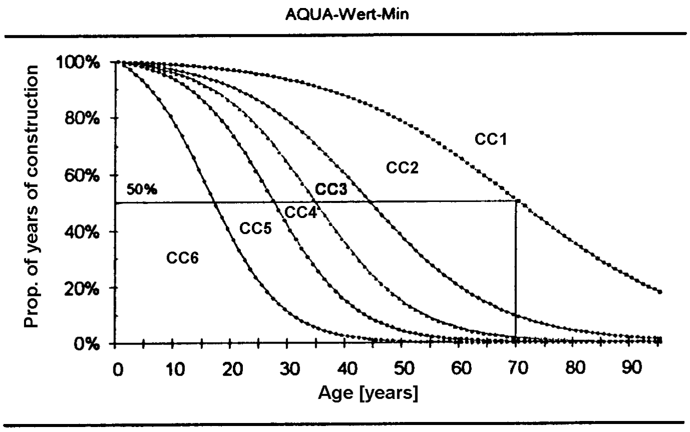

Diagram 5: All condition transition functions

1. Example of a reading for diagram 5: (from the Y axis [50 ~ to the curve and to the X axis [70 years])
   Result: 50 % of the system components will reach a useful life of at least 70 years before transition into condition class 1. The useful life expectancy therefore is 70 years.
2. Example of a reading for diagram 5: (from the X axis [60 years] to the curve and to the Y axis [66 %])
   Result: a useful life of at least 60 years will be reached by 66 % of the reaches.

The result is that useful life expectancies, dependent on age, condition and water management requirements, can be determined in a simple way for every sewer system. The determination of such is free from subjective estimates and can, therefore, be judicially examined. Only the years of construction and the condition classes of the system components are required as the data basis. For sewer systems that have only been partly inspected, missing data on the condition can be estimated by means of a stochastic model [11] (extrapolation).

5. Determining the remaining useful life of individual reaches

The recorded condition of many sewer systems shows that the replacement requirements of old, long-lived reaches overlap with those of more recent, short-lived reaches. This causes financing straits for maintenance planning that are difficult to manage. The useful life expectancy, which indicates an average value, cannot be called on as the cause of the replacement requirements to forecast requirement fluctuations such as these. Instead, the individual remaining useful lives must be directly used, the variability of which is the cause of the medium-term fluctuations in the replacement requirements.

An indication of the individual remaining useful life of a reach is shown by the rate at which it has aged in the past. If the marginal conditions are constant (material, laying quality, ground, sewage etc.), the individual rate of the aging process for this reach can be expected to remain constant. The past rate of the aging process of a reach is established – within a corridor – by its condition and age. This means that an individual condition forecast can be prepared for every reach that has undergone primary inspection up to the end of its useful life . The individual remaining useful lives thus found are a suitable basis for plotting the future replacement requirements.

- The aging of reaches is fundamentally a stochastic process, i.e. dependent on chance. There are reaches that age more quickly and others that age more slowly, thus attaining a longer useful life. In Diagram 5 this is correspondingly shown in that each reach runs through the diagram horizontally at a different height. The dwell times in the condition classes are restricted on this horizontal aging path by the respective intersecting points with condition transition functions.
- The aging path at an average rate of aging can be read on the horizontal 50 % line. This rate of aging is fallen below by one half of the system components and exceeded by the other. The half-life value for the 70-year useful life can be read on this path. Worthy of note is that the average dwell time in the condition classes varies greatly. It is 17 years in class 6, for example, and only 8 years in class 4. The relative dwell times in concrete and vitrified clay pipes are significantly different because the predominant aging processes (corrosion, rupture) differ.
- The rate of aging in the past can be narrowed down for reaches that have already been inspected and the individual condition forecast, therefore, is more precise. Thus, a reach that is inspected at the age of 40 years in condition class 4 has aged at a below-average rate of between 15 % and 36 %. At this low rate of aging, condition class 1 will not be reached before the age of around 88 years. This means that the estimated individual remaining useful life of this reach is 48 years as of the date of inspection.

The useful life of reaches to be laid in the future cannot be directly calculated from inventory and condition data. A subjective estimate has to be relied upon in this case. A longer useful life expectancy than that of the existing components is to be anticipated due to the fact that former structural failings and damage by third parties, things which are known from the weak-point analysis, are avoided.

The result shows that by modelling the aging process by means of condition transition functions for every reach and shaft an individual forecast of the dwell times in the condition classes is prepared, which takes account of previous depreciation and the current maintenance condition. These forecasts are free from subjective estimates. A condition forecast for the entire sewer system, assuming undisturbed aging, is shown from their overlapping. As can be seen in Diagram 6, an undisturbed aging process would worsen the condition of the system to an unacceptable degree within a short space of time.

