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Oppgavens tittel: Use and Collection of data in Gemini VA in Asset Management	Dato: 30/6-10 Antall sider (inkl. bilag): 99			
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Abstract

As the water and wastewater network in Europe is declining, the recommendation is to move towards Asset Management, as this is a proactive approach to system rehabilitation. This thesis has been written at LNEC, Portugal, in cooperation with the AWARE-P team, who is developing a software to deal with future planning of rehabilitation of the network. The work has been to collect the need of data in their modules, looking at data collected from other rehabilitation softwares and comparing it to what is available in Gemini VA to value the use of Gemini VA for rehabilitation planning support.

Planning tools for rehabilitation of water and wastewater networks is still in the developing phase. The programs are often data hungry, and collecting data is time demanding. Gemini VA represent a good software for collecting base data used in rehabilitation planning, and is the most used water and wastewater maintenance software in Norway. It's important to identify the limits and possibilities of the software for future development, and the goal of this thesis has been to look into improvements of the software to give better data at a lower time cost.

In the Asset Management approach the condition of the network must first be decided. This analysis can be done with basic data such as material, construction year, dimension and condition factor from surveys done on the network (CCTV etc). When the condition is determined, assessments within cost, performance and risk can be completed at the strategic, tactical and operational level.

Gemini VA can provide a lot of base data, but even though the data is available, the preparations is time demanding, and the only data validation feature available, is a material-dimension-construction year-validation. Therefore historical data, and the rest of the structural data, must be validated manually.

Gemini VA should try to move towards an Asset Managment approach by including more validation reports, pre made statistical reports, and visualisation effects of the statistics. The software should also include cost, more information on stormwater assets, water quality tests and more pumpingstation and treatment plant information. Gemini VA can be used to collect data for a national statistical database for utilities with low or poor record of historical data to retrieve statistical numbers for planning (failure rate for different materials, etc).

Sammendrag

Vann- og avløpsnettet i Europa er i forfallende tilstand, og anbefalninger for å forbedre dette er at driften og rehabiliteringsplanleggingen bør vendes mot en proaktiv forvaltning, kalt Asset Managment, eiendelsforvaltning. Denne oppgaven er skrevet hos forskningsinstitusjonen LNEC i Portugal, i samarbeid med AWARE-P prosjektet som skal utvikle en programvare for fremtidig rehabiliteringsplanlegging av VA-nettet. Innsamling av data for bruk i deres moduler, studering av data brukt i andre rehabiliteringsprogram og sammenligning av disse med tilgjengelig data i Gemini VA er gjort for å se hvor godt Gemini VA egner seg som støtte i denne type planlegging.

Planleggingsverktøy for rehabilitering av VA-nett er fortsatt i utviklingsfasen og de allerede utviklede programmene er datasultne og innsamlingen av dataene er tidskrevende. Gemini VA representerer en god programvare for innsamling av grunnlagsdata til bruk i planlegging av rehabilitering, og er det mest brukte programmet i Norge for å systematisere drift og vedlikeholdsdata i VA-nettet. Det er derfor viktig å se på begrensningene og mulighetene programmet kan bidra med i fremtiden. Målet med denne oppgaven har vært å se på forbedringer av programmet og på bruken av innsamlede data, for å gi bedre data til en mindre tidskrevende pris.

I fremgangsmåten til Asset Managment må tilstanden til nettverket først defineres. For å gjøre dette må grunnleggende data samles (material, anleggsår, dimensjon og tilstandsfaktor hentet fra undersøkelser hvis tilgjengelig) slik at man kan gjennomføre undersøkelser innen kostnad, funksjon og risiko på et strategisk-, taktisk- og driftsnivå.

Gemini VA kan gi en god mengde grunnlagsdata i fremtidsplanlegging, men selv om dataene er tilgjengelige, er det tidskrevende forberedelser som må gjennomføres, og det er kun én valideringsfunksjon i programmet (material-dimensjon-anleggsår). Historiske data, og resten av de strukturelle dataene, må valideres manuelt.

Gemini VA burde bevege seg mot Asset Management ved å inkludere flere validerings raporter, forhåndslagde statistiske rapporter for fremtidsplanlegging og bedre statistiske visualiseringseffekter. Programmet burde også inkludere kostnad, mer informasjon rundt overvannshåndtering, vannprøver tatt på nettet og mer informasjon rundt pumpestasjoner og renseanlegg. Gemini VA kan blir brukt datainnsamling til en nasjonal statistisk database hvor kommuner med lite eller dårlig samling av historiske data kan hente statistiske tall for gjennomføring av planleggingsverktøy (feilrate til ulike materialer,etc.).

(sign.)

Preface

In a world where the water and wastewater infrastructure is declining, the urbanization is growing and the climate is changing, the need for a good infrastructure management is getting more and more important. To obtain a management strategy that is both cost and work effective, the utilities needs to improve the long term planning of rehabilitation, by choosing the right type of assets to the right type of rehabilitation at the right time. This goal may be achieved by implementing asset management, which focus on a proactive approach for rehabilitation of the network in the most cost and work effective way.

This thesis focus on the data need for doing analysis on the strategic and tactical level in the asset management approach. It looks into the use of Gemini VA as a tool to give the base data for the analysis in an Asset Management approach with the main focus at the performance and risk assessments at the strategic and tactical level.

This thesis is submitted in English as the final report for the civil engineering study at Norges Tekniske og Naturvitenskaplige Universitet, NTNU, Trondheim. The work has been carried out in Lisbon, Portugal, in cooperation with the AWARE-P project by LNEC, from January to July 2010, under the supervision of Sergio T. Coelho and Helena Alegre.

Data from the municipality of Trondheim has been used to explore the software Gemini VA by Powel, together with the knowledge of the researchers at LNEC to form a report on the data collection for use in Asset Management.

Trondheim, June, 2010

Kjersti Holte

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I would like to thank my main supervisor, Prof. Sveinung Sægrov, for giving me the opportunity to work on a future-oriented research program, for giving good support, good backup on his knowledge on the topic and introducing me to his contacts at LNEC, Portugal.

I would also like to thank Dr. Rita Ugarelli for the good guidance and inspiration, both during my stay in Portugal and after in Norway. She has been a great source of inspiration and a resource of knowledge on the topic to me.

I would like to express my gratitude to Sergio T Coelho and Helena Alegre and the rest of the AWARE-P team for including me on all levels in the project, for sharing their knowledge and inspiring me to further work on this topic. My experience of working with this research group and at LNEC has been more valuable to me than what I can include in my thesis, and I'm sincerely grateful for being able to learn as much as I have during my stay in Portugal.

I would like to thank SINTEF for great cooperation with ideas and discussion, especially Leif Sigurd Hafskjold and Ingrid Selseth for good guidance.

The experience of working with data wouldn't have been the same without the effort and willingness from the municipality, I would therefore like to thank Trondheim municipality and Ranveig Høseggen for support with Trondheims database and hydraulic model, for giving me real data to use in my comparisons.

I would also thank Powel for great support and free use of their software. A special thank to John Bjørndal for help of installation of database, maps, software and supplying me with user manuals and quick guidance response on email.

Contents

List of figures

List of tables

List of equations

Executive summary

Asset management

To obtain a sustainable water and wastewater system, it's important to be in control of the condition of the network, and the focus all over the world, is to move towards Asset Management. Asset Management is defined as the art of balancing performance, cost and risk (Brown 05) and the ideal finishing product is an integrated and proactive approach at the three levels of strategic, tactical and operational planning.

Performance, cost and risk

The performance assessment is a mean to decide the condition of the system to provide support to set the best rehabilitation rate. By mapping the condition, the utility will get an overview of the needs for operation and maintenance work on the system in the future. The performance analysis is to be completed by

1. Defining the objects
2. Defining the assessment criteria
3. Defining performance measures and targets
4. Assess performance vs. objectives

Risk is defined as frequency of a failure times the consequence of the failure. There are three types of failure: structural, hydraulic and quality. To establish the frequency of the failures, historical data must be collected and analyzed to predict a failure rate. The consequence of a failure is either financial, functional impact on other areas, environmental or within public health and safety. A risk analysis is usually distinguished in the following categories:

1. Structural,
2. Operational
3. Loads
4. Environmental
5. Other infrastructures

To make a good rehabilitation plan, a condition analysis must be completed in order to understand the network. The condition can be decided from the pipe network records, the pipe inspections in field, and laboratory testing of pipe samples.

Cost in rehabilitation is influenced by different strategies (preventive and non-preventive). It's important to see the structure of the economy and to move from a reactive to a proactive approach, for an easier way to develop and use a capital investment plan.

Planning and rehabilitation tools

Different tools are available for planning and rehabilitation. CARE-W, CARE-S and AWARE-P are all planning- and rehabilitation tools for Asset Management.

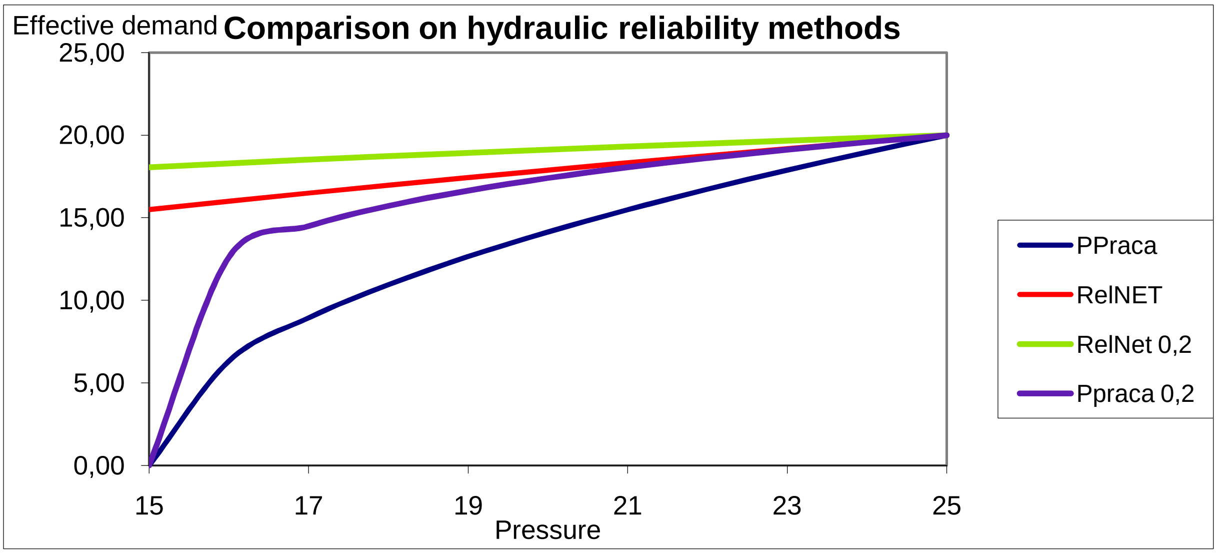
The performance tools are based on performance indicators, where the user uses his network data to define the indicators.

For the risk analysis, CARE-FAIL was used to estimate the failures in the CARE program together with CARE-REL as a reliability tool. The reliability calculates the hydraulic performance (by the use of a hydraulic model) and gives a hydraulic critical index for each pipe.

Future planning tools from CARE are the Long Term Planning and the Annual Rehabilitation Plan features. These are used for analysis on necessary investment levels in the future and the rehabilitation rate. For LTP the most important data specifications are pipe material, construction period and diameter. The ARP analysis proved to be a tool for the experienced user with a lot of data, and inexperienced user will easily get lost in the software.

Reliability tool

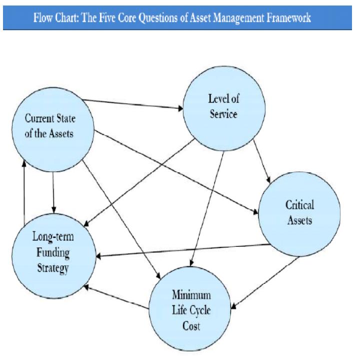
AWARE-P developed a new tool for calculation of reliability, based on the CARE-REL tool. The solution gives a higher HCI than RelNet because the AWARE-P procedure includes the minimum pressure and gives a continuous curve when system drops to minimum pressure.



The AWARE-P reliability tool seems to give approximations closer to reality.

Implementation of Asset Management

There are several methods to move towards Asset Management. The five core questions of reaching Asset Management is given in the figure below, by answering these the utility can reach their Asset Management approach.



A top-down analysis is supposed to be the best approach to Asset Management as it represents a proactive approach. In infrastructure Asset Management there is no one-size-fits-all manual, all approaches must be linked to each country's overall sustainable strategy.

Data management

To run tools for planning and rehabilitation, a lot of information on the assets needs to be collected. The most basic collection of the system is construction year, diameter and material. Other important descriptive data to collect from the network is storage and information management, processing and analysis of water consumption, performance evaluation, assessment of water losses, analysis and prediction of failures in pipelines, cost-benefit analysis and decision support as part of rehabilitation. Good data quality is essential to give a good analysis, and usually the utilities have more data available on the water network than the wastewater network.

A benchmarking project in Scandinavia has collected numbers on the water and wastewater service since 1995, where the goal was to get a model that can be used to judge the quality, the service and the efficiency of the utility. Comparisons and statistics are completed towards the rehabilitation rate and the life expectancy of the network, and there are many different factors that influence the criteria, such as different condition judgment, different rehabilitation work and different assets included in the analysis.

Gemini VA

Gemini VA is a software by Powel used in Norwegian municipalities based on an MsAccess database with georeferenced projection of the data. The work orders, called diary, are included in the software and they are all linked to the individual asset, down to Asset ID level. The software has been developed since the 1980's, and is today a stabile and well functioning software.

Gemini VA is almost complete on available inputs, but some of the inputs are not registered at all by the municipalities and poor historical registrations are both a source of error when completing analysis on the data. Gemini VA still lacks good data validation analysis as the only validation available is material-dimension-construction year. The main areas where the input information is missing, are the pumping stations and the overflows, structural information such as pressure class, ground surface, joint type, etc.

Important registrations at operational level such as material, dimension and construction year are registered by 99%. The main areas of assets with documentation are the pipes and the manholes.

Issues concerning sources of error in the database such as splitting of pipes, duplication of diary, double registration of pipes and text fields with important information, have been improving with time.

Integrating Asset Management in Norway with the use of Gemini VA

Using the five core question on the Gemini VA software to see how much information is available, the main missing areas are cost, manpower, service, and live data recordings. Validation of data recordings is important, and as mentioned earlier, these should be included to a larger extent.

Graphical figures are not available in Gemini VA today, introducing an easy graphical view of the statistics, would be a valuable feature for the user to visualize his network.

Principles for establishing a database

ERSAR, the Portuguese regulator, have specifications in form of PIs that the Portuguese utilities needs to report on. When comparing the input data in these PIs with the available data from Gemini VA and Trondheim municipality, the result is that the areas of missing information is on personnel, energy consumption, cost, different factors, pumping stations, customers, property, treatment, storm water, etc. Some of this is due to non-registered values, other because no possibility of registry in Gemini VA.

Gemini VA provides good support for registering a new network in a database. With the cooperation of the computer personnel and the pipe personnel, the network information can be quickly digitalized. If good routines are implemented, the network will soon have good structural information.

Conclusion

Gemini VA gives good support for data collection on water and wastewater networks. The software introduces a high level of data collection for use in the asset management approach, and if properly used by the utilities, the information gives a good foundation for making different analysis and retrieves statistical numbers for further analysis.

The main lacks of the software are data validation reports, visualization effects, summary reports for use in planning, information on treatment plants, data on water samples taken from the network, costs, critical delivery points, inputs from other softwares such as EPANET, SWMM etc, and operating personnel.

1. Introduction to Asset Management

A growing urban development has been ongoing for several years, the whole world is facing a problem with declining infrastructure, especially within water supply and wastewater handling, due to the utilities cannot keep up with the pace of the development. As water and wastewater infrastructure is one of the most important elements of the society, it's important that they are managed in a sustainable way. This management includes many areas of different studies, such as control of leakage, energy efficiency, risk and reliability, rehabilitation and technical performance. It's important for the utilities that they cope with the growing urbanization, so that the water and wastewater infrastructure is in a good condition also in two and three generations into the future. To obtain a sustainable water and wastewater system, it's important to be in control of the condition of the network, and the focus all over the world, is to move towards asset management.

Humphrey and Brown defined Asset Management in 2005 as "the art of balancing performance, cost and risk. Achieving this balance requires the alignment of corporate goals, management decisions, and technical decisions. It also requires the corporate culture, business processes, and information systems capable of making rigorous and consistent spending decisions based on asset-level data." (1) The ideal approach to infrastructure asset management for urban water systems is an integrated and proactive management approach that involves the three different decision levels: strategic, tactical and operational. The performance assessment of urban water systems is one of the main pillars of an integrated approach of IAM, and involves all three decision levels (2). The three areas of performance, cost and risk should be implemented on each of the three levels of approaches, strategic, tactical and operational. The different parts of the utility: management, information and engineering, needs to be involved in all of them. The information flow is visualized in the matrix in Figure 1

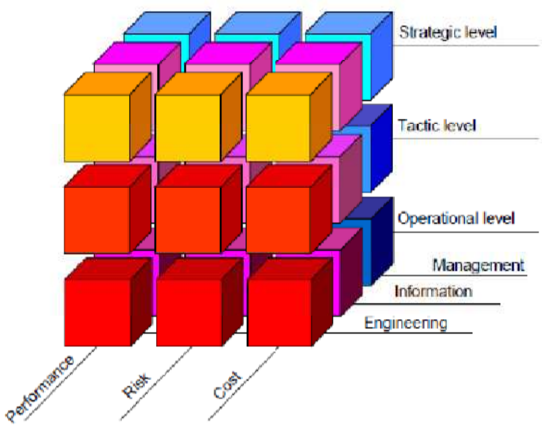


Figure 1: Infrastructure Asset Management [Alegre (2007)]

1.1 Strategic level

The Strategic Level involves identifying the condition of the water network, setting of goals and "benchmarking" can be done by implying indicators. To get an overview of the financial need over the long term period, a long term analysis should be completed. This is to be used with the master plans of the utility. Included in the long term analysis should be a prediction of the long-term rehabilitation for defined scenarios, these are usually based on expected service life distribution for pipe material groups (3).

1.2 Tactical level

The tactical planning on rehabilitation includes system performance (avoid hydraulic bottlenecks), condition of single pipes (structural capacity), customer perception (avoid complaints) and a selection and ranking of projects (3).

1.3 Operational level

For the rehabilitation decisions taken on the operational level means technological decisions. This means an overview of what is available for which problem to what time with which benefits. It's important to select/choose the best technology for the selected projects (3).

2. The three pillars in Asset Management: Performance; Cost; and Risk

2.1 Performance assessment

Good knowledge and an understanding of the condition is a prerequisite for making the correct decisions, while the wrong decision has great financial consequences on the utility. It's important to know the time for rehabilitation on a pipe, to exploit the function and the cost to the maximum. The pipe should be replaced just in time, JIT, which means that the pipe is replaced at the moment the unacceptable condition appear. Today, most often, a pipe is replaced after a break, which means more cost at a non planned level (4).