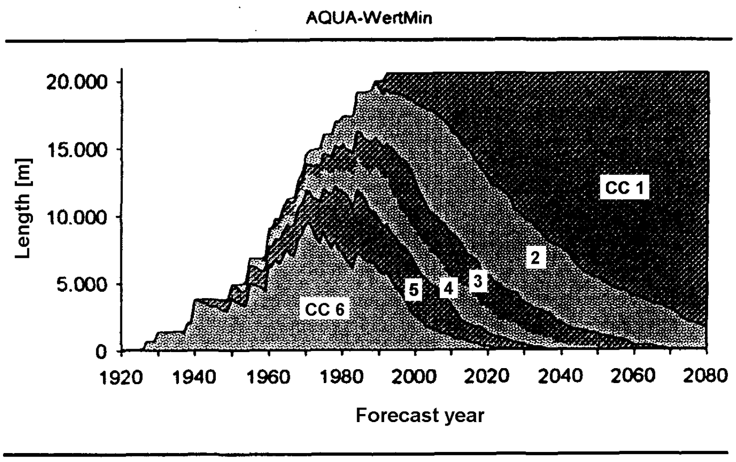

Abb. 6: Aging forecast

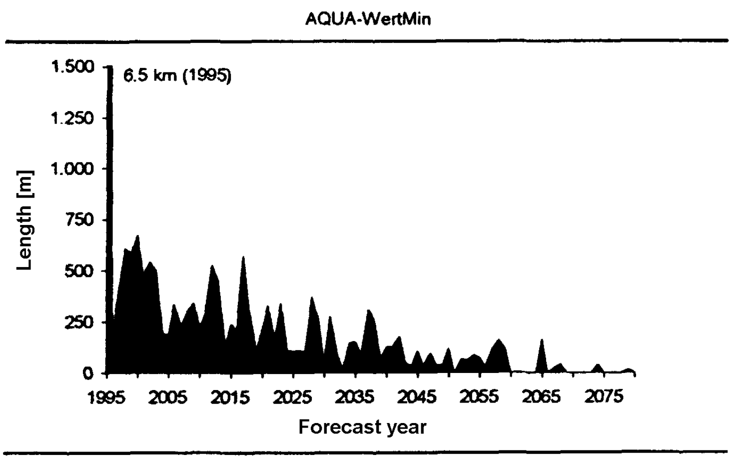

Abb. 7: Initial replacement requirements of reaches

Immediate replacement of all reaches that, due to age, enter condition class 1 would entail both an investment expenditure and construction volume that fluctuate greatly (Diagram 7). Extreme surges in investments are not feasible, however, for various reasons:

- steady receipts from sewage charges
- limited loan potential
- maintaining road traffic
- limited construction capacities.

The annual investment budgets are, therefore, smoothed out within the scope of long-term maintenance planning.

6. Long-term maintenance planning

Long-term maintenance planning is made up of three components, avoiding weak points, budgetary planning and inspection planning.

6.1 Avoiding weak points

General quality standards, independent of time limit, for new construction, rehabilitation, operation, inspection and maintenance are determined here. This topic is not dealt with here.

6.2 Long-term budgetary planning

Here the planning data for investments, repairs, operating costs, writing off, loan requirements, implicit interest and other financial flows are described. The purpose of long-term financial planning is to determine budgets for the short-term planning of measures and time scheduling (see Diagram 2) as well as for the financing plan.

6.3 Inspection planning

This is where the dates of the next respective follow-up inspections are determined. Within the scope of a prognostic inspection strategy these individually optimized inspection dates replace rigid inspection intervals. The strategic importance of long-term financial planning lies in the fact that the demands made on the efficiency and reliable disposal of the sewer system must be coordinated with the accepted financial requirements. Rehabilitation times and methods can be optimized to cover the rehabilitation requirements with available financial resources. The scope of decision-making in sewer management investment planning differs from the traditional decision rules of business and management economics in that it is decisively determined by liquidity squeezes (little room for maneuver with loans). This means that a cost minimization in terms of dynamic capital budgeting can only be realized to a certain extent when selecting the technology (repair, renovation, replacement). Instead, the rehabilitation backlog first has to be reduced with (the most important) cost-effective renovation and repair methods.