The performance assessment is a mean to decide the condition of the system (the strength and weaknesses) to provide support to set the best rehabilitation rate as well as allowing independent and standardized comparisons. To evaluate performance of water services, performance indicators are used to view the continuous improvement. The approach requires a definition of service objectives and an evaluation criteria, it requires performance indicators, establishment of service targets to assess the target's implementations as well as supervision and performance comparison of the utility's quality of service (2).

By optimising the utility's strategy on short and long term basis, the service level will be met at the lowest cost. Every utility should strive for a best possible operational maintenance to the lowest cost. The figures of cost in water and wastewater utilities are great, the infrastructure is critical for the society (as it influences health, economy, and environment), therefore it's important that the lifetime of the network is pushed to the maximum. To optimize the network it's important to validate the status of the system. That means keeping a track of the assets of the system (the value, owner, location, construction year, etc.) as well as all occurrences and work completed on the assets. By keeping a record over the performance of the network (errors/yr, distribution stops/year*km, overflow/yr*km, customers complaint/km, etc.) the validation on future analysis will be more reliable and less time demanding, and critical assets can be found and improved. It's important to register how and why they fail, so that information for the probability and consequence can be gathered (5). The performance of a system is hard to predict, due to the uncertainty of the consequences around a failure. The management has to decide what the acceptance level on each failure with the difference consequences. Each utility might have its own level of safety, and will therefore have different goals to implement in the asset management plan.

By mapping the condition, the utility will get an overview of the needs for operation and maintenance work on the system in the future. When a complete mapping has been done, analysis can be done to localize which pipes that need what kind of rehabilitation.

When considering the condition of the asset, the assets are usually not renovated (replaced or repaired) as one, but as an individual component. The maintenance is on the other hand seen under the system as a whole. Infrastructure AM differs from other AM by the way that the utilities are a natural monopoly in the society, it's therefore important to complete a value assessment to control that they are run as properly as possible. Often the service also taken for granted, especially in the western countries, and since most of the assets are buried (out of sight out of mind), the condition assessment is very difficult. This requires engineering competence on a high level, to assess asset condition and setting up investment priorities. The system behavior cannot be summed by the performance of the individual components (e.g. hydraulic, water quality, service reliability) (1).

A Portuguese project on Asset Management rehabilitation (2010) generated performance indicators together with all the end users of the project, with the aim to let the user define which indicators that is best suited for their own needs. All imaginative indicators will be available, but not all are a request/demand to make the system and the analysis run. The PI's were gathered from different sources such as IWA, CARE, ERSAR and the AWARE-P Rehabilitation Manuals. They are defined depending on if they belong to the strategic or the tactical level in the planning approach. 6 strategic rehabilitation goals are represented in the manual produced in the same project, these are: Public health protection; satisfaction of the demands and expectations of the service by the customers; service supply in normal and emergency situations; service sustainability; promoting the communities sustainable development; environment protection (6).

The performance analysis is to be completed in the following order (7):
1. Defining the objects;
2. Define the assessment criteria;
3. Define performance measures and targets;
4. Assess performance vs. objectives.

The aware-p experienced that Differencing strategies at the strategic level from the tactical level was hard, since not the same people are working with the same concerns (wrong perspective), examples of this is that the basic strategy doesn't include objectives made in further down in the analysis. (Main problem is that the strategy doesn't include things they include further down in the analysis). 7 different strategic objectives have been outlined in AWARE-P, divided in 5 main categories, as described below.

Table 1: 5 main categories [AWARE-P, LNEC]

Public Health Protection and Safety
Occupational Health Protection and Safety (wastewater)
Meeting users' needs and expectations
Provision of the service under normal and emergency situations
Sustainability of the undertaking
Protection of the environment
Promotion of sustainable development of the community

1. Minimization of the overflow discharges (wastewater)
2. Minimization of hazards to populations safety (wastewater)
3. Continuity of the service
4. Safety and emergency management
5. Coverage and availability of the service
6. Compliance with the legal requirement regarding health and safety issues at a working environment (wastewater)
7. Promotion of sustainable development of the community
8. Minimization of the negative impact in the economical activities (wastewater)
9. Wastewater treatment (wastewater)
10. Financial Sustainability
11. Efficiency in the use of human resources
12. Efficiency in the use of environmental resources
13. Infrastructural sustainability
14. Control and prevention of the pollution
15. Adequacy of the water quantity in all consumption points of normal and emergency situations (water)

16. Compliance with all legal requirement concerning public safety and quality for human consumption (water)

2.2 Risk assessment

In the third edition of the Guidelines for Drinking-water Quality, published by WHO, it is pointed out that a comprehensive risk management approach is the most effective way to ensure the safety of drinking water supply As a part of risk management, WHO recommends preparation of Water Safety Plans, WSP, including system assessment, operational monitoring and management plans (8).

Prediction of when a failure might occur and the consequence of this failure is essential in Asset Management. Because, by doing this, the calculation of risk can be done. Risk is important to identify, because by identifying it, it's possible to estimate it and by action reduce its consequence or even eliminate it (5).

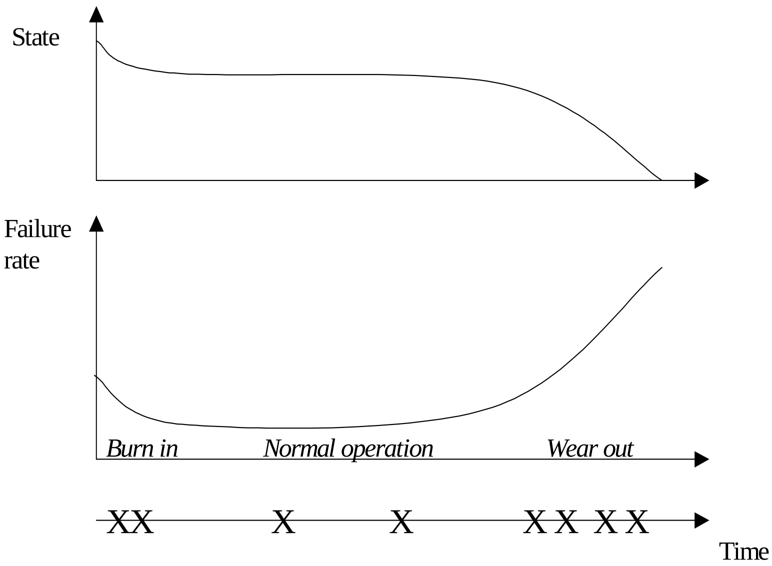


Figure 2: Wear out curve [Sægrov, NTNU]

Risk is a function of the probability of failure and the consequence of the failure. The probability is often referred to as the frequency of failure.

$$Risk = Frequency \times Consequence$$

A failure is the non-fulfillment of a functional requirement, and to identify all potential failure modes of an item, all functions and associated functional requirements of the item must be identified. There are three main failures: structural failure (breaks, bursts), hydraulic failure (the demand is not met, component failure, internal deterioration) and water quality failure (9).

To establish the frequency, historical data must be collected. Accurate data in a short time frame is more valued than poor data in a long time frame. When data is collected the estimation of frequency and consequences of events can be established, then the analytic determination of frequencies and consequences can be done by system modeling and evaluation of risk reduction (5).

2.2.1 Probability and frequency of failures

Probability is usually estimated by using the existing failure data to make failure rates, or by setting condition class after conducting an inspection.

The failure data is usually validated by a reliability tool, to assess another component than the rate to get a result as close to reality as possible. For hydraulic reliability, a hydraulic model (EPANET, SWMM) is usually used to estimate the component hydraulic failure. This model includes pressure, extreme tapping, quality of water etc. This can imply which pipes that face a hydraulic criticality.

2.2.2 Consequence of failures

Some consequences of failures are listed below (10):

- financial (damages in system components),
- functional (service continuity (CMC)),
- impact on other infrastructures/structures,
- environmental and
- public health and safety

2.2.3 Condition Analysis

A condition analysis gives the base information to make a good rehabilitation plan in the asset management framework. Both the performance and risk assessments are important to the rehabilitation, and they both rely on the condition analysis to give good information.

There are several available methods for making a condition analysis. The basic method is depending on the pipe network records, the pipe inspection in field and laboratory testing of pipe samples. The more advanced methods include leakage control, pipe scanning, digital photo and radar for condition measurements of sewers and storm water pipes. The pipe network records are systemized data of all occurrences on the network (4).

2.2.4. Risk analysis

When doing a risk analysis for wastewater, 5 categories of risk are distinguished. These are shown below.

probabilistic principle

- Structural risks (relating to the pipe geometry, mechanical properties and damages);
- Risks on operating conditions relating to the influence of damages on the behavior of the pipe and also the network (slope and hydraulic performance)
- Risk relating to actions varying in function of applied loads (soil, permanent loads, surface loads);

data fusion principle

- Environmental risks (leaks, pollution, category of the transported waste water);
- Impact on the other infrastructures located in the vicinity of the pipe.

In the analysis the areas and criteria must be defined. Areas are the affected surroundings while the criterion is the reason for the area to be affected. Examples are shown in the table below (11):

Table 1: Examples on area and criteria in risk

Area	Criteria
Geotechnical (related to the soil)	- Movement of the soil particles - Settlement - Voids
hydraulic (flow risk)	- action mechanical action of the flow - physical and chemical action of the flow - hydraulic loads);
endogenous (linked to pipe)	- geometry of the sewer - state of the sewer
environmental (linked to the environment and the functioning of the sewer, impact risk)	- consequences on the functioning of the sewer - consequences on the functioning of other sewers - repercussion on the roads (consequences on the surrounding buildings and on social costs buildings) risk

2.3 Cost

Within cost it's important to have alternative strategies and to see which are achievable. There are non-preventive and preventive strategies, dependent on the resources the utilities have available. The long time budget gives the total cost. It's important to develop routines to see the structure of the economy to get the most out of it (budget, loans and other financial support to renew and replace). It's suggested that the utilities make a list after critical points, error analysis, probability of errors, analyze consequences, find risk for breaks/errors. To move from reactive to proactive, know the costs and benefits of rehabilitation vs. replacement, look at the life cycle costs for critical assets, use resources by critical assets, develop and use Capital Investment Plan. It is recommended (by Ugarelli) that a top-down LCC model should be used. This is because Asset Management then will be initiated and it will optimize the level of costs allocated to asset classes. With a top-down analysis /man/ first get the overview, then divide it and get sub-levels, then you get the lowest level to reach the target. Increasing details, analysis and de-aggregation of data. A top down analysis represent a proactive approach, and is shown in Figure 3 (5).

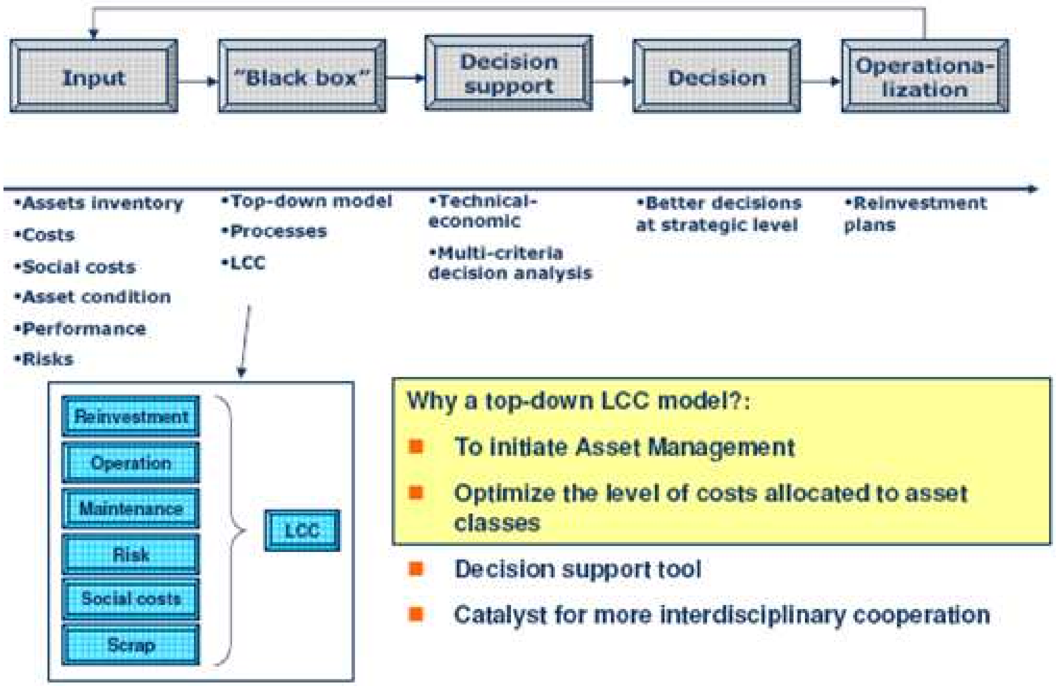


Figure 3: A top down analysis [Ugarelli, SINTEF (2009)]

To be cost effective, proactive maintenance involving inspection and repair must be focused on those pipes which can be shown to have an early predisposition to failure (12).

The main functions of cost that is important to assess in asset management due to rehabilitation is repair, investment, costs regarding water losses, inflation rate, discount rate and the current book values.

It is certain that every asset eventually fail, but the assets are not created equal/equally valued. Failures that directly affect the system performance are failures constrained by cost, and the investment should be guided by the risk of failure (likelihood and consequence) (5).

3. Tools for Planning and Rehabilitation

Water- and wastewater utilities have to manage huge amounts of data generated from different sources such as activities from maintenance and projects, rehabilitation, capital improvements projects, cost, employee information, etc. Different types of data from multiple sources must be properly organized, integrated, processed and analyzed in order to make optimum system management decisions (asset management).

It appears that the lack of information on which to conduct a meaningful analysis of system performance is common to many (though not all) cities in Europe, Australia and North America. Whilst modern information systems are being rapidly introduced their use has often appeared to lag behind similar developments in water supply and other infrastructure assets with the emphasis too often being on data presentation rather than effective analysis. Increasing customer and regulatory pressures will force a more comprehensive approach in the future where sewer maintenance will need to become more proactive to protect customers from the consequences of failure on increasingly ageing networks (12).

A range of techniques is being developed to target maintenance and work most effectually, based on statistical appraisals of past system behavior, broadly defined performance indicators to ensure acceptable levels of service are maintained, cost optimization of rehabilitation strategies and improved understanding of the influence of the pipe structure and layout itself on contributing to blockage and flooding episodes (12)

3.1 CARE – Computer Aided Rehabilitation

Care was a project under the 5th Framework Program of the European Commission carried out on water (Care-W) and wastewater (Care-S) from 2001-2004 and 2002-2005. Both projects developed a software dealing with fundamental instruments for estimating the current and future condition of water and wastewater networks. The Care-W software included tools for indicating performance; pipe failure; long-term investments needs; and a selection and ranking of annual rehabilitation projects (13).

The ultimate product out of the Care-S software, sewer rehab manager, is a decision support system that enables municipal engineers to establish and maintain effective management of their sewer networks. The software includes tools for indication of performance; defining socio-economic and environmental risk caused by a malfunction sewer system; assess the hydraulic, environmental and structural condition; defining the best long-term strategy for rehabilitation investments; and a multi-criteria decision tool supporting the choice of high priority rehab projects (14).

3.2 AWARE-P

AWARE-P, Advanced Water Asset Rehabilitation-Portugal, aims at providing Portuguese water and wastewater utilities with the know-how and the tools needed for efficient decision-making in the scope of water supply and wastewater asset management, specifically in systems rehabilitation (15).

The project results in two manuals, one for water and the other one for waste- and storm water. They are meant as guidance to Portuguese utilities on how to implement the best strategy for rehabilitation of the network, the proactive strategy, as described in IAM, Infrastructure Asset Management. Both manuals are sectionalized in three parts; General

Framework, Integrated Approach for Rehabilitation and Tools and Techniques to Support Rehabilitation. The integrated approach of rehabilitation describes the three levels of planning, as described in IAM, the Strategic-, the Tactical and the Operational level. The manuals give guidance on the rehabilitation for water distribution and collection, including the network, pumping stations and reservoirs. Treatment plants are not included in AWARE-P.

Another task of the project is to have a software ready within April 2011. This software are to be used as a guidance tool for rehabilitation work (The software is to be used as a foundation for decision-making on the rehabilitation process.), on how to choose the one which parts to rehabilitate first, based on given figures. The project is divided in 3 different main approaches to rehabilitation planning (which the decision is based upon), these are performance, risk management and cost assessment. The project aims to improve the quality of service to the customers, and ensure that the operation of the water and wastewater system, the economical, financial and environmental management is sustainable.

As mentioned above, the project is divided into 3 main aggregation levels, as described in Figure 4; Performance, Risk and Cost, and these are implemented as the three levels in the assessment process in the software.

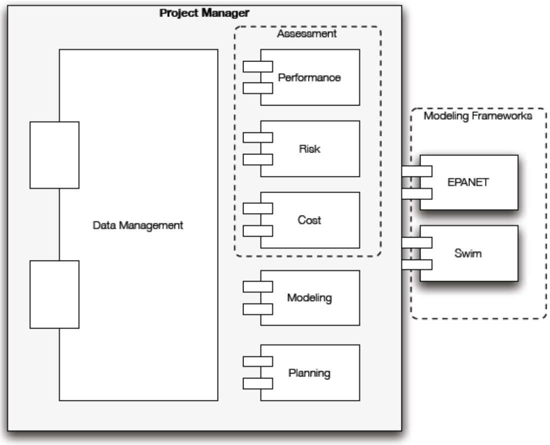


Figure 4: The 6 modules implemented in the software [LNEC]

The software consists of 5 processes/divisions: utility (UT); system (SY); subsystem (SS); cluster (CL) and component (CO). The component can be either a link or a node, the cluster is a grouping or a set of components. This way it might be possible to analyze the risk at parts of the network as a lumped (aggregated) model or at a component based level = detail. Lumped meaning you can compare and rank groups of assets, while the component-base is on individual components, like the methods in CARE-ARP. At the tactical level there will be a need of a combination of these two. <tactical vs. operational>, <macro vs. detailed>. The subsystem is a functional unit, either geographically, topologically or tagged (from another program, EPANET/GIS). In the software, the user can set different scenarios and alternatives. A scenario is defined as a system load state and set of operational conditions, such as design peak etc, while an alternative is an operational state (the user can set status-quo, which means normal operation or the continuity of the operation/maintenance, or a <u>change</u> from status-quo). Status-quo does not mean the same as doing nothing. There are three terms within the alternative: infrastructural term (TIF), maintenance term (TOM) and other terms (TNI).

3.3 Performance in rehabilitation planning

Indicators are usually tools to see the value of the performance of the network. The indicators are valuable information if automatable, unfortunately, a lot of the information must be collected manually. The AWARE-P project focus on two performance tools, a PI-tool (performance indicators) with a focus on parts of the network, a lumped analysis, and a PX-tool (Performance indices) meant for component analysis. The main difference of the two tools is that the PX tool includes extra performance functions.

The indicators and indices to be used are chosen from a library, and the input data is gathered from
- System data (length, material, age),
- Operational data (failures, blockages),
- Rehabilitation data (length rehabilitated), and
- Costs.
The outputs from the performance indicators will be represented by tables, graphs, and GIS representations with colour categories.

Figure 5 shows how the operation of the PX tool in the AWARE-P project.

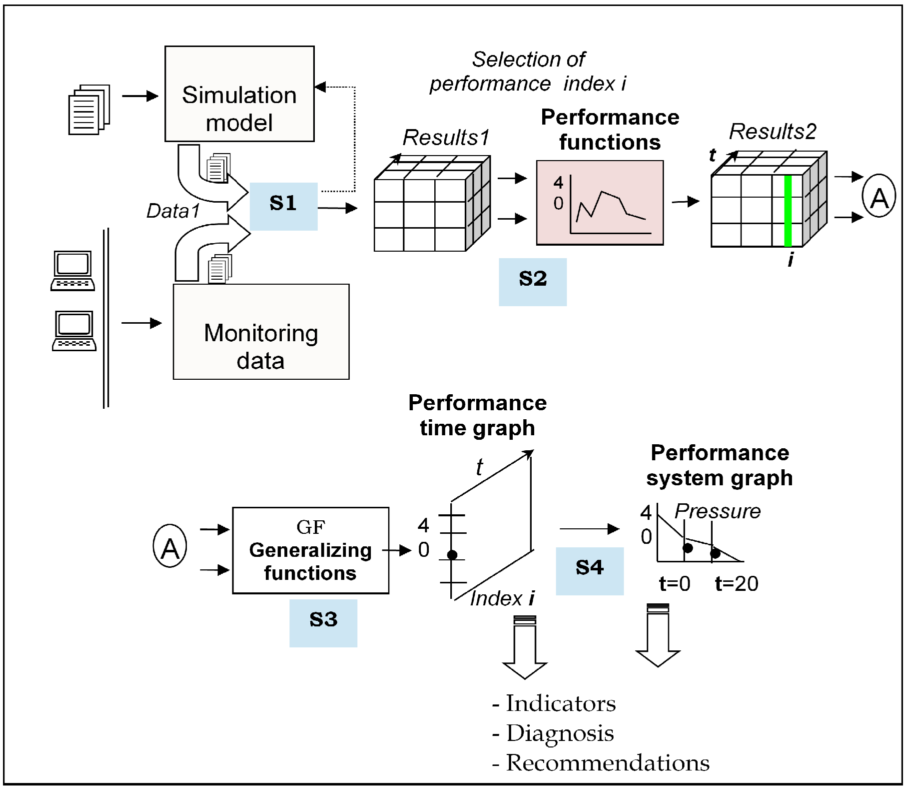


Figure 5: Operation of PX tool [AWARE-P, LNEC (2010)]

Simulation and monitoring data (S1) form the base for the PX calculations, this data will be given a performance value (S2), either classified from 1-4 or from 0-100(A). The performance indices will then run through a generalising function (S3) to receive the total score for the whole system performance. Several load scenarios can be tested (worst performance, peak flow, etc), for later comparisons when the performance assessment has been done (7).

3.4 Risk in rehabilitation planning

When estimating risk in rehabilitation planning, it's important to have a good description on the failure estimation as well as the hydraulic reliability of the network. The failures also have to be identified, the risk must be estimated and the consequences must be evaluated. When working with failures, there are both predictable and unpredictable cycles of the network, these represent the trends. Different tools to calculate each of these are available, but good data consistency is important for having a good estimation of the risk. How to measure risk and failure data is somewhat complicated, because there is no ultimate tangible factor that is directly linked to the failure. Some estimation can be done related to cost, but regarding consequences that affect people and human health, these are not easily valued in money.

All relevant data should be collected, this information normally includes dates, geology and hydrogeology, mechanical properties of the file, construction method (trench, embankment, tunneling), materials, incidents, and repair work orders. When conducting a risk analysis, the change in rate of deterioration is important, as well as the presence of factors contributing to the continuation of the observed deterioration (11).

A risk analysis begins with data collection on the failure history of the network. This data is used to estimate the frequency of the network failures through an analytical process, while models can be used to evaluate the consequences. This way action can be done to reduce, or even eliminate, the risk of failure (5).

3.4.1 Failure estimation

CARE-W based their failure tool, CARE-FAIL, on a set of statistical tools that obtained a probabilistic forecast of failures such as damage and loss of water supply following bursts and leaks. The underlying procedure quantified the effect of external conditions to the failure probability such as soil, material, construction year and number of previous failures. The numbers of previous failures are the most sensitive parameter for the tool (13).

The structural condition in CARE-S is calculated by different network aggregated models, which calculates the distribution of condition defined by classes and pipe specific structural models. The models calculates hydraulic performance and structural condition on a local (pipe based) level and comprise structural failures, strength reduction due to H2S attack or external corrosion, pipe blockage and in-/exfiltration of water. Rehabilitation impact on socio-economic consequences such as socio-economic costs and social life quality is also included (14).

In the AWARE-P project the probability assessment block in the risk model had taken into account the failure rate. There are three main trends mentioned in the project, (taken from Rausand and Høyland.): decreasing failure rate (DFR), Constant Failure Rate (CFR) and increasing failure rate (IFR). These three trends correspond to different stages in the structural life of a pipe, and the rates can be associated with the three main life cycles of a pipe where as DFR right after construction date of pipe (these failures are often due to poor construction or design), CFR in the life period of pipe (usually presented as random failures) and IFR at the end of the pipe life, the wear out period, where the deterioration process accelerate and failure rate increases (10)

In AWARE-P the failure estimation will be flexible, this means that the three stages of the life-cycle of the components is included. The failure rate, in real life, is not constant, but follows a trend line as shown in the bathtub curve. The Poisson distribution model, as used in CARE-W, operates only with a constant failure rate.

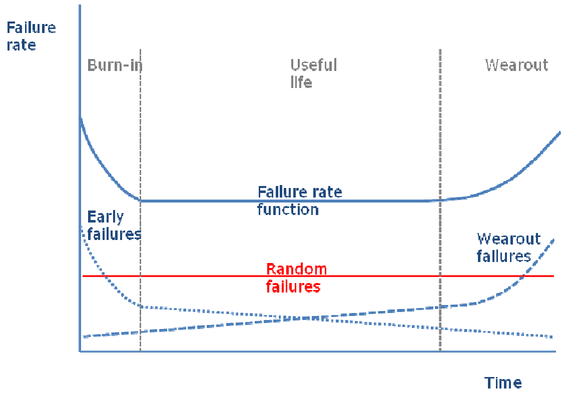


Figure 6: Failure rate curve for pipes [AWARE-P, LNEC]

In the risk module in AWARE-P, a GIS spatial analysis will be used as a tool to analyze the consequences of the failures. The user will have the ability to pick and play with different layers to make buffers or to see influence areas by selecting locations/intersections. By doing these analysis, choosing from other GIS layers, it's possible to see which areas are affected by a given failure.

3.4.2 Reliability

The reliability tool of CARE-W, CARE-REL, used a commercial hydraulic model (like EPANET), and combined it with a routine that forecasted the probability of failure for each pipe, resulting in a hydraulic criticality index, HCI (13). The tool, named RelNet, was developed to calculate the hydraulic reliability of the network, resulting in a hydraulic critical index. The software should be used for tactical planning, therefore it should be run on subsystems or zone areas, and not for the system as a whole. RelNet does not consider failure rate and is based only on hydraulic computation. The final index is a value varying between 0 and 1, where HCI=1 means that a pipe break will result in interruptions to supply to all customers served by that pipe.

The aim of the RelNet model was to assess the service reliability of each node and consequently the total reliability of the network using the reliability of the elements of the network. The reliability is based on required pressure in each node of the network and the model simulates random network load state (topology, demand, selected physical parameters – roughness etc.) Outputs in the model are node reliability, total reliability of the network and the impact of each pipe section on total reliability of the network (pressure zone). The Relent model is based on stochastic principle using the Monte-Carlo method (16)

For the wastewater network, CARE-S validated the hydraulic performance through evaluation of current best practice using 1D model (MOUSE, INFOWORKS, SWMM), the degradation of the network, and the environmental impacts of rehabilitation. The degradation model (FLUENT) describes the temporal decline of the hydraulic performance. Important information for the degradation tool is the technical state or failure of the pipe (to model structural collapse) and the operational state and failure of the pipe. For the operational state, each pipe is modeled regards to infiltration of groundwater, exfiltration of sewage, sewer blockages/"chokes" (sediment build up, ragging, root intrusion), and design deficiencies (negative slope, "sags", bottlenecks) (14).

3.5 Decision-making and future planning tools

The two main resulting tools in CARE-W were the Long Term Planning (LTP) tool and the Annual Rehabilitation Planning (ARP) tool. For strategic planning and investment, the LTP analyses the necessary investment levels in coming decades and how this is influenced by different rehabilitation strategies. The most important data specification criteria for classification for the LTP were pipe material, construction period and diameter.

3.5.1 LTP – Long term Planning

Table 2: Summary Care-W-LTP [SINTEF, appendix G]

Specification	Data input	Result
Mandatory input data	year of installation	
	asset type	
	length	
Other input:	current failure rate	
	current leakage rate	
Currency unit	Volume unit (Length unit import X Conversion factor)	=Length unit in charts
Stock (import) =	[Year]	Inventory of assets by asset type and installation year
		Asset type fraction of total stock
		Distribution of assets by installation year
		Age distribution of assets
	[Type]	Cumulative age distribution of types
		Cumulative age distribution of assets
		Survival function of asset types
		Average age and residual service life expectancies of asset types
	[Length]	Cumulative residual service life distribution of asset types
		Cumulative distribution of assets
Failure rate	Increase (failure rate) %	Service life expectancy , yrs
Leakage rate	Increase (leakage rate) %	[from – to, 100%,50%,10%]
Prognosis [start yr] [end yr]	Parameter aging functions	Future rehab work
	[aging factor, failure factor, resistance time, expected value, standard deviation]	[year]
	Type of prognosis	[asset type = material]
	[forecast future rehabilitation needs]	[length rehab/yr]
	[rehabilitation strategy] + [eco val]	Efficiency of rehab
		[costs][increase]
		[failure rate][increase]
		[leakage rate][increase]
		[resistant time]
		[efficiency factor]
Economic input data	[variable production costs per year] [increase] =	
	[inflation rate][discount rate]	
	[repair cost pr failure][increase]	
	[maintenance and insp. Per km][increase]	

Kanew was a methodology used in Care-W to evaluate and select the rehabilitation planning and is a well-known rehabilitation approach. The procedure starts from a network inventory, mileage per vintage and pipe types, where the pipes are defined by aging behaviour (material, capacity and corrosiveness) (13). Kanew doesn't include time functions such as future change of rehabilitation and improvements of technology, the software with a good implemented Kanew is a commercial program, and therefore expensive to implement in a freeware.

3.5.2 ARP – annual rehab planning

The decision support tool for annual rehabilitation planning (ARP) in CARE-W included (13)

- A multi-criterion selection and ranking system that combines results from the CARE-W tools with additional information supplied by the user.
- Enables analysis of the entire network, sectors or clusters of pipes.
- Provides a recommendation of groups of pipes that should be considered for rehabilitation.
- Supported by tools for prediction of future failures as well as water supply service reliability

Information required for the calculation of the decision criteria is derived from the performance indicators, hydraulic reliability software, failure prediction tools and the utility databases (13). ARP demands a lot of data to run. If data is missing from the other tools, this information must be given in another way.

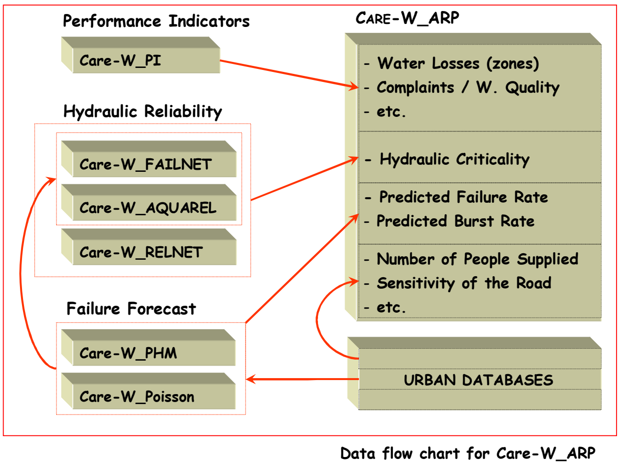


Figure 7: Flow of information used in the ARP tool [CARE-W]

The results of Care-W-ARP showed that a decision support system should be flexible to comply with present intangible rules and shares of responsibilities, to allow for a smooth implementation and to accompany afterwards the evolution in processes which this decision support system could facilitate or even foster (13). The ARP tool proved to be a tool for the experienced user with a lot of data. An inexperienced user will easily get lost in the software.

The Multi-criteria decision support for CARE-S was based on (14):

- Defining appropriate long-term rehabilitation strategy
  - Forecasting the future condition of sewer pipes by deterioration models
  - Determination of deterioration rates and the associated rehabilitation needs for <u>maintaining the actual condition of the network in the long term</u> and <u>reaching an improved level of service within the given horizon</u>
  - Forecasting PIs of the network for different strategies (scenarios)

    - Evaluation of different scenarios, and choosing the best rehabilitation strategy.
- Setting priorities for rehabilitation projects
    - Selection of projects with highest cost efficiency
    - Rehabilitation projects are selected from structural, hydraulic, environmental and socio-economic criteria, and the associated direct/indirect cost.
    - Candidates for rehabilitation are selected, step-by-step, in an interactive elimination process.
- Choosing the right rehabilitation technology
    - Best rehabilitation technique is chosen from a set of candidates fulfilling the requirements under specific local conditions.

The Rehabilitation technology information system included (14):

- Available techniques and contractors
- Chart of different methods
- Cost of rehabilitation
- Alternatives for rehabilitation
- Criteria for choice-making

4. Comparison of the reliability tool of CARE-W and AWARE

In water supply reliability, LNEC has improved the RelNet software used in CARE-W. A comparison is made and the results are described in the following.

4.1 Running the hydraulic model

Some basic errors were discovered when running the hydraulic model in the freeware Epanet. The hydraulic model of Trondheim Municipality generated several errors in the EPANET program. The first error listed was error 201: *syntax error in a line of the input file created from your network data. This is most likely to have occurred in .INP text created by a user outside of EPANET*. Other errors listed were error 203, *object refers to undefined node*. For example the line 37312/328449 had an error203, this line is connected to node 1_458 and 171. All these errors are pumps.

```
[VSD_PUMPS]
;-----------------------------------------------------------------------
; Pump          Node     Pressure    Speed      Speed     ControlType
; ID            ID       min         max        0/1       (downstream node, any node)
;-----------------------------------------------------------------------
     328449         30  55.000000   0.200000   1.000000           0
     328556       1_84  45.000000   0.200000   1.000000           0
     328557       1_82  45.000000   0.200000   1.000000           0
     328558       1_84  45.000000   0.200000   1.000000           0
     328594      1_537 107.500000   0.200000   1.000000           0
     328595      1_537 107.500000   0.200000   1.000000           0
     328598      1_263  68.000000   0.200000   1.000000           0
     328599      1_261  68.000000   0.200000   1.000000           0
     328611      1_571  76.000000   0.200000   1.000000           0
     328626      1.530 120.699997   0.200000   1.000000           0
     328974        1_9  56.599998   0.200000   1.000000           0

[EMITTERS]
;-----------------------------------------------------------------------
; Node           Flow Coeff.
; ID
;-----------------------------------------------------------------------

[DEMANDS]
;-----------------------------------------------------------------------
; NodeID              Demand   Pattern
;-----------------------------------------------------------------------
          1   0.009920         99       ;Lekkasje
          1   0.055556         23       ;Husholdning
        1_0   0.001512         99       ;Lekkasje
        1_0   0.002315        103       ;Husholdning
        1_1   0.000802         99       ;Lekkasje
       1_10   0.000659         99       ;Lekkasje
       1_10   0.006944         11       ;Husholdning
      1_103   0.000685         99       ;Lekkasje
      1_104   0.000359         99       ;Lekkasje
      1_104   0.041667         12       ;Husholdning
```

Figure 8: View from hydraulic model, non working nodes

All [VSD_PUMPS] were removed from the reading, each line started with ";". After reloading the model the Error 201 at line 53418: *[TIMES] STATISTICS NONE* occurred. Statistics none was changed to statistic none. These two errors were also noted in Stian Bruaset's master thesis, *Optimization of water network operation and maintenance.* The following adjustment had to be made in the .INP file of Trondheim water network:

-remove part called "[VSD -PUMPS]"
-change "STATISTICS NONE" to "STATISTIC NONE"
-add value for quality time step: for example 0:05"

When running the analysis the status report gave "WARNING: System unbalanced at 5:30:23 hrs." The time frame was set to 1 hour at 7:30 in the morning, when the demand in Norway are supposed to be at maximum. This file was then used in calculation with RelNet and AWARE-P's version of RelNet.

4.2 Background information and differences in the models

Definitions:

Base Demand The average or nominal demand for water by the main category of consumer at the junction, as measured in the current flow units. A negative value is used to indicate an external source of flow into the junction. If left blank then demand is assumed to be zero (17).

HCI - RelNet Hydraulic Critical Index. A HCI equal to 1 means that a pipe break will result in interruptions to supply to all customers served by that pipe (13).

The AWARE-P team developed an easy model based on the RelNet model used in Care. The result is given in HCI, Hydraulic Criticality Index, the same as RelNet. The application is based on a Demand Driven Analysis (DDA), used in this comparison, analysis it uses the EPANET model and is programmed using the VBA language within the excel interface. The model aims to adjust the effective demand of a water supply network based on two pressure criteria: minimum pressure and reference pressure (18). It uses Paul Praca's methodology, where the effective demand was based on the pressure criteria and can be defined by the user.

$$Q = Q_0 * \sqrt{\frac{(P_{\text{junction}} - P_{\text{min}})}{(P_{\text{ref}} - P_{\text{min}})}} \qquad (1)$$

Q is the demand at the junction after being adjusted according to pressure criteria, P junction is the pressure calculated in the junction and Qo is the demand at calculated using the EPANET model.

RelNet is based on the equation

$$Q = Q_0 * \sqrt{\frac{(P_{\text{junction}})}{(P_{\text{ref}})}} \qquad (2)$$

Experiences from LNEC show that a more realistic equation is shown by:

$$\frac{Q}{Q_0} = \left(\frac{P}{P_0}\right)^{0,2} \qquad (3)$$

When applying these equations in a excel sheet, with minimum pressure set to 15 and maximum pressure set to 25, the graph develops as shown below.