Liquidity-oriented system rehabilitation with measures whose effect does not last long, however, fundamentally conceals the danger of a gradual loss of material value in the system components which could pose insoluble financial problems for coming generations. Medium-term rehabilitation plans are secured by long-term forecasts in order to counter this danger.

- The rehabilitation methods offer the choice of pipe replacement or renovation. Furthermore, rehabilitation can often be postponed by some years. In this case repair costs to restore impermeability are incurred.
- At the present state of the art the useful life of renovated reaches is to be estimated at roughly half of that of replaced reaches. Under these conditions it is more economical in around ¾ of the cases to replace the pipe and have a future useful life of 80 years than to renovate and have a useful life of 40 years [12]. If the useful life of renovated reaches increases noticeably due to technical progress, this ratio could change round!
- In practical planning the availability of financial resources (loan potential) is limited. In this case renovation may be more economical than pipe replacement because it improves the condition of the sewer system – with the same budget – more quickly and thus cuts repair costs. To be noted, however, is that subsequent reinvestment has to be made in the form of pipe replacement. A very high renovation quota can only be realized, therefore, for a limited period of time.
- Repair costs that annually are clearly higher than the writing-off of new reaches are the consequence of postponing necessary rehabilitation. This uneconomical way of dealing with the situation is only appropriate for short transitional periods to overcome liquidity squeezes.

In the practical planning process it is advisable first of all to plan the most economical method at the time for each rehabilitation measure and to prepare a forecast of the system's condition and the financial resources for this replacement strategy. If it is not possible to reduce the rehabilitation backlog in this way due to liquidity constraints, the renovation quota is to be increased commensurately. This is illustrated by the following example.

The question to be examined in the inspected system [12] was whether the rehabilitation budget to date of DM 800,000 a year – with adjustment to the price index – would be sufficient to maintain the condition of the sewer system. The following is determined as a standard strategy:

- investment budget: DM 800,000 a year
- replacement proportion: 75%
- renovation proportion: 25%

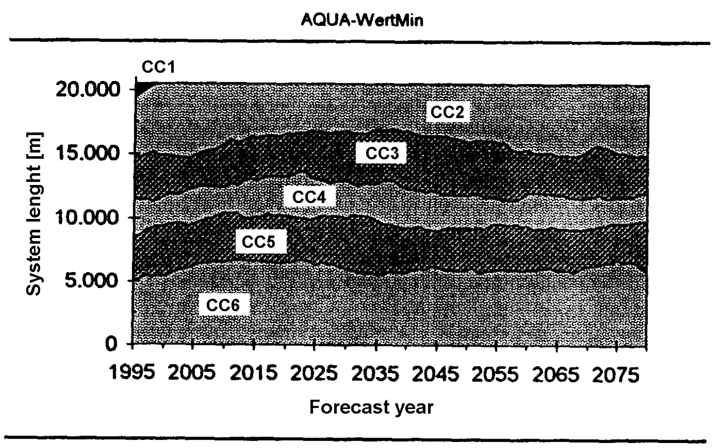

Diagram 8: Development of the system's condition with the standard strategy

Diagram 8 shows that with this strategy the condition of the sewer system remains constant with only slight fluctuations. High repair costs are incurred, however, (DM 400,000 a year) as a result of the fact that around 5.5 km of the pipe length remain in condition class 2.

- The repair costs forecast is based on an engineering determination of the costs of locally dealing with the damage in reaches in condition classes 2 and 1. These costs were apportioned to an assumed effective period of 10 years. As a result DM 75 per 1 (m/a) was determined for condition class 2 and DM 131 per 1 (m/a) for condition class 1.
- The repairs are necessary to guarantee the legal and penal obligation to maintain a permanently watertight sewer system in accordance with § 18b WHG (Water Resources Law).

In comparison to the standard strategy, the condition of the system can be noticeably improved up to the year 2020, despite the limited budget, with a graduated rehabilitation strategy. Besides the improved condition of the sewer system, repair costs are cut on a steadily increasing basis during this period, amounting to savings of up to DM 200,000 p.a.. The investment budget has to be increased to DM 1 million p.a. as of around 2020 in order to maintain and expand the sewer system's improved condition in the long term. This increase in the investment budget does not entail any additional expenses, however, because it is financed by savings made on repair costs in the past and the future. As a result a considerable improvement in the condition of the sewer system is achieved in the long term when the graduated rehabilitation strategy is used, the expenditure on overhauling (investments + repairs) being roughly the same. The graduated rehabilitation strategy is defined by the following:

As of year	**Budget/year**	**Proportion renovation**	**Proportion replacement**
1995	800,000 DM	75 %	25 %
2000	800,000 DM	50 %	50 %
2020	1,000,000 DM	25 %	75 %

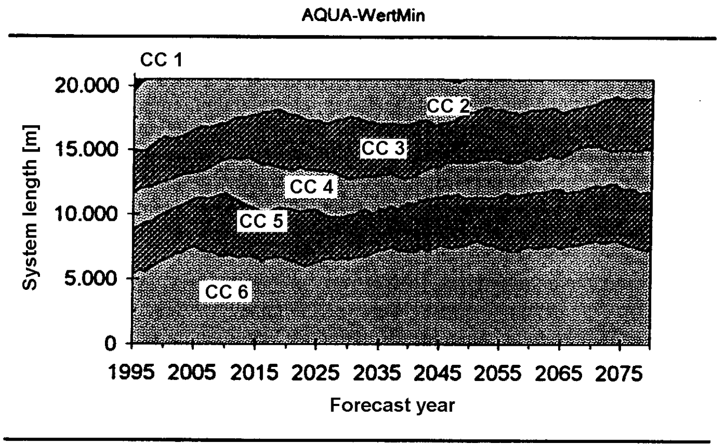

Diagram 9: Development of the system's condition with the graduated renovation strategy

Diagram 9 shows that the condition of the sewer system improves noticeably up to the year 2020 with the graduated rehabilitation strategy (the system lengths in condition classes 1 and 2 are halved). Condition improvement then stagnates until 2050, despite an increased investment budget, due to the fact that the renovation quota has been reduced to 25 %. It is not possible to keep the renovation quota at 50 % as reaches that have been renovated cannot be renovated again; they have to be replaced, which is expensive. As of 2050 the condition of the sewer system once again improves, so that in the long term only a third of the present system length is in poor condition.

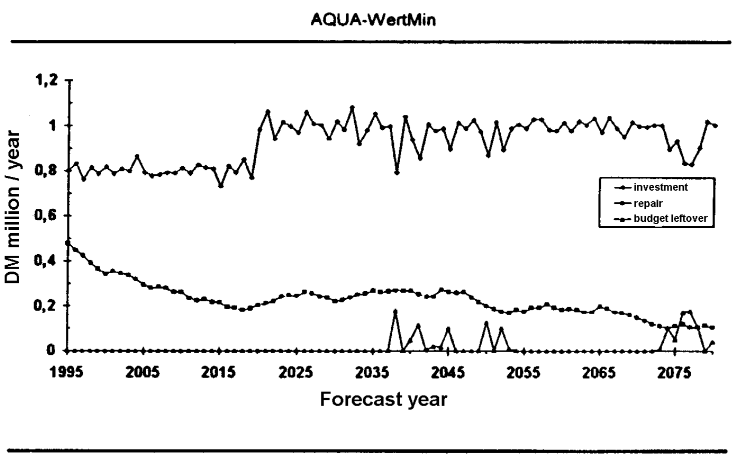

Diagram 10: Expenditure with the graduated renovation strategy

Diagram 10 shows that with the graduated renovation strategy there are budget leftovers in some forecast years as it is impossible to spend the entire budget earmarked for renovation. These budget leftovers should, if possible, be used for replacement. More important is that the repair costs will be reduced to half their present level with this strategy due to the improved condition of the sewer system.

All calculations have been made on the assumption of a useful life expectancy for new reaches of 70 years, i.e. disregarding an avoidance of present weak points in the future. If the useful life of reaches laid in the future is increased to 80 years and that of renovated reaches to 40 years, the condition of the sewer system will improve, even without the planned increase in the investment budget in the year 2020.

To sum up it can be determined that the graduated rehabilitation strategy is considerably more favorable than the standard strategy developed from dynamic capital budgeting because it noticeably improves the condition of the sewer system up to the year 2020, nor are any additional costs incurred as compared to the standard strategy (with a renovation quota of only 25 %) to safeguard the improved condition of the system in the long term.

With a re-installation value for the sewer system of DM 87 million, the annual reinvestment costs amount to only 0.9 % or 1.1 % of this sum. In addition, the inspection costs that would be incurred for a 10-year repeat interval are cut by more than half. This example shows that the maintenance and financing of sewer systems by means of forward-looking maintenance is expedient not only because of the fact that reliable disposal is ensured and the groundwater protected, but also because it leads to better results from an economic and operational point of view than annually related individual decisions.