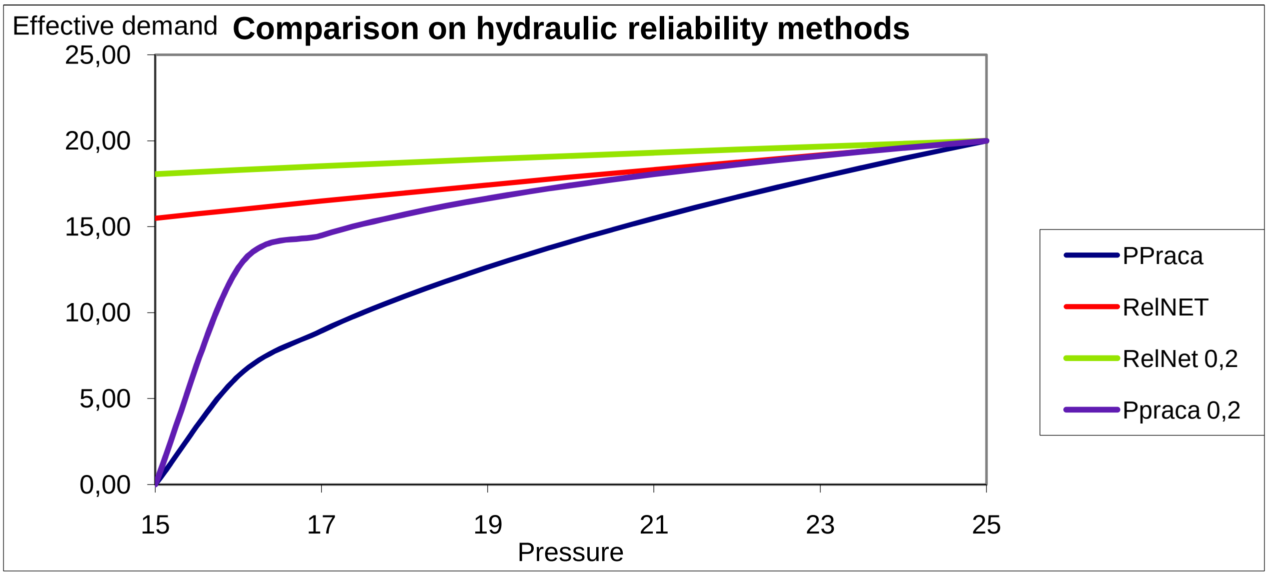


Figure 9: Result from comparing RelNet and hydraulic reliability model by AWARE

The new equation developed by LNEC gives a better approximation to real life, as shown in Figure 9. When the pressure drops towards the minimum, the effective demand is decreasing in continuous way, while RelNet's equations gives the effect of having a well functioning water supply system until the minimum pressure is reached.
The HCI is calculated:

$$HCI_j = \sum_{i=0}^{n} d_i - c_{ij} \tag{4}$$

j – Link
n – Number of consumption nodes
d – Water demand at node *i*
c – Available consumption at node *i* when link *j* fails

Demand consumption:

$$HCI_{j-1} = HCI_{j-1} + DO_{i-1} - DO_{i-1} * \sqrt{\frac{P - P_{min}}{P_{ref} - P_{\min}}} \tag{5}$$

Where j = link and i = junction (node)

FailNet:

$$HCI_j = \sum_{i=0}^{n} (d_i - c_{ij}) * t_{c_j} \tag{6}$$

Where:
j = link,
n= number of consumption nodes on network
d_i = water demand
i = node
c_{ij} = available consumption at node i when j fails
t_{cj} = repair forecasted.

When running the equations with a normal demand and a minimum pressure of 15 and a maximum pressure of 25, 21 pipes scored a HCI larger than 0,1 after running the (3 version. The same pipes received the same score using all three equations described above. All these pipes are either laid in 1963, 1991 or 1994. They all have a diameter bigger than 400mm and are all transmission mains. They vary in length from 3 meters to almost 4 km. 90% (18/20) is of concrete. There is not more than 0,01 difference between the HCI's. In a city of the size of Trondheim, that means that of Trondheim's 25391 service connections, AWARE-P mean that 253 more houses will have problems with their pressure and water supply.

To visualize the real differences between the two equations, the base demand was increased and multiplied by 1,7. This was done to set a larger load on the network so that it is possible to pick the critical areas. At the same time the minimum and maximum pressure was set to 50-65. At this high demand the minimum HCI was 0,33 with the equation of AWARE-P and 0,308 with the equation of CARE-W. The maximum HCI was 0,53 with AWARE-P and 0,509 with CARE-W.

Demand 1,7 higher	**Demand 1,7 higher**	**Demand 1,7 higher**	**Demand 1,7 higher**
Pressure limits 50-65	**Pressure limits 50-66**	**Pressure limits 50-65**	**Pressure limits 50-66**
HCI - LNEC	**HCI - RELNET**	**HCI - LNEC**	**HCI - RELNET**
min	**min**	**max**	**max**
0,333	0,308	0,53	0,51
0,33	0,31	0,52	0,50
0,33	0,31	0,52	0,49
0,33	0,31	0,50	0,48
0,33	0,31	0,50	0,48
0,33	0,31	0,50	0,48
0,33	0,31	0,50	0,48
0,33	0,31	0,49	0,47
0,33	0,31	0,49	0,46
0,33	0,31	0,49	0,46

It's important to mention that this great demand is not realistic, that it is only used as a comparison to the two models.

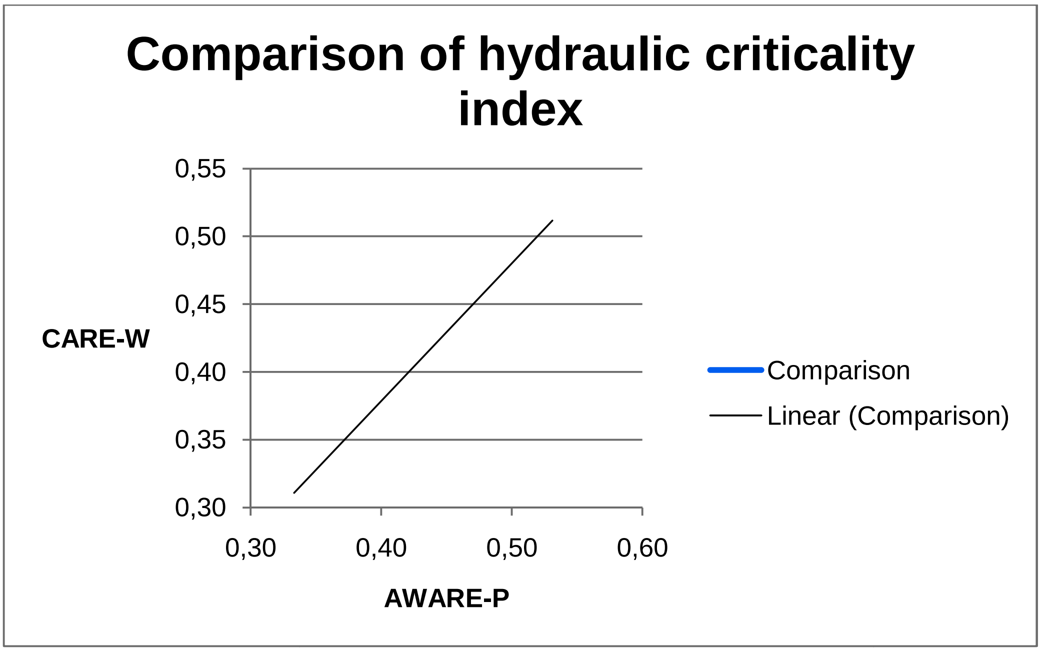


Figure 10: Comparison of HCI in CARE-W and AWARE-P

When comparing the HCI at a pipe that is connected to nodes with a pressure between the valid limit (above 50) to the invalid limit (below 50), the AWARE-P equation gives a HCI of 0,45, while the RelNet version gives a HCI of 0,42. This implies that the AWARE-P equation gives a higher number (3%) of the houses that does not receive sufficient water supply.

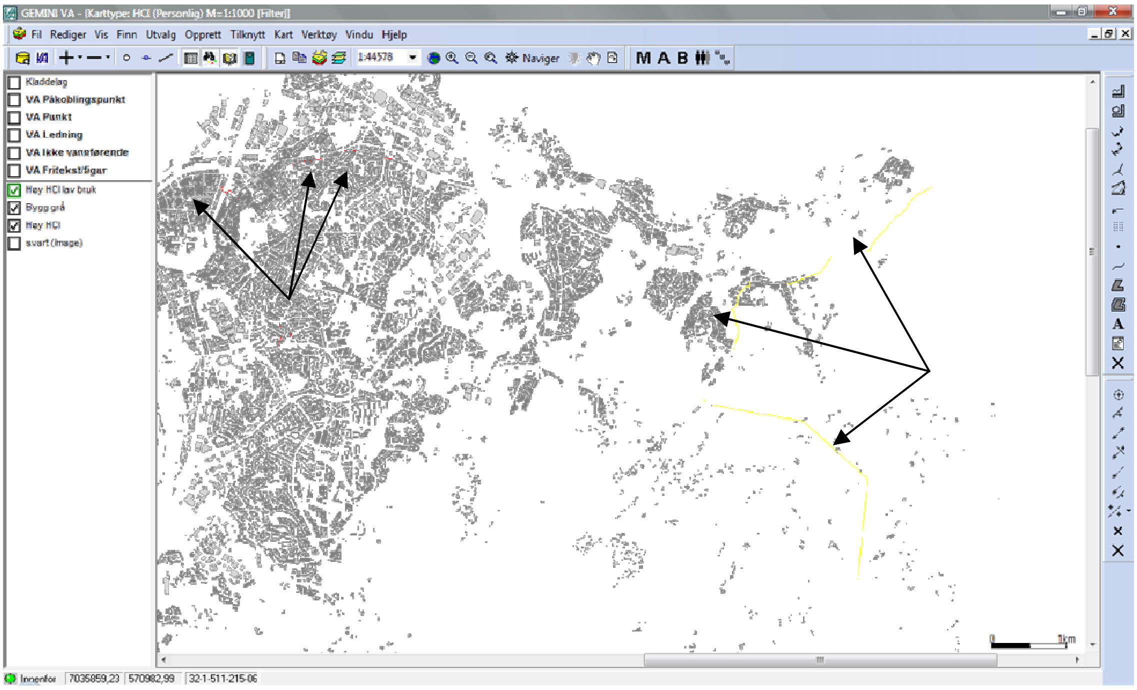


Figure 11: Pipes with a high demand, marked yellow (RelNet) and red (AWARE-P)

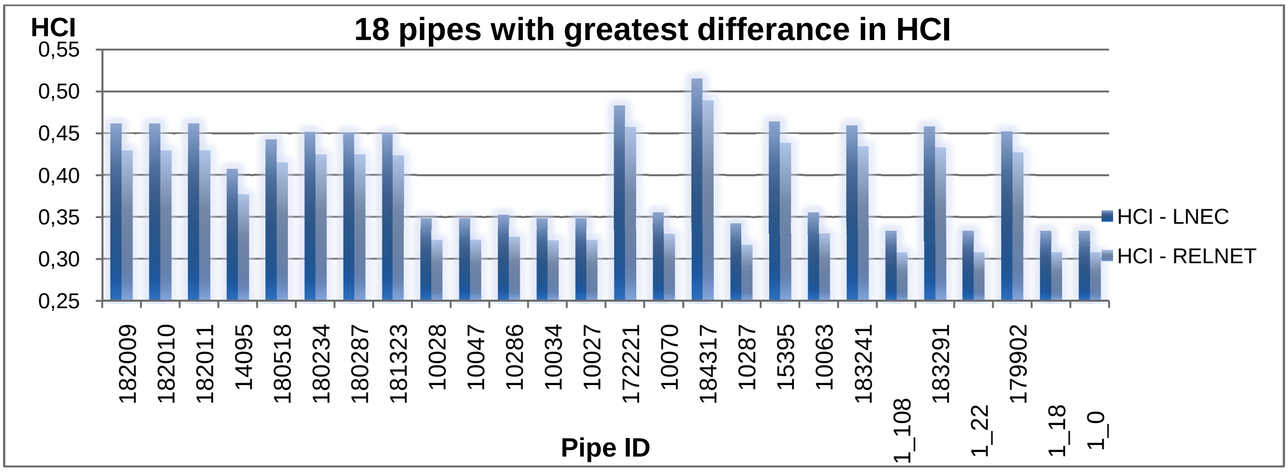


Figure 12: 18 pipes with greatest difference in HCI

Table 3: Pipe ID's with highest HCI score

Highest HCI score			
RelNet normal demand	**AWARE** **normal demand**	**RelNet** **high demand**	**AWARE** **high demand**
188701	188701	188701	188701
192811	192811	11099	11099
185995	185995	184317	184317
190279	190279	181397	187500
190278	190278	187500	187480
190274	190274	187480	181397
189272	189272	187478	187478
189241	189241	184576	184576
190263	190263	187357	187357
190268	190268	187393	187393
190260	190260	187758	172221
190266	190265	188001	187758
190264	190262	172221	188001
190265	190266	176419	176419
190261	190261	176595	185995
190262	190264	188879	188879
190267	190267	4_77	176595
189240	189240	185995	172220

From Table 3 it is obvious that the difference between the two methods is not big when the pressure and demand acceptance is non-critical. When running the different methods with a normal demand, there are 4 pipes that are not in the same order regarding HCI, but the 18 pipes of the highest HCI of both methods include the same pipe ID's. The differences are very small, the differences occur from the 2, 3 or 4th decimal.

When running a simulation with overload, the differences are greater. Half of the HCI's given at the top 18 does not match. The differences are still quite small, but there are also 2 pipes in each method that is not represented in the other method's top 18.

4.2.1 Result

It's clear that AWARE-P's version has a higher HCI than RelNet, and is therefore more pessimistic or strict on the hydraulic failure expectancy of the network. The difference between the two equations is that the AWARE-P equation includes the minimum pressure in the fraction under the square root, the demand (Q) will be smaller than the demand using the RelNet equation, hence the value of HCI will be higher since the subtrahend in the (5 is lower.

The decisive factor in the two equations is the difference in the demand when the pressure drops toward the minimum pressure, as shown in Figure 9. Because of the continuous graph, the equation used by AWARE-P should give a result that is closer to reality, and since it marks the same pipes as the RelNet model, that was tested on real networks in the CARE project, it proves to be a reliable, though more strict and pessimistic, hydraulic criticality index tool.

5. Implementation of Asset Management

Implementation of Asset Management is a thorough process and there are several different guides available on how to implement the approach. An example on a 10 step process is included below (Figure 13), together with the five core questions of Asset Management framework (Figure 14).

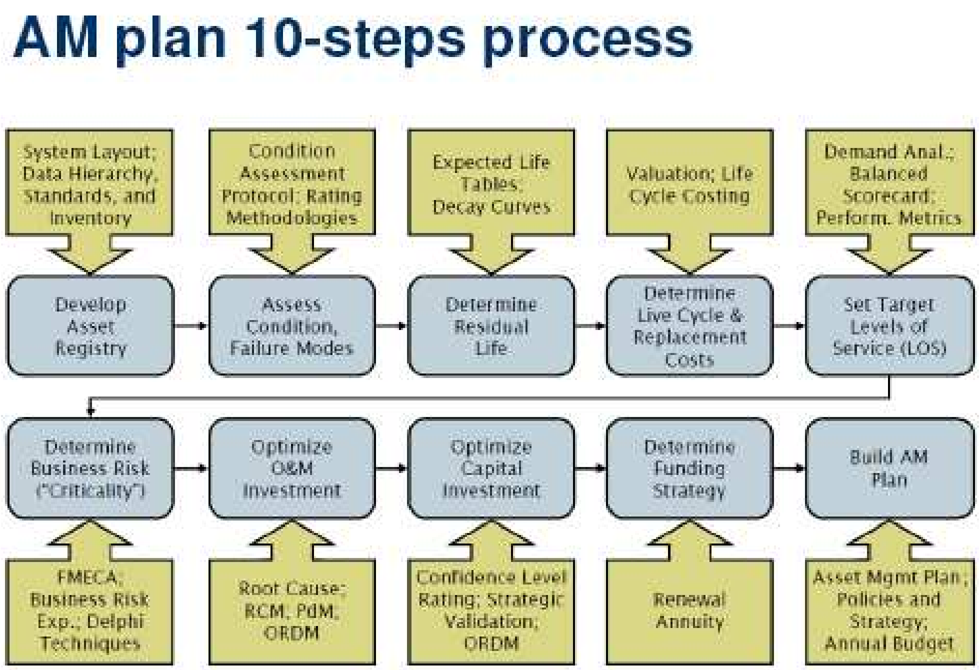


Figure 13: The ten steps process [Ugarelli, SINTEF (2009)]

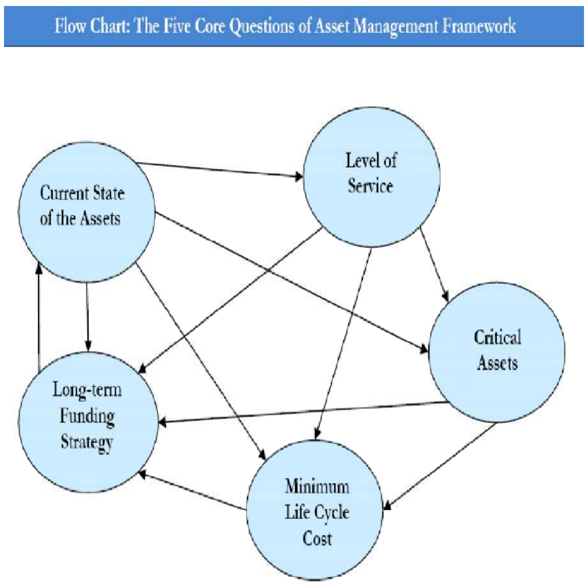


Figure 14: The five core questions [Ugarelli, SINTEF (2009)]

An example on how to implement these five question is given in the scheme below (5).

Task	Question to answer	Best practice
Current state of assets	What does the utility own? [asset]	Asset inventory
	Where is it? [Location]	System maps
	What is its condition?	Condition assessment and rating system
	What is its useful life?	Useful life assessment
	What is its value?	Asset values and replacement costs determination
Level of service (LOS)	What do the regulators require? [laws and regulations]	Understand regulatory requirements
	What are the utility's performance goals?	Communicate to the public a level of service "agreement". Make your service objectives meaningful to the customers.
	What LOS do the utility's customers demand?	Analyze customer demand and satisfaction
	What are the physical capabilities of the utility's assets?	Use level of service standards to track system performance over time
		Performance indicators (failures pr year, stoppages per year pr km of pipe, overflows per year per km of pipe, customer complaints per km of pipe)
Critical Assets	How can assets fail?	List assets basted on criticality
	How do assets fail?	Conduct a failure analysis
	What are the likelihoods and consequences of asset failure?	Determine probability of failure
	What does it cost to repair the asset?	Analyze failure consequence
	What are other costs that are associated with asset failure? (social, environmental)	Compute risk of failure
Minimum Life Cycle Costs	What alternative management strategies exist?	
	What strategies are the most feasible for my organization?	Deploy resources based on asset conditions
85% of a utility's annual expenditures	Maintenance options (non-preventive or preventive)	Move from reactive to proactive maintenance
	What work is done where and why?	Look at lifecycle costs for critical assets
	When to repair, rehab and replace	Know the cost benefits of rehab vs. replacement
	Capital Investment plan (CIP) projects. What and when.	Develop and validate CIP
Long Term Funding strategy	What is the full economic costs associated with the utility	Routinely review and revise the rate structure
	How can full cost pricing be implemented	Fund a dedicated reserve from current revenues
		Finance asset renewal and replacement through financial assistance

As mentioned in Figure 3, a top down analysis is the best approach to asset management, as it represents a proactive approach. A top down analysis is done by answering these questions:

1. What asset is known?
2. What condition the assets are in?
3. How these assets are performing?
4. What service is currently delivered and what it needs to deliver in the future?
5. Which risks there are to the service?
6. What assets will costs over their planned life?
7. When assets need to be repaired or replaced and how?
8. What may need to be done differently in the future?

In Infrastructure Asset Management there is no one-size-fits-all manual. All approaches must be linked to each country's overall sustainable strategy, it must be linked to each utility and must take the diverse stakeholders into account. Also other areas might be dependent on an Asset Management plan by the utilities, for example IWRM, Integrated Water Resources Management, has directions/approaches that are directly linked to the urban waters services, in particular managing wastewater as a resource while protecting human and environmental health. The IWRM has been criticized to be impractical in real life because of the challenges of integration. Theoretically it makes sense, but it is not easily implemented (19).

Asset Management also face integrationproblems with the water and wastewater industry. There are several separate divisions today, and with implementation of asset management they have to cooperate. At the same time the experience from IWRM is that involving stakeholders can dramatically improve the quality of decisions as well as compliance with them. It builds trust, lays the foundation for implementation, and often results in a better balance between the three ‘E’s of equity, economics and environment. But for participatory processes to be effective, stakeholders need to be brought in at the appropriate stage and their participation needs to be grounded in a well defined and accepted structure (19).

6. Data management

To run tools for planning and rehabilitation, large amounts of base data, on each individual assets, must be collected. Today, these data are widely spread and not always stored in a digital format. Often the number of inputs exceeds the number of available data from the municipalities and if the data is available, it is often not compatible. The structural data available is usually a lot more systemized and easy accessible than the historical data. For both the CARE programs, a lot of data was needed, these are listed in attachment 1 and 2. For the CARE-S analysis on establishing critical condition class of the pipe, important data needed was material, period of construction, location, use for waste and/or storm water, profile, diameter, etc. Both of the programs are data hungry and time demanding on data collection.

Tests of the program were carried out through the project by the end-users, which made it possible to evaluate data availability on corporate databases as well as their structure. This enabled the way for future implementation of rehab programs based on CARE-S and CARE-W, and new ideas for data recording were identified by the end-users, but also extra functionality needed in the software were identified (14).

6.1 Data – use and collection

To achieve a good condition analysis on the network, all approaches are dependent on the reliability of the data about the pipe's physical attributes and its failure or performance history. Sewerage databases are often not as complete as the water mains databases, which can place significant restrictions on the level and type of analysis which can be achieved. The accuracy of any methodology cannot be greater than that of the original information about the networks state variables. Poorly calibrated models or other sources of data inaccuracy are great sources of error and today's system need considerable efforts to be made in standardizing data records and implementing and updating them. Standardization of information is important if a widely usable decision support system is to be created (12).

When using softwares to evaluate a network based on the data collected, it's important that the data is well systematized and equally entered throughout the whole utility. Though each utility control its own flow of data collection, dependent on their strategic goals, it's important to have guides with definition of the data to obtain a high level on the collection of input data to be used in future rehabilitation plans.

Norwegian utilities benefit from already having a well defined collection of data due to the great uniform use of Gemini VA. Norway also benefits from not having a strong private market within the water and wastewater infrastructure, this way it's implement a national standard of data collection and also to implement a national database. It's important to integrate one common base solution, independent on the different utilities. Making a collection standard is a big challenge, but in order to do good future predictions, it's important that the data follows the same footprints.

The privatization of water supply distribution and treatment increase the need of surveillance by the authorities. The Portuguese regulations, ERSAR, have developed several indicators for the utilities to include in a mandatory annual report. The AWARE-P team has collected the most important PI's from this list to make it more specified for Asset Management. The compatible solution of these tables to Norway is included in chapter 9.

When CCTV inspections are made in the pipe network, the reports specify what condition the different pipes are in. The inspection data should be applied for classification of condition to estimate future condition using the statistical tool for condition transfer and existing data on wastewater pipes. The services life for each condition class should be estimated (4). Regarding CARE-S, end-users often lacked data needed in the CCTV-valuation (often only about 1% of pipes are inspected, and when CCTV are available, they are not digitalized but recorded on written protocols), and hydraulic modeling data (small number of end-users performs hydraulic modeling). All information collected from inspections and other activities giving the condition of structural and functional components of the network (pipes, tanks and equipment), results in records that enable the utilities to evaluate the operational components and take the right decisions for further planning. Inspections are usually registered as maintenance work, and output data must be included in the evaluation of further inspections (6).

To develop a rehabilitation plan it might be necessary to conduct additional inspections or to modify the condition of "today" to set the frequency of the inspections to which pipes into the inspection plan. The frequency is dependent on criteria such as:

- component type (e.g. reservoir, valve, pump station),
- type of inspection (e.g. operational or structural). Type of inspection also affect the time and money needed for future inspections (e.g. accessibility, flow, equipment)
- the structural condition, location and functional relevance of the component or
- date of last inspection.

Inspections may be direct observations (visual, video camera, sonar/radar), and using these observations to set the physical features of the pipes, influences the choice of future inspections (diameter availability to equipment etc.). Most common techniques for assessing the physical condition are the use of performance indicators (Frequency of breaks in pipelines; actual losses, etc) (6).

Design or record drawing information may be inaccurate when checked against field data and so should not be relied upon when building models as it may not be a true representation of the as built system (12). Figure 15 describes general data requirements for a data management system.

Table 1
Data requirements for a data management system

Requirements	Description
Accuracy	All pipe and channel sizes and other physical attributes are known and the connectivity of the system is confirmed
Completeness	All constructed works are identified with no gaps existing in the pipe and channel networks unless confirmed by field study
Spatially defined	The location of the network should be referenced to the cadastral or property and road base to the nearest meter for presentation of the data in a GIS and for accurate development of hydraulic models
Known system condition	Moves to condition based depreciation rather than straight line depreciation on design life make condition assessment essential
Data transfer	Information must be easily transferred to the format required by modern hydraulic modelling products and GIS software
Asset management	Business decision rules using asset condition (likelihood of failure) and asset criticality (consequences of failure) should be used to define proactive maintenance, inspection or rehabilitation programmes
Maintenance management	The drainage information system should link to a maintenance management system for recording incidents and for recording the nature of field operational work undertaken
Quality Assurance	The procedures for editing existing information or adding in more information need to be covered by sound QA and incorporate security on who can edit the data

Figure 15: Date requirements, Fenner(2000)

The most basic data collection of a system is the construction year, diameter and material. This is usually the most registered data available in an utility as it's the most important data for the operational and maintenance level. For rehabilitation planning, data collection is a very important task, as the planning needs a lot of data to cover different areas such as:

- storage and information management;
- processing and analysis of water consumption;
- mathematical modeling of systems;
- performance evaluation;
- assessment of water losses;
- analysis and prediction of failures in pipelines;
- cost-benefit analysis;
- Decision support as part of rehabilitation.

Good data quality is essential to give a good analysis. It's important to assess the level of reliability of the existing data, meaning accuracy, consistency and updated information. Structural and functional data gives the state of the pipes, and is gathered by inspections. Spot metering, periodic or continuous magnitudes gives a characterization of the functional status of the network (hydraulic performance and the water quality) (6).

Fenner (2000) recommend to identify this following data information in the sewer network:

- digitized sewer line plans,
- manhole cards,
- customer contacts data,
- blockage reports completed on site,
- individual collapse and flooding databases,
- pipe material,
- sewer type,
- pipe size,
- pipe depth and event history,
- gradient (usually not standard in databases, though very useful),
- pipe age,

- soil type,
- pipe loading,
- cost on pipe repairs.

The key physical attributes which need to be collected are

- manhole cover levels,
- pipe sizes,
- invert levels of incoming and outgoing pipes and
- pipe material.

Other useful information which can help inform decision support models are:

- pipe shape;
- function and location of upstream catchment conditions;
- hydraulic load and frequency of surcharge;
- drift-, underlying geology-, and groundwater levels;
- traffic and surface loadings;
- age and construction techniques;
- event history and frequency of CSO operation;
- years since last inspection/previous maintenance/rehabilitation history.

The quality of the data record and the management in general is critical for an efficient use of the CARE-W, principles and methods for improving data quality were developed within the project. The CARE software is complex and demanding, consultation and proper training is essential to use the program, and the experience is that it was too complex for the average end-users to use.

Already in 1980 the DOE, England, made a list of different means of measurements that might form part of a comprehensive sewer record system (20), these were:

Table 4: Given by report 25, DOE

Operational records	Structural records	Other relevant aspects including
Complaints of nuisance or pollution	Information concerning the dimensions of manholes, etc. including sizes of clear opening for access	Rainfall data
Blockages	Details of the structural condition of sewer and manholes	Borehole records
Infiltration	As laid drawings and specifications including pipe bedding details, etc.	Ground conditions and water table
Surcharging and flooding		Traffic loading
Hydraulic data, e.g. capacity and flows		Details of utilities in the vicinity or other information gained during excavation
Future extensions		Rodent control schedules and test bait results
Silting, low flows and cleaning		
Ownership (relating to access)		
Trade effluent discharges		
Maintenance and related expenditure		
Connections or facilities for connections		
Repair/renovation/replacement operations and their related costs		
Cases of damage arising to adjoining services and/or property		

Additional information given, (12. final report of IWE)

RELEVANT TO BURIED APPARATUS:	**RELEVANT TO WATER IN TRANSIT:**
PLOTTING OF BURSTS AND LEAKAGES	MAINS PRESSURE AND HYDRANT FLOWS,
DATA FOUND WHEN UNEARTHED (COVER, OUTSIDE DIAMETER, ORIGINAL GROUND AND PIPE LEVELS, TYPE OF GROUND, PROXIMITY TO OTHER EQUIPMENT),	PRESSURE REDUCING VALVE SETTINGS,
FUTURE INTENDED MAINS,	WASTE DETECTION PLANS,
INTERNAL CONDITIONS OF MAINS LEADING TO MAINS CLEANING AND SWABBING PROGRAMMES,	COMPLAINTS REGISTER INDICATING AREAS OF TASTE,
RECONDITIONED SECTIONS,	PRESSURE AND COLOUR PROBLEMS
VALVE SETTINGS,	FRINGE SUPPLY DETAILS AND
TYPE OF HYDRANT OR AIR VALVE,	PRINCIPAL METERED CONSUMERS).
COMPLICATED JUNCTIONS AND	
AS LAID PLANS AND SECTION DRAWINGS,	
VALVE AND HYDRANT REGISTER,	
PROPERTIES SUPPLIED IN RURAL AREAS	

Other details that will need to be recorded and referenced to the master plans include the results of network analysis and the locations of priority users.

6.1.1 Typical forms mentioned in the report 20:

Sewers:	Water mains:
- Penstocks, - maintenance schedules, - CCTV survey, - summary of blockages, - jetting/winching reports etc. + - manhole details, - pipe length details, - storm overflow, - outfall, - inverted siphon, - pumping station, - rising main, - collapses and blockages, - flooding incident, - sewerage complaint, - rodent control, - trade effluent discharge, - private connection, - unconnected properties, - building over agreement/easement.	- booster stations, - waste surveys, - meters, - service connections, - abandoned mains, - hydrants, - summary of bursts, - flushing schedules, etc. + - pipe length, - complex junction, - valves, - main laying record, - main laying summary, - burst report, - operational complaints summary, - water supply complaint, - water supply sample, - sample of water main.

The pipe network records are systemized data of all occurrences on the network. such as pipe properties (localization, construction year, diameter, material), failure data (localization, time, control of diameter and material, observations) and maintenance (pipe inspection and cleaning). When a pipe is taken out of the network, it still contains important information for the statistical analysis, they should therefore not be taken out of the database. The record of the failures should be as complete as possible (4).

GIS deliverables within storm water shall include land use; stream centerline; cross section location; field surveys/benchmarks; watershed, sub watershed, and subarea delineation; photograph location; outfall locations; existing and future floodplain boundaries; and improvement locations. Hydrologic and hydraulic data required such as subarea delineation, overland slope, travel times, imperviousness, curve numbers, channel cross section, reach lengths, and slopes (21).

6.2 Benchmarking project in Scandinavia

Oslo, Stockholm, Gothenburg, Malmoe, Copenhagen and Helsinki have in a benchmarking project collected numbers on the water and wastewater service since 1995, where the goal was to a build a model that can be used to judge the quality, the service and the efficiency of the utility. In 2008 a group of people were to look into the level of network rehabilitation in the 6 cities, to see if there were possible to find comparable processes.

The projects has focused on the technical part and not the economical, since the condition of the pipes is most important from a rehabilitation perspective. Collection and storing of the asset data is very important to make statistics to map the future needs. These data includes construction year, pipe material, operational problems and surveys generally (ex. CCTV). One of the biggest challenges, is to survey the network databases to find what is documented and reported. It has been difficult to get good numbers on how many meters that rehabilitates each year because of the lag in the reporting to the database (22).

Expressions/definition on the rehabilitating on the project is:

Table 5: Definition of rehabilitation [Krog, A (2009)]

REHABILITATION = RENEWAL AND IMPROVEMENT	
RENEWAL	IMPROVEMENT
Renovation and new constructions with open trench, CBI (coating) and lining Cracking, equal dimension New construction due to the need of other infrastructure, same dimension	New construction, new pipe with improved structural, functional and technical facets. Cracking, bigger dimension New construction due to the need of other infrastructure and bigger dimension
NEW CONSTRUCTION	
Construction of pipes on new ground, no pipes available in the area New pipe by separation of pipes New pipe by duplication of pipes	

All cities in this project rehabilitate the pipes less than expected life cycle, that is due to the fact that network still hasn't reached its expected life cycle. The average age on the network and the rehabilitation need expressed in percent is affected by massive new construction. In the long run the rate of renewal on the network should equivalent to the expected lifecycle. That means that if you expect the network to last in an average 100 years, the renewal rate, in the long run, would be 1%. All the cities expect a greater need for renewal in the future, except for Copenhagen's wastewater network. An increased rehabilitating need means the budget has to increase as well. Copenhagen's network is older than other cities because of an higher renewal rate on the wastewater network. Regarding the water mains, the pipes with the largest diameter has been renovated first, which gives a lower rate to the same costs (22).

Table 6: Results from the benchmarking project [Krogh, A (2009)]

	Copenhagen	Malmoe	Gothenburg	Stockholm	Oslo	Helsinki
Average age water (2008)	71	46	39	50	54	45
Average age wastewater (2008)	55	46	38	47	49	34
Average age rehab pipes last 10 years (water)	80	61	51	71	63	-
Average age rehab pipes last 10 years (wastewater)	80	56	36	63	68	-
Rehab. water (m) average pr year last 10 years	4800	3900	8100	17700	9600	5600
Rehab. wastewater (m) average pr year last 10 years	24100	4500	3700	17000	9400	12200
Rehab. water (%) average pr year last 10 year	0,4	0,45	0,47	0,83	0,7	0,49
Rehab. wastewater (%) average pr year last 10 year	2	0,33	0,15	0,56	0,5	0,7
Expected life length in average (water)	100	100	100	80	90	70
Expected life length in average (wastewater)	130	100	120	70	80	50
Expected rehab. need (%) water 2010-2020	1	0,8	0,7	-	1	1,2
Expected rehab. need (%) wastewater 2010-2020	0,2	0,5	0,4	-	0,6	1,8
Personnel for long term rehabilitation planning (average man-year)	4,5	2	2	4	4	0,2

At the wastewater network the differences are big. Gothenburg, who has the longest life length, defines a wastewater pipe as functional even though the condition is low as long as it operates OK. If no disturbances occur (e.g. a blockage), the pipe will operate, though it might be broken. This gives a longer life on the net, since the pipes are operating longer than if it would if the rehabilitation was controlled after regularly CCTV inspections.

Helsinki has the shortest life length on the wastewater network because of the concrete material most wastewater pipes are made of. The quality of concrete has varied a lot because of different productions and the lack of material after the war. The life expectancy (LE) on wastewater networks are set to 50 years, while for storm water pipes the LE is 70 years (due to the sulfate in the wastewater pipes).

The water network doesn't have the same variety in the LE as wastewater, though Malmoe set their pipes to have the LE twice as high as Helsinki. This is due to the good ground material conditions in Malmoe and that the city's operational disturbances and leakages is low compared to the other cities. Helsinki has also included the valve's LE into the total, because the pipes are dependent on the function of the valves, and the valve's LE is usually shorter than the pipe's. If the valves don't function, it would be hard and costly to operate the pipe network (e.g. repair breaks) and this would influence the amount of rehabilitation.

When repairing or renewing the valves, it is expedient to rehabilitate the pipe as well if the pipe is old. The level of proactivity and reactivity differs between the different cities. While Copenhagen, Oslo and Helsinki are more proactive and run more CCTV inspections, Stockholm prioritize the customer relations. By 2010 the project would focus on which criteria's is controlling the rehabilitation need in the cities (leakage (in/out), number of breaks, complaints, etc) (22).

Most utilities will benefit on having benchmarking projects with other utilities, for comparisons, new ideas around different approaches, experience and so on. Asset management is not, as mentioned earlier, a one-size-fits-all approach, and different solutions to rehabilitation is a valuable lesson.

7. Gemini VA

Gemini VA, a software supplied by Powel, is one of the most used softwares by Norwegian municipalities to keep a good record of the Water and Wastewater (W/WW) system. As an example of the availability and the recordkeeping of the software, this thesis focus on Trondheim Municipality, which has implemented a full Gemini database with a large number of historical data with good consistency.

The Gemini software is not a GIS software, but it has a GIS interphase and can export both shape and .inp (hydraulic models) files. The main purpose of the software is to keep a good record of the structural assets of a utility (pipes, valves, manholes, pumping stations, etc.) and the maintenance history on each asset. The software is a system of databases with an advanced descriptive presentation and registration manager, Figure 16.

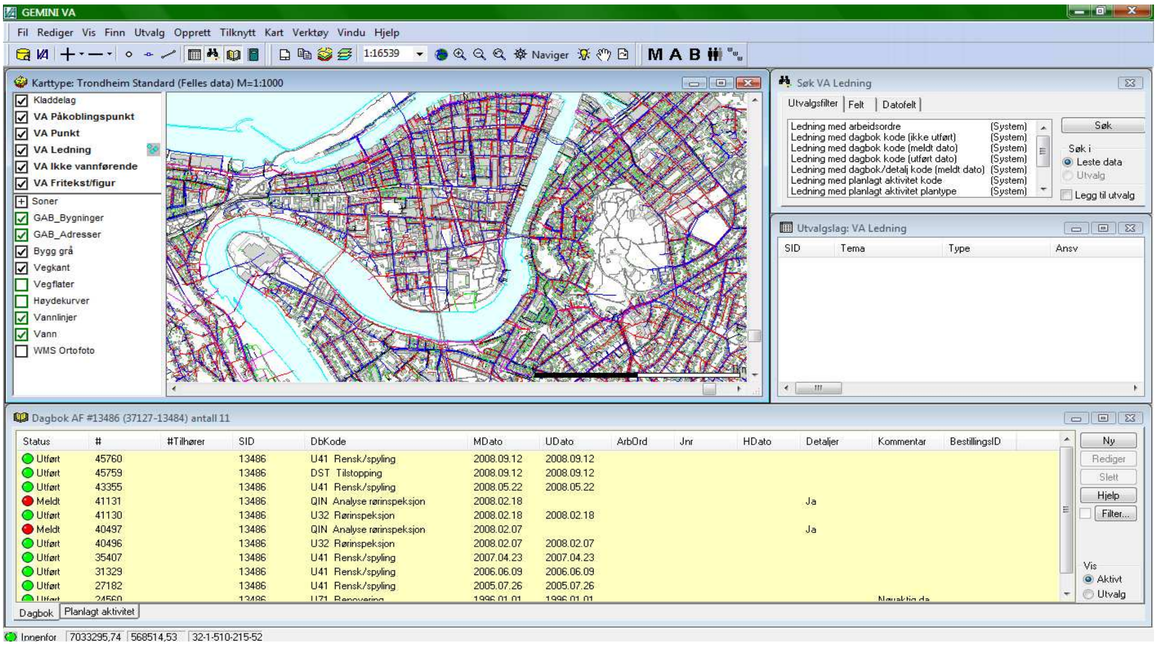
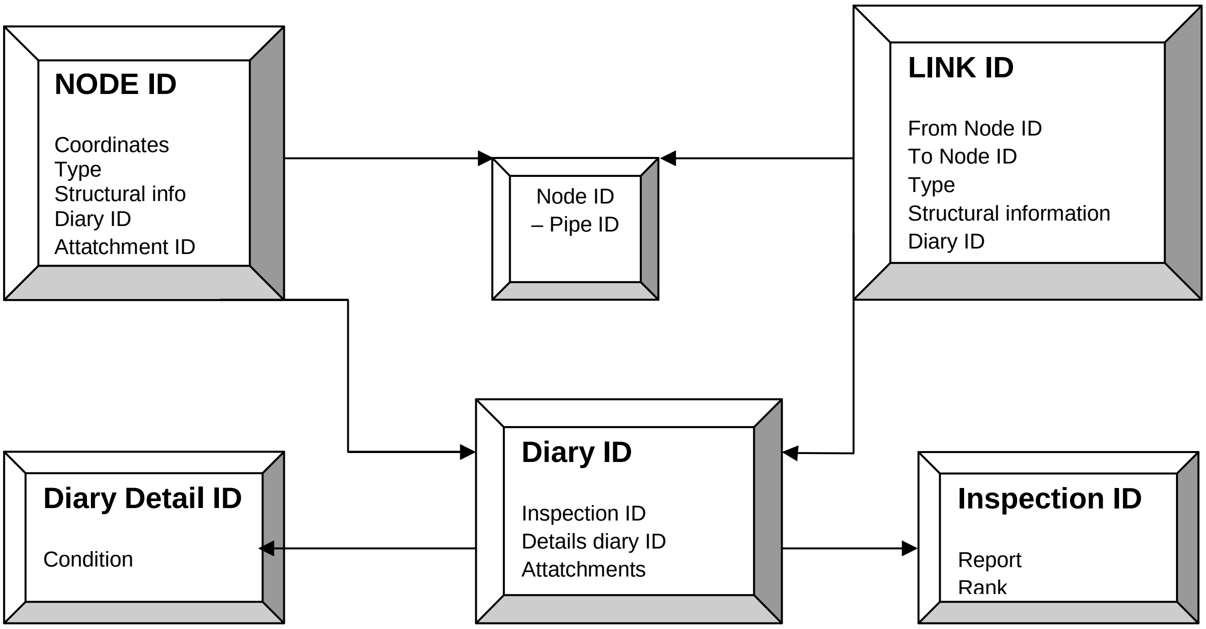


Figure 16: Gemini VA screenshot

There are three main registration areas: network information; diary and planned activity. The network information includes mainly structural information on the different assets (construction year, diameter, material etc.), the diary keeps the record of the completed workorders and other occurrences on the network (breaks, flushing, leaks, inspections, etc); and the planned activity keep the record of the date and description on the known future activities (flushing program, inspection program, etc.). Information on the workorders are all registered with date, and marked with a status of being completed (green) or not (red). The program also preserves the historical diary registrations, by registering this as "historical".

Another software from Powel used by the municipalities in Norway are Gemini Melding, Gemini Message. This software takes care of the communication with the customers and deal with the complaints. This is a tool for customer service more than operating the network, but the information can help the municipalities setting priorities on different rehabilitation projects based on the number of complaints and other occurrences registered in Gemini Melding.

Gemini VA's database is smartly built up by several different databases and queries, and with links to other databases controlled by the municipality. The network is registered by nodes with coordinates and the pipes are links between these nodes. The nodes consist of manholes, pumping stations, valves, service connections, etc, and links consists of all pipes (inclusive tunnels).



Queries in Gemini VA can be done to make statistics or other valuable information about the network. As an example on how the databases are built, the boxes above shows how the condition class is linked to each pipe ID, or how reports on inspections are linked to a node, and how the Node ID is linked to the Pipe ID. It is also possible to link the queries to other databases and get results within the network, e.g. pick number of people living at an address by links to the people registry database.

There are 4 important types of information sources in Gemini, these are field layer, map layers, control file and theme map. The field layer is made up of nodes, links and text. These are the main features in Gemini and are the direct link to the database. The map layer is a raster picture in the background which gives an orientation to where the network is located. Control file is to ease the use of the map functions and the theme map is to promote the information that is in focus, e.g. number of breaks, renovation types, by construction year, by material, etc.

The diary part of Gemini VA is the important feature for making condition assessment and value the performance of the network for future rehabilitation planning. The feature called planned activity is more interesting for operation than rehabilitation, and will not be further discussed in this thesis.

7.1 Gemini and collection of data

Gemini VA includes a lot of information to be included on the network. A summary of available data is presented in Table 7.

Table 7: Registered information in Gemini VA

LINE	INFORMATION RECORDED	NODE (INCL. PUMPING STATION)	INFORMATION RECORDED	OWERFLOWS	INFORMATION RECORDED	CONNECTION POINT	INFORMATION RECORDED
TOTAL ID	125688	TOTAL ID	132831	TOTAL ID	99	TOTAL ID	58637
BELONG TO NET TYPE	99,93 %	STATION	0,28 %	CATEGORY	68,69 %	LSID	100 %
RESPONSIBLE	99,98 %	FCODE	100,00 %	CONTROL	4,04 %	TYPE	100 %
OWNER	99,99 %	FUNC	89,81 %	CONTROL DIM	42,42 %	OWNER	87 %
STATUS	99,99 %	TYPE	51,16 %	WASTEWATER MEDIUM	-	YEAR	78 %
STREET CODE	93,06 %	OWNER	93,53 %	WASTEWATER MAX	-	DATE REGISTERED	100 %
LENGTH	100,00 %	STATUS	99,85 %	STORMWATER NORMAL	-	DATE CHANGED	8 %
FLOW DIRECTION	9,03 %	YEAR	73,36 %	EXCESS STORMWATER	-	DISTANCE	84 %
RISC	0,01 %	RISC	-	STORMWATER TO TP MAX	6,06 %		
REGISTRY DATE	99,99 %	COUNTY	48,25 %	STORMWATER MAX	-		
CHANGE DATE	81,45 %	STREET CODE	47,90 %	STORMWATER START	-		
MATERIAL	37,42 %	HOUSE ADDRESS	10,59 %	OUTLET HEIGHT	33,33 %		
DIM	44,02 %	LOCATION	23,26 %	WEIR HEIGHT	33,33 %		
YEAR	93,18 %	ACCESSIBLE	0,00 %	FLOODING CONDITION	-		
FORM	2,12 %	SHAPE OF OBJECT	21,87 %	SHUTTER	5,05 %		
DIM VERTICAL	0,17 %	WIDTH OF OBJECT	0,05 %	POLLUTANT CONTROL	9,09 %		
JOINT TYPE	30,04 %	LENGTH OF OBJECT	0,02 %	DISCHARGE TO	80,81 %		
PROD STANDARD	18,61 %	BUILDING STYLE	21,33 %	RESIPIENT	82,83 %		
REINFORCEMNT	18,25 %	CONE	0,13 %	PE	82,83 %		
STD DIM RATIO	0,10 %	MIDDLE DECK	0,01 %	CATCHMENT AREA IMPERMEABLE	-		
RINGSTIFFNESS	0,29 %	DATE REGISTERED	98 %	CATCHMENT AREA TOTAL	-		
PROTECT INTERNAL	2,71 %	DATE CHANGED	65 %				
PROTECT EXTERNAL	2,77 %	PUMP CAPASITY	-				
NOM PRESSURE	0,56 %	PUMP POWER	-				
PRESSURE CLASS	0,07 %	WELL_MAX_LEVEL	0 %				
RENOVATION METHOD	0,57 %	WELL_MIN_LEVEL	0 %				
OLD MATERIAL	0,57 %	WELL_VOLUME	0 %				
OLD DIM	0,57 %	WELL_UNITS	0 %				
OLD FORM	0,00 %						
OLD DIM VERTICAL	-						
OLD YEAR	0,57 %						
GROUND SURFACE	29,32 %						
EXTERIOR MASS	3,99 %						
SONE	55,54 %						
DIARY		DIARY DETAIL		INSPECTION OBSERVATION		INSPECTION ADDITIONAL INFORMATION	
TOTAL ID	50238	TOTAL ID	28099	TOTAL ID	61850	TOTAL ID	10835
DIARY CODE	100,00 %	DETAIL CODE	100,00 %	DISTANCE	100,00 %	DATE	99,98 %
DATE	100,00 %	CVALUE	29,82 %	TYPE	21,85 %	SIGNATURE	40,85 %
WORKORDER	21,49 %	CPRIORITY	3,78 %	CLOCK POSITION	55,81 %	WEATHER	40,44 %
COST DAMAGE	0,18 %			RANK	44,78 %	PREWASHED	45,91 %
COST COMPENSATION	1,10 %			TEXT	99,57 %	DAMAGESCORE	-
DISTANCE	9,96 %						

7.1.1. Registry of new pipe

All history related to a pipe such as maintenance work, repair and failures are tracked to each pipe-ID with a describing code in the diary feature of Gemini. Due to the coding and the links, a statistical tool is available to make different analysis. The statistics can be carried out on either the pipe diary or node diary. When a pipe is replaced, the old pipe still remains but changes the status from operating to "put out of service". This way all history remains in the database and can be included in the statistics for future planning. The information on the old pipe doesn't change, it is still given with the operating nodes ID. The new pipe will get new ID, and will (if at the same node) have the exact same to-from node. The nodes will be registered with all the information, the new and the old pipe, but the old pipe with the status "not operational". When running operational statistics, all historical information can be filtered out.

When replacing a pipe, it's recommended that a RDEL is marked as material and the replacement is registered in the diary to avoid too many registered pipe ID's. A pipe is usually 6 meters long, when searching for pipes less that 6 meters 1852 pipes are found (not including private owned, out of these 50% are water mains, 11% is wastewater, 14% is stormwater and 22% is combined sewer.

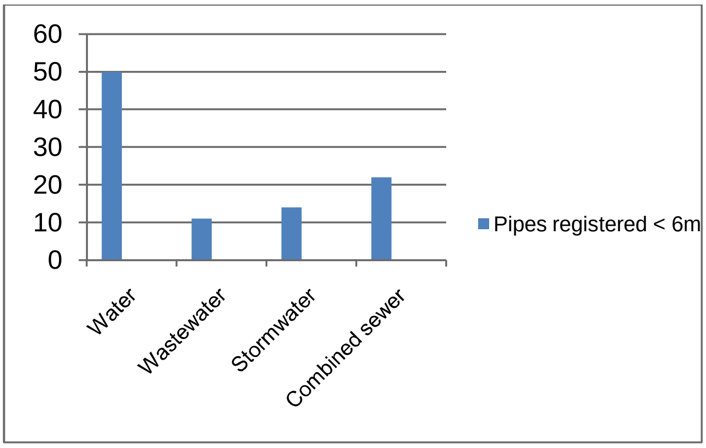


Figure 17: Percentage of pipes registered with a length less than 6m.

The short pipes are equally distributed to the year they were edited, no change in registration has improved on the length the latest years. A pipe length varies from 0 to over 5000 meters, each refers to one pipe ID. When using the diary function, the statistics is given in numbers and not in length. This means that a pipe with 2 breaks at a distance of 30 meters have the same rate as a pipe with 2 breaks on 500 meters. It's important that the user is aware of this, and always use units in the calculations.

As described above, a pipe put out of service retrieve the status "not operational". Though the pipe is still linked to the original manhole, the ID from the new and old pipe is untraceable. When splitting a pipe, the diary on the original pipe is duplicated and linked to both pipes. A warning box appears when splitting, saying that the diary must be taken care of manually. The date of the split is not easy traceable. The only linkage that can be found is the construction year, the connected node (should have one in common) and the date.

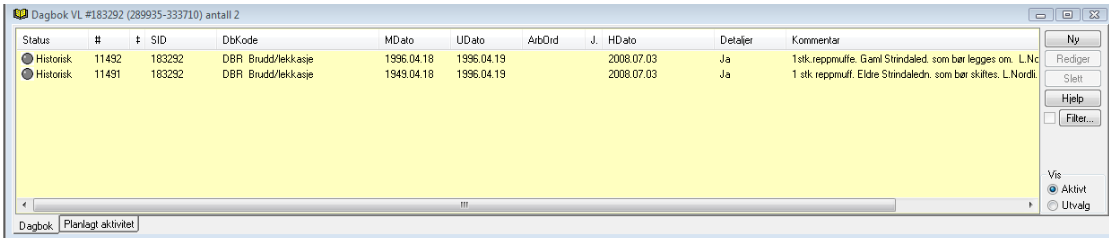


Figure 18 Example of error in diary. Two breaks registered, same break in reality.

The service lines are linked to the network by a node (service connection) on one end, and to the Property/ Building (GBA) code at the other end. Making an analysis of the people belonging to this service connection should be linked to the national people registry database. Theoretically it's feasible, but it's not easy, and it cannot be done directly in Gemini VA.

7.1.2 Workorders, Diary

All occurrences on the network (breaks and leaks; inspections; maintenance and rehabilitation, etc) are registered in the diary. The diary is linked to each pipe or node ID. The breaks can be registered as a distance from the manhole in the Diary detail database, which will appear as breaks on the pipe in the map. Unfortunately, these breaks are not georeferenced, which means they can only be used at the operational level and not at the strategic or tactical level, where they could be implemented in a statistical analysis. This is shown in Figure 19.

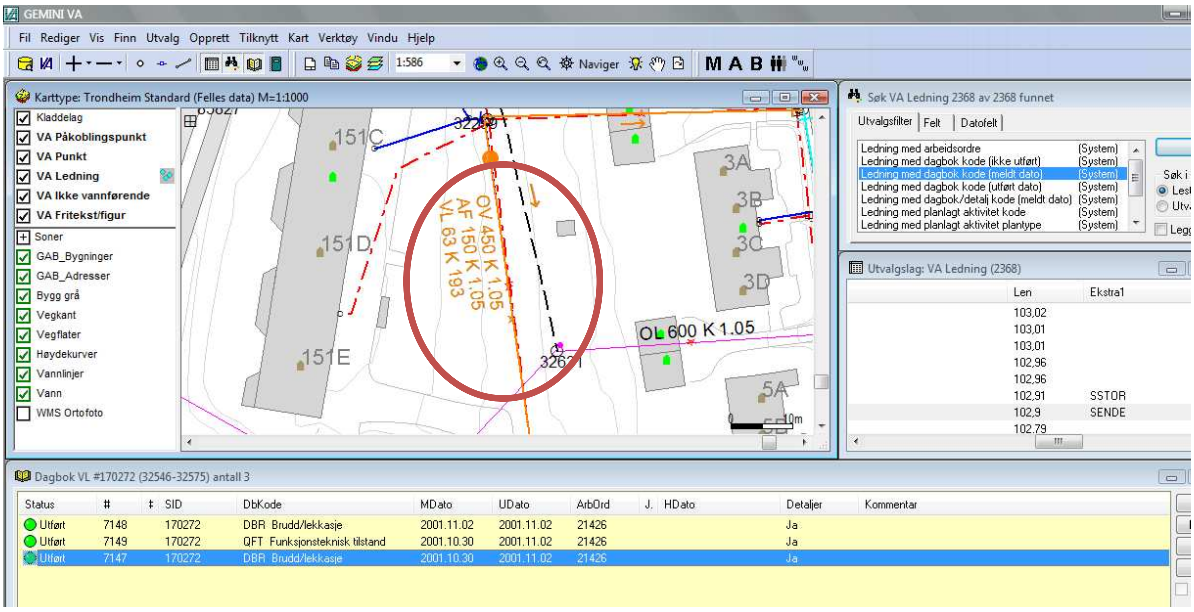


Figure 19: Several breaks are registered with a distance on a pipe in Gemini VA

The diary database is built up by a link to the Pipe ID or Node ID, depending on where it belongs. Each diary record has information as shown in Table 8.

Table 8: Diary registration

DIARY ID	PIPE ID/ NODE ID	DIARY CODE	DATE FINISHED	DATE REPORTED	STATUS	WORKORDER ID	DETAILS	OPEN TEXT FIELD

Most of the diary information is readable for statistics and automatic reports. An open text field is not favourable to researchers as it might contain important statistical information that is not registered anywhere else. To the operators it's often used as descriptive additional information. It's important to remember that an open text field creates a room for statistical error.

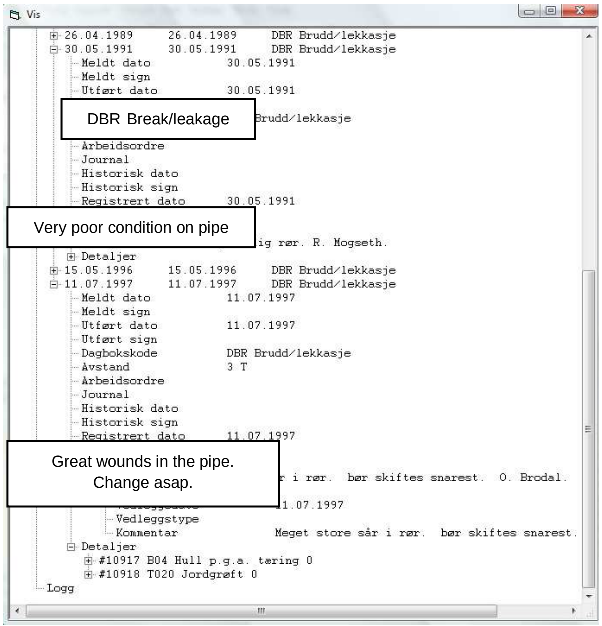


Figure 20: Example on important details added to a pipe in an open text field

8. Integrating Asset Management in Norway with the use of Gemini VA

Norwegian water and wastewater utilities is responsible for maintaining the pipe network with all its belonging assets in a good condition for generations to come. It has been focused on the deterioration of the network the latest years, and most municipalities is behind schedule in rehabilitation. The infrastructure is a valuable property of the society, and if not maintenanced properly, the amount of money spend on rehabilitation is far greater than necessary if good rehabilitation practice was implemented. To maintain the water and wastewater network and industry in a sustainable way, Norway should, as any other country, implement asset management planning.

The infrastructure is buried and not easy accessible, therefore the authorities of Norway wants the water and wastewater network to have a life cycle prediction of 150 years. To achieve this goal, the rehabilitation strategy has to be planned and structured the best possible way. By implementing the asset management approach and using good analysis to predict the lifetime and integrate the proactive management, the most vital and important areas to do the rehabilitation will be selected.

In Norway, the service lines and the service connections are private property of the customer. The responsibility of the municipality ends at the service connection. 47,3% of the total length of the city of Trondheim is marked as privately owned in the database. Out of these pipes, 83,3% are not registered with material. 16,2% does not have registered construction year. 67,9% of the private pipes does not have registered dimension. Though the operational responsibility is private, 553 pipes have a diary register, which count as 0,6% of the total of the private pipes (number, not length). Out of these diary registrations it was reported 18 breaks/leakage and 18 cloggings. It's important to remember that all maintenance and work done on the service connection, is done at the municipality's pipe.

8.1 Gemini and Asset Management

8.1.1 Using the five core questions on Gemini VA

For Gemini VA to be an asset management program, several features needs to be implemented. Together with Gemini Melding, the software represent today a good foundation to make the condition assessment, some of the performance assessment, and parts of the risk assessment. To be a fully integrated asset management software, the software needs to improve, but also, the data inputs from the municipalities need to be revised. An overview of what is available in Gemini VA and what needs to be improved is described in the following (any shortcomings of the software is highlighted as a bullet list) pages, the scheme on how to implement the five core questions of asset management is used as a guide.

<u>Current state of assets</u>.

Assets the utility own is already implemented to a large extent in Gemini. All assets available in the software are linked with an ownership, which makes it easy to do analysis using filtering tools. Assets that are not implemented:

- Treatment plants are all excluded
- Pumping stations are available, but does not have sufficient information to be a part of the asset management holding. The power use, the amount of water discharged in overflow, etc. are missing, mostly because of missing input.
- No information of asset storage holding.

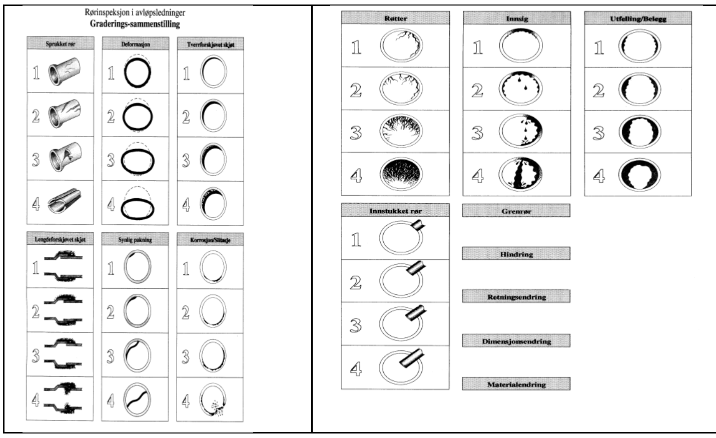
Statistical information from treatment plants and information from the water samples could be implemented in Gemini VA.

Where the assets are located is implemented by a georeferance (coordinates) and also often a street code. Old pipes also stay in the system with a reference, this makes it easy to make good statistics.

- Since Gemini VA is not a GIS program, the availability of making buffer analysis with different layers is not there.

The possibility of making theme maps to present assets with given condition is a good tool for making condition analysis and for future planning.

The condition and its useful life is available on pipes, where the pipe is marked with a function technical code and a score from 1-4. 1103 pipes (3 wastewater, 1 storm water, the rest water) are registered in Trondheim. When a pipe inspection is completed, the pipe get a score (In Trondheim's database this range from 0-2903), 9231 pipes are registered with pipe inspection, 10835 inspection ID's are available, only the newer pipe inspections gives condition class. 2045 inspection ID have a condition class > 0. If this feature was more used by the municipality, the structural condition of the network would be easier available.



	Weighting of observations				
	Grade of significance	Insignificant ⟷ Significant			
	Observation	Grade 1	Grade 2	Grade 3	Grade 4
Material	Cracked pipe	0	1	8	12
	Corrosion/abrasion	0	0	3	9
	Deformation	0	1	2	2
Operational	Longitudinal displaced joints	0	0	5	9
	Transverse displaced joints	0	0	5	9
	Visible gaskets	0	1	3	3
	Roots	0	1	5	9
	Infiltration	0	1	6	9
	Fouling	0	1	3	3
	Inserted branch pipes	0	0	1	3
	Change in relative depth of flow [1]	0	1	5	9

[1]Performed only as manual analysis based on reported relative depth of flow

- A automatic condition assessment should be available, and the ranking system should be available as a standard inside the software to make it easier for the user.
- The value of the asset is not included since no cost is available in the software (except for damage and compensation).
- If a unit cost were included in the diary specification, e.g. when a pipe is constructed, rehabilitated or renovated etc., a statistics would be available of unit repair cost, unit inspection cost, unit cleaning cost, unit construction cost of manholes etc.
- If a link was created to the accounting database, the information would be available without doing the same inputs twice.
- If a pipe was noted with a risk factor, the importance of pipes could be included in an assessment of cost vs. importance when it comes to rehabilitation.

With the availability of a cost function, the asset values and the replacement costs could easily be calculated.

<u>Level of service</u>.

The laws and regulations are usually put out by politicians, the municipality, the regulators or the state. It's important that these are understood and known about, so that no mistakes are made.

- Gemini could include a information support in their software. Information on regulations can be given as link to www.lovdata.no, were all Norwegian laws are accessible, and outlines from standards could be included as a wiki-manual on internet. This way it could easily be updated, and could contain information to Norwegian utilities as the AWARE-P manuals are for Portugal. The wiki-page should preferable be an open source managed by the regulators, but could also be implemented as a feature of Gemini VA.

Powel assert that a professional edition of Gemini VA has a report function to generate the KostRa and Vreg reports (national statistical reporting). This only generates information on the amount of pipes that is new constructed or renovated, 12% of the report is covered by this report function.

- If information about the treatment plant, water samples, costs, personnel, etc. was included, or directed to the database, the whole of the report might be automatically generated.

Through Gemini Melding the utility has a tool to register every complaint in a systemized way, a low number of complaints might indicate satisfied customers.

- More features around the level of service could be included in the software, at least the ones regulated by law. (Number of combined sewer outflow, drinking water samples on the network, etc)

When assessing the physical capabilities of the network, performance indicators is a good tool to assess the performance of the network or the assets. A lot of the information to fill in PI tables are given by Gemini VA and Gemini Melding.

- The information on the storm water assets have limited or no option of recordings in Gemini VA. Implementation of additional information should be included.

Critical assets. The critical assets are to a certain extent included in Gemini VA as described in the condition point above.

- Gemini VA does not include critical assets beyond the structural criticality. Assets based on criticality of location and demand should be available.
- To determine the probability of failure, an automatic generated report could be made if hydraulic information from e.g. EPANET could be retrieved back into the database. Together with all other structural information available in Gemini, this report could give the pipe a failure score. Risk of failure should be computed when using asset management.
- An easy way for calculate expected lifetime in a Gemini VA report could be to calculate a score depending on material (ductile iron > PE > asbestos cement), quality of construction work (not included in Gemini VA today), filling material etc.
- When computing risk of failure, social cost and environmental cost are associated with the failure, these are only included in Gemini VA as damage and compensation cost. Should also include construction cost, rehabilitation cost, repair cost, etc.
- If using another program to generate the failures and criticality, Gemini doesn't provide any inputs in the database to include the result from these programs.
- Also when running several test, the historical prediction should be available, to see how the performance is developing, and to calibrate the model.

- Gemini VA can only be used to calculate cost in a very simple way by (material * cost factor).

Minimum Life Cycle Cost. As maintenance cost make about 85% of a utility's annual expenditures, it's important to involve the strategy of the utility, and within maintenance, the utility choose whether they follow a non-preventive or preventive strategy in their rehabilitation work. The non-preventive strategy is in the long run more expensive than the preventive one.

- To look at the life cycle costs for the critical assets, the costs regarding repair, construction, the cost of replacement vs. rehabilitating could be gathered in a statistic if the inputs were available in Gemini VA.

If Gemini VA could give directions on the order of the maintenance work to establish a proactive approach, it would lead the utility to a more asset management system.

To value the strategies that are most feasible for the organization the resources should be distributed based on the asset condition. The asset condition has a good coverage in Gemini VA and the distribution should be feasible.

- To make it easier on the utility, a standard report could be available linking the assets by condition, material, diameter, length, etc. This report should contain all assets, and by linking the condition of the assets given in the report to the amount of work needed, the cost of rehabilitating and the risk of not rehabilitating, Gemini VA could supply the utility by providing a good base for the decision making upon the strategy to choose.

The cost benefits are important. Gemini VA provides information on what has been done where and sometimes why, this is important to decide the order on which areas or assets that should be rehabilitated first, and what kind of rehabilitation technique that should be used.

- If Gemini VA implemented a wiki on rehabilitation and replacement techniques, so that the user would know when to rehabilitate, when to repair and when to replace it would be valuable for the user. This information could also be linked to an external webpage, as the laws and regulations were suggested in the LOS section above.

The capital investment plan (CIP) is important as a feature to plan the different projects on deciding on what to do where at what time. By making a CIP it's easier for the utility to develop a long term funding strategy.

- Gemini could have a function that makes it easier to develop and validate a CIP.

Long Term Funding Strategy. When implementing a cost function the full economical cost of the utility should be defined. How full costing can be implemented is an important question, but it's complicated and not easily linked to the water and wastewater database.

8.1.2. Improvements for Gemini towards Asset Management in general

Gemini VA is today a operation and maintenance program, used at the operational level of asset management. It contains a lot of information, and is a good tool to use at the tactical and strategical level. Gemini VA should include statistical information from other assets of the network, not only the pipes and manholes. Statistics from live monitoring data could be implemented and saved as diary features on the assets (hour of overflow at pumping stations, power supply numbers, etc). Including other assets and live information, the lifecycle cost assessment can be implemented to a greater extent. Cost and employees are not a part of the system at all, this could be implemented by running statistics from other databases every half year. Having one software where all search functions are implemented, gives a greater chance for the system being assessed the way it's supposed to.

Improvements on Gemini VA regarding long term planning for a municipality could be included by implementing an automatic report collecting information on the individual assets and the break data to do a "pre-analysis module" as in CARE-LTP. To run this type of analysis, the individual assets must be sorted by year, amount, material and dimension, with each pipe-ID's break date, such as year of break and type of date. To include all information, the history on pipes put out of operation should be included. An improvement for Gemini VA would be to include "end of service year" as an extra feature to make easier analysis. The result of this report would be an overview with the grouping of assets into ageing homogeneous asset types, giving information such as "service life of asset".

Another automatic report, also gathered from CARE-LTP, would be to make a base for the strategy and choices of the analysis. This report should include the individual asset construction year, length/amount and type. For each type a current break (and leakage) rate should be calculated based on the break information. Type, amount and date of rehabilitation of each asset-ID should also be included in the report. Based on this information the user can calculate the future break rate and the efficiency of the rehabilitation. Economic information is important for future planning, but no inputs are available in Gemini. Economic information Gemini VA could include is the repair cost of breaks, investment costs for specific rehabilitation methods, the cost of water losses and the current book values of the assets.

When a long term analysis has been made, it's important to validate this information. Gemini VA could also include a report that can verify this information, or give information that can be used for calibration of the models. This reports need to include time series data such as "amount of rehabilitated assets per year per rehabilitation method", "amount of breaks", "break rate", "amount of losses", "leakage rate", "repair costs", "investment costs per rehabilitation method", "inflation rate", "discount rate", and "book values". All this information is not available in Gemini VA today, but if they were included, this type of report would be very useful for the user, and could be generated for the time aspects decided by the user.

Features from Gemini VA gives a good foundation to establish a national database, where rates, probabilities and performance indicators should be included. This would be important and essential information that can be used as a base for municipalities with similar networks, but is missing the digital registry.

To save time consuming data validation for statistical reasons, Gemini VA should have a more validation of data features, including diary, and better help, guide and search function available digitally inside the program.

8.2 Data validation and detection of failures in Gemini

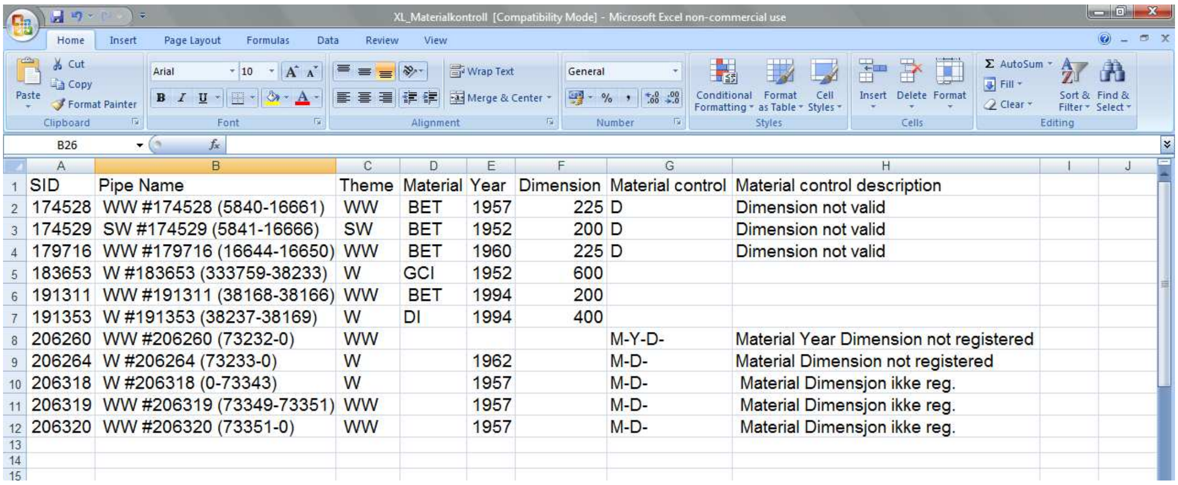
To validate a database, different actions could be implemented. Norway has a well developed database in the biggest cities and biggest municipalities, and with the focus on rehabilitating models that has been the last years, SINTEF has started a procedure to validate the databases. The process has been used for the CARE-W tool LTP, where the construction year is the parameter with the biggest influence. Material and dimension are among the other features that plays a important role for the development of the lifetime of the pipes. The described process, for structural validation, is collected from two different assessments done by SINTEF, one for Kristiansund municipality and another for Trondheim municipality.

1. Define the type. (e.g. the LTP analysis is defined for the water mains, type=VL)
2. Illogic values such as
    a. A ductile iron pipe with a dimension higher than the delivered dimension on the marked
    b. A PE pipe with a construction year before they existed
    c. Unknown use of a diameter depending on material
    d. Unknown code used for status
    e. Ductile pipes with construction year prior to implementation in practice
    f. Grey cast iron pipes with a construction year after out of production year.
    g. General lack of information
3. Status. Exclude the non operational pipes for further analysis. (Status=Drift)
4. Run a statistic on the owner and maintenance responsibility, validate information. Make statistics on the following:
    a. Number and length of pipes registered by owner
    b. Number and length of pipes registered by responsibility
    c. Municipal owned pipes distributed by responsibility
    d. Responsibility distributed by owner

    Exclude private operational responsibility in the analysis (driftansvar≠privat).
5. Locate errors in the database, validate information.
    a. Construction year – important for the LTP analysis to decide aging probability. The construction year is individual for each municipality, usually it is not less than 1850 and never newer than today's date.
    b. Material – important for which lifetime that can be expected
    c. Dimension
6. Tables of different possible errors:
    a. Construction year – number, length, percentage
    b. Material – number, length, percentage
    c. Dimension – number, length, percentage
    d. Material vs. construction year – unique value
    e. Material vs. dimension – unique value

When using the failure statistics in Gemini VA, each municipality should validate their own historical data, to prevent misguiding reports. As mentioned earlier, a homogeneous and reliable dataset from a shorter period, is better analyzing material than uneven data from a longer period.

The structural data in a municipality is usually well sorted. To prevent errors in the database, Gemini VA has already implemented a script validating the combination of the material, construction year and dimension. The logical coding list the valid material by year, the valid diameter by material and the combination, and is completed by SINTEF. A completed material control on a few pipes is shown in Figure 21.



SID	Pipe Name	Theme	Material	Year	Dimension	Material control	Material control description
174528	WW #174528 (5840-16661)	WW	BET	1957	225	D	Dimension not valid
174529	SW #174529 (5841-16666)	SW	BET	1952	200	D	Dimension not valid
179716	WW #179716 (16644-16650)	WW	BET	1960	225	D	Dimension not valid
183653	W #183653 (333759-38233)	W	GCI	1952	600		
191311	WW #191311 (38168-38166)	WW	BET	1994	200		
191353	W #191353 (38237-38169)	W	DI	1994	400		
206260	WW #206260 (73232-0)	WW				M-Y-D-	Material Year Dimension not registered
206264	W #206264 (73233-0)	W		1962		M-D-	Material Dimension not registered
206318	W #206318 (0-73343)	W		1957		M-D-	Material Dimensjon ikke reg.
206319	WW #206319 (73349-73351)	WW		1957		M-D-	Material Dimensjon ikke reg.
206320	WW #206320 (73351-0)	WW		1957		M-D-	Material Dimensjon ikke reg.

Figure 21: Material control completed in Gemini VA

Other logical coding that can be implemented by script is:

- Dimension of links registered to a node, if different size: validate manually.

And validating input scripts can be:

- Dimension must be picked from a list and not typed in after choosing material from a picked list. This way human errors is reduced, and illegal values is prevented
- Construction year can only be between a lower limit (given by the municipality) and a maximum limit (the date of "today"). The same year as the year in "meldt dato"(registered date) in the diary function should be default value.

8.3 Registration of failures

Failures are in Gemini either registered as a break/leak(DBR) or a blockage(DST). A third option called *other (DAN)* is also included, and the user can specify the registration in an open textbox. The problem with this type of data, is that it cannot provide easily generated information to the statistics, as it has to be taken manually out of the system. As the graph in Figure 23 shows, these registrations are decreasing, probably due to an improved software with a more thorough database.

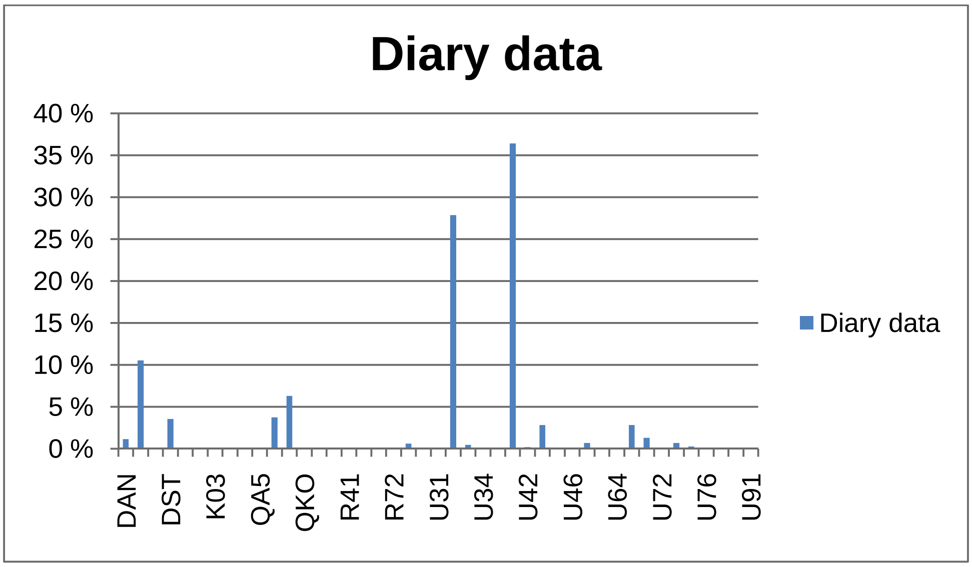


Figure 22: Diary data overview from Gemini

10% of the information given is referred to as OTHER

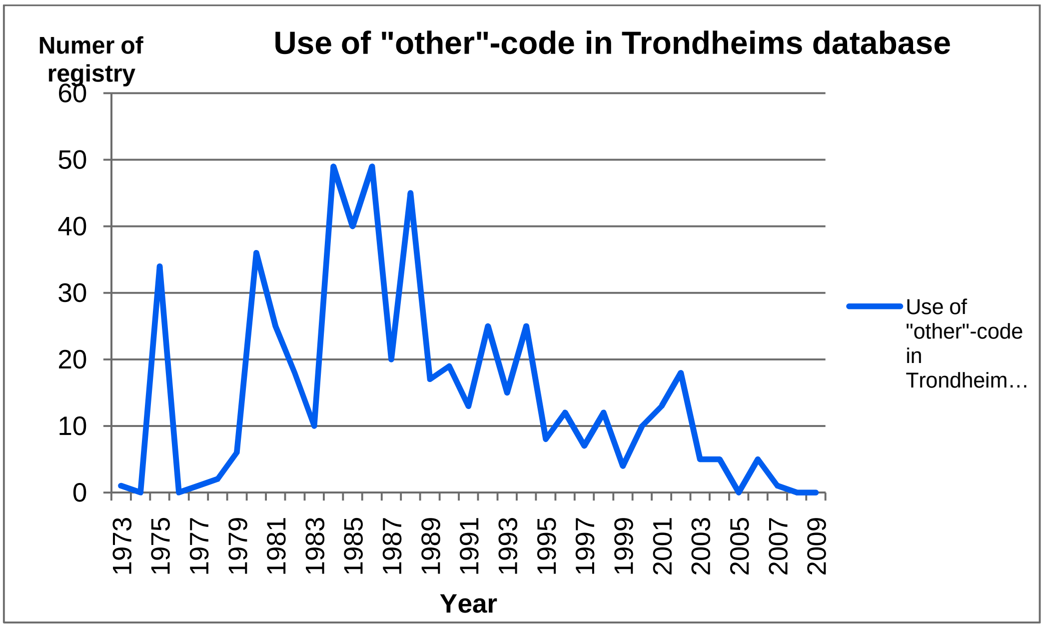


Figure 23: Registration of operation code "other" in Gemini VA

The location of the break is reported at the pipe ID, and registered with the position in meters, but the distance is not geo-referenced. When splitting a pipe, the history of the pipe follows both new pipe ID's. When splitting, Gemini VA generate a warning saying the information must be located to the pipe it belongs to manually. All registrations that is done manually, should have a validation test. If the diary is not manually fixed, this problem will be a source of error when running a failure statistics.

- A validation script of breaks can be included by comparing the Diary-ID, Pipe-ID, belonging Node-ID (out of the two, one must be linked to the same ID), and the Diary-Type.

When splitting a pipe, Gemini VA automatically generates new pipe-ID's.

- If these ID's was traceable to the Parent-ID, it would be easier to keep a record and validate diary information. E.g. PipeID 1 would be split in PipeID 1 and PipeID1_1, If again split it would be PipeID 1_2 or PipeID 1_1_1. A validation script of diary duplications would be easier to discover as PipeID 1 and PipeID 1_1 could not have the same break at the same day. Also, when the software duplicates the diary information, the duplicated diary get a new diaryID, if it would get a underscore in its ID, it would be easier to trace.

Other possibilities to avoid errors and missing data in the database is to guide the user of a recommended minimum of input (dimension, material, construction year).

- By registration of a new pipe, the minimum inputs could be marked with a star to point out that these facets should be included.
- When analyzing the network for errors, by using a validation report (in the future), the errors should be added in the "utvalgslag", active objects, and highlighted in the software.

Other validations, error highlighting, that could be included in the software is:

- Pipe length equal to zero should be discovered and fixed. Some pipes with a length of 0 has all information saved. Such as material, diameter, etc.
- A definition of legal inputs on coordinates (top right corner and lower left corner) should be implemented to avoid assets outside the municipality's area.
- Diary codes that is no longer in function, should be changed into a the new code, examples are listed in attachment 7.

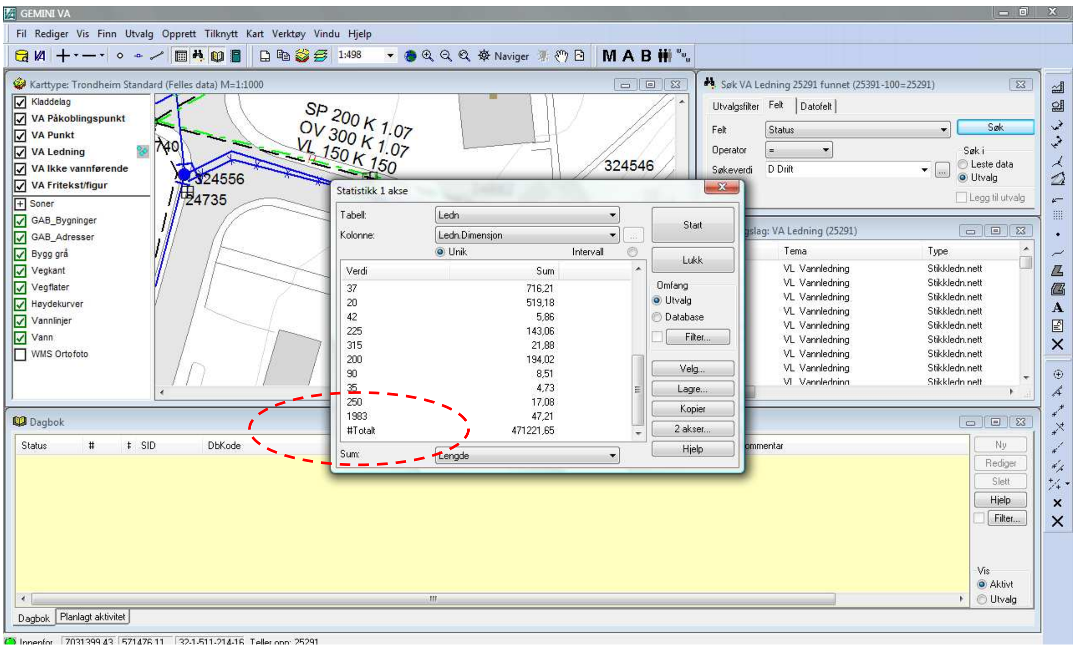
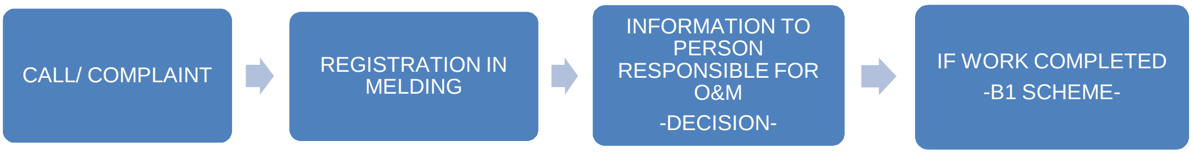


Figure 24: Example on typical error. Dimension on service connection is registered as a year

When running the material control already implemented in the software, the output is an excel file with registrations of what is correct and not. If the outputs could be generated back into the "utvalgslag", the active layer, the user could easily change and add the information. Also the software could suggest statistical inputs that fit each asset that is missing information, e.g. if a pipe is missing information, and the pipes connected to the node on each side has the same construction year and the same material, it's statistically a fair chance that this pipe would have the same information.

8.3.1 Diary reports improvement

Registration of different happenings on the network is registered in Gemini. Before this is registered there's usually a typical pattern followed, as showed in figure below:



Every work completed on the water and wastewater network should end with a filled B1 report. The B1 report describes the disruptions and the work done. The report is used national wide, but each municipality can make their own adjustments, the B1 report attached is adjusted for Trondheim Municipality.

As described in 6.2 Benchmarking project in Scandinavia, some of the statistical analysis did not describe the reality as the reporting of the work completed to the software was behind schedule. To improve the reporting of work completed on the network, a mobile digital updating information system could be implemented in the software. Here the operators could document the work by sending a description (in format compatible with the software) by SMS including a MMS picture or a drawing. This could be important information during the weekends, when only the operators are at work by on-call shifts. Also in the end, the municipality would probably prevent loss of information because of easier documentation, and less resources spend in the paper treadmill.

8.4 Data needed in AWARE-P compared to what is available in Gemini VA

Data processing of both CARE programs were estimated to be the total of 75% of the whole process. Only 25% of the time were used for calculation and modeling. This 75% have to be reduced. The biggest problem is the lack of data and inconsistent use and reporting of data (3). To see how the data needed in the AWARE-P project is compatible with the database of Gemini VA, the input data was taken out from Gemini VA by the use of data available in Trondheim municipality's database, the result is presented in below.

8.4.1. Risk Module

		Availability in Gemini VA			
Input data	**Type**	**Water**	**Wastewater**	**Combined**	
Identification of the component (unique in the tool)	COMPONENT	X	X	X	Pipe ID
sequential number that identifies each recorded failure (with no physical meaning)		X	X	X	Failure ID - Pipe ID
material of the component (unique in the tool)		X	X	X	Material - Pipe ID
Length of the pipe (unique in the tool)		X	X	X	Function - Depending on coordinates - Pipe ID
date of installation - **at least year** (unique in the tool)		X	X	X	Construction year - Pipe ID
number of service connections		X	X	X	Service connections, number
Number of customers connected to the pipe		?	?	?	Service connections – GAB – People registry
year of last inspection		X	X	X	Date - InspID - DiaryID - Pipe ID
Pipe condition code		X	X	X	K01 - DiaryDetail ID - Diary ID- Pipe ID
date of failure		X	X	X	Date - DiaryID - Pipe ID
type of failure		X	X	X	Failure code - DiaryID - PipeID
failure mechanism		X	X	X	Detail reason code - Diary DetailID - Diary ID- Pipe ID
shape of cross-section (unique in the tool)		-	X	X	Shape code - Pipe ID
size of cross-section (unique in the tool)		-	X	X	Size shape code - Pipe ID
invert level of upstream component (pipe) node		-	X	X	Node level - Node ID - Pipe ID (to from node)
invert level of downstream component (pipe) node		-	X	X	Node level - Node ID - Pipe ID (to from node)
User-defined for each dimension; these data come from regulations, regulators or are defined by the user.					
identification of the area/cluster	SYSTEM/ LUMPED	x	x	x	Make selection - Save selection - Run analysis on selection
total length of pipes in the area/cluster		x			as above
Average depth of the component (pipe)		-			
Average year of installation		x			as above
date of failure		x			as above
type of failure		x			as above
failure mechanism (cause)		x			as above
the user choose a risk matrix type (scale and risk levels)					

8.4.2 Structural links not included in Gemini VA

The wastewater node in AWARE-P is a manhole. Information on the manhole not included in Gemini VA is:

- Patrimonial code – direct link to pay system
- Search function for inlets in manholes (the pipes coming into it, density and type)

- Manhole cover type

For the municipality and registrations:

- Dimension of manhole, in Trondheim only 0,2% is registered.
- Physical condition, conservation status, non registered.

For the wastewater link, information missing in Gemini VA:

- Patrimonial code – direct link to the pay system
- Pipe roughness
- Pavement type (it's already linked to a street-ID)

For inspection data reports:

- An easier way to collect information from the reports and make statistics

For use in SWMM modeling:

- The information stored on the wastewater network is not sufficient to run a model in SWMM. The main problem is that the information is not provided by the municipality. Bad information to implement in SWMM model. Missing a lot of information.

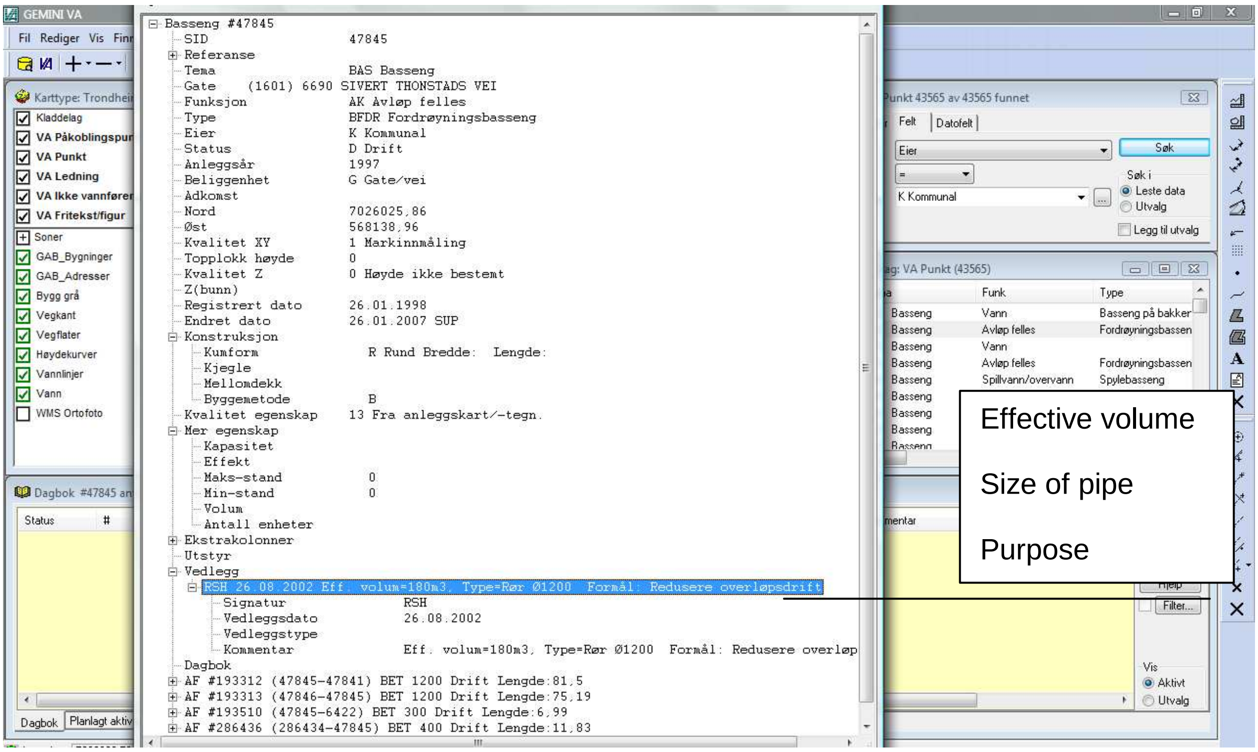


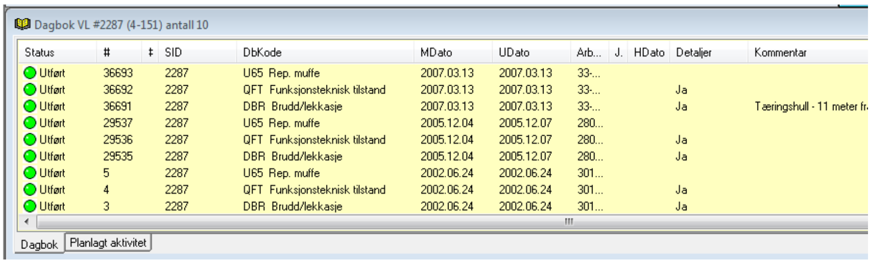
Figure 25: Example on information stored only as txt

This is a typical error in Gemini. Information on this drainage pool has a lot of valuable information stored in a text field that cannot be analyzed. The municipality should avoid storing important information in the "comment" field without saving it as a code. The text cannot be taken easily out statistically without a lot of work.

For the water node AWARE-P differs from the Norwegian system, as the project does not consider manholes for water. As for the pipes, the valves, pumps, and other objects that belong to the water network, are considered as links, like in EPANET. The water manholes in Norway is usually just a access point to the water network, and does not have the same role as in wastewater, but as Norway also have combined manholes, these must be considered in the performance and risk assessments.

8.4.3 Workorders and Diary information not included in Gemini VA

To calculate the efficiency and the amount of time spent on each work, the dates should be as specific as in hours. In Gemini VA the dates are given by dd.mm.yyyy as shown in Figure 26. When running analysis on the workorders, the minimum time difference is in hours.

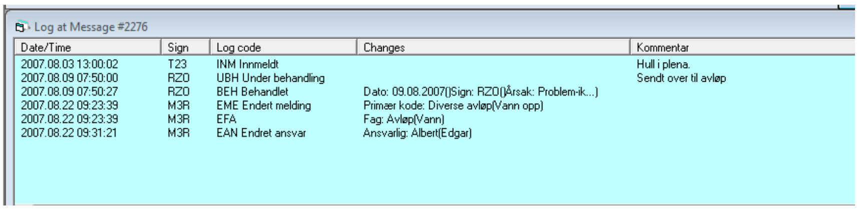

Dagbok VL #2287 (4-151) antall 10

Status	#	‡	SID	DbKode	MDato	UDato	Arb...	J.	HDato	Detaljer	Kommentar
Utført	36693		2287	U65 Rep. muffe	2007.03.13	2007.03.13	33-...				
Utført	36692		2287	QFT Funksjonsteknisk tilstand	2007.03.13	2007.03.13	33-...			Ja	
Utført	36691		2287	DBR Brudd/lekkasje	2007.03.13	2007.03.13	33-...			Ja	Tæringshull - 11 meter fr
Utført	29537		2287	U65 Rep. muffe	2005.12.04	2005.12.07	280...				
Utført	29536		2287	QFT Funksjonsteknisk tilstand	2005.12.04	2005.12.07	280...			Ja	
Utført	29535		2287	DBR Brudd/lekkasje	2005.12.04	2005.12.07	280...			Ja	
Utført	5		2287	U65 Rep. muffe	2002.06.24	2002.06.24	301...				
Utført	4		2287	QFT Funksjonsteknisk tilstand	2002.06.24	2002.06.24	301...			Ja	
Utført	3		2287	DBR Brudd/lekkasje	2002.06.24	2002.06.24	301...			Ja	

Dagbok | Planlagt aktivitet

Figure 26: A view from Gemini VA Diary

In Gemini Melding the date is more accurate (includes time), but the efficiency is difficult to calculated for the system, also Gemini Melding is not as good as Gemini VA to make statistics or search for defined objects.


Log at Message #2276

Date/Time	Sign	Log code	Changes	Kommentar
2007.08.03 13:00:02	T23	INM Innmeldt		Hull i plena.
2007.08.09 07:50:00	RZO	UBH Under behandling		Sendt over til avløp
2007.08.09 07:50:27	RZO	BEH Behandlet	Dato: 09.08.2007()Sign: RZO()Årsak: Problem-ik...)	
2007.08.22 09:23:39	M3R	EME Endert melding	Primær kode: Diverse avløp(Vann