To be fundamentally kept in mind is that it is not the (theoretical) economic efficiency of single measures which is to be optimized in long-term investment planning, but the economic efficiency of the entire strategy, taking into account liquidity constraints. Thus, if a large replacement backlog coincides with tight liquidity constraints, the ideal action to take economically is to first reduce the replacement backlog largely by means of renovation measures and then to proceed step by step to replacing the pipes.

If there are sufficient financial resources (e.g. private operators), a strategy is selected - according to dynamic capital budgeting – with a lower renovation quota and with even more pipes being laid at the beginning.

Such a strategy improves the condition of the sewer system and disposal reliability more quickly and – despite the return on the capital employed – is more cost effective.

In individual cases the optimum investment strategy is found by comparing alternative strategy forecasts.

7. Optimizing the times of inspections

The system of individual condition forecasts allows the condition of the sewer system – at first without repeat inspections – to be aged by way of calculation and an across-the-board description of the condition to be drawn up for each forecast year [13]. This forecast is then confirmed or corrected for individual reaches shortly before they reach a critical condition by means of a repeat inspection.

This prognostic inspection strategy is designed to recognize the critical intervention condition of a reach in good time, before damage occurs, with as few inspections as possible. It replaces fixed inspection intervals with individually calculated inspection dates.

As a result the number of inspections required is reduced to around 3 during the useful life of a reach:

1. Calibration inspection when about half of the expected useful life is completed, to determine the individual rate of aging and analyze weak points.
2. Confirmation inspection before transition to condition class 2. This confirms or corrects the condition forecast.
3. Intervention inspection before transition to condition class 1. This checks on how urgent the approaching rehabilitation is if it has not already been carried out.

In contrast to regular repeat inspections at intervals of 10 or 15 years [14,15, 16, 17, 18] cost savings of over 50 % are achieved with the prognostic inspection strategy. In addition, the condition of the sewer system can be plotted and forecast across the board at any time.

8. Systematic condition classification

The serviceability of forecast models to determine the (remaining) useful life and optimize times in the prognostic inspection strategy requires a purpose-oriented definition of the condition classes of reaches and shafts. Condition classes for reaches are determined by mathematically aggregating the damage classes of the individual damage in the respective reach. Different classification methods are to be used, depending on the intended application:

- According to the draft of A 149, the condition classification usual up to now of determining the condition class of a reach on the basis of the greatest individual piece of damage is appropriate for prioritizing rehabilitation and repair measures [19]. These priority-related condition classes ensure that measures to remedy damage and repair measures are ordered correctly in terms of time, but they do not describe the depreciation of the whole reach.
- Punctual, individual items of damage, however, are only of limited importance for mapping the depreciation of whole reaches. For a value-related condition classification, therefore, the damage class according to the classification model from S&K-KAIN [20], with appropriate importance being given to depreciation, is included in the condition class of the reach.

9. Result

The serviceability of our supply networks and private production facilities is guaranteed by systematic, preventive maintenance strategies. More reliable disposal can also be achieved cost effectively by preventive maintenance in the sector of sewage disposal. The strategies that have proved their worth in other sectors are modified, however, for modern sewer management.

Due to the high costs of collecting data on the condition and to the necessity of covering widely fluctuating rehabilitation requirements with limited and constantly flowing financial resources, both the times of inspections as well as the methods and times of rehabilitation are optimized from an economic point of view.

Optimization is carried out, taking account of age-related depreciation which generates the replacement requirements. An example shows that a satisfactory sewer system condition can be achieved in this way, even if the investment budget is limited.

10. Summary

Maintaining the serviceability of sewer systems as well as the required sealing to prevent exfiltration and infiltration involves considerable investment and repair costs, the financing of which can lead to an erratic increase in cost-covering sewage charges. The cause of this is the fact that the rehabilitation backlog of old parts of the system in inner city areas overlaps with the rehabilitation requirements of more recent parts of the system caused by structural failings and structural damage. In this situation, the maintenance of sewer systems requires a modern sewer management system with analysis of the weak points, interactive strategy development and optimized inspection planning. With this range of instruments the condition of the system can be improved in the short term and secured in the long term without an erratic increase in charges. An example shows how, within the scope of forward-looking maintenance planning, the condition of the sewer system can be adapted to legal requirements without increasing charges. The instru-

ments required for this are optimized renovation measures, a reallocation of the budget from repair expenditure to replacement investment, and optimized times of inspection. Maintenance of the sewer system components is guaranteed by means of a long-term strategy forecast. In particular, security is provided for the fact that sewer maintenance can be financed not only now, but also by future generations.

Key words: sewage discharge, sewer system, finances, costs, data processing, calculation methods.

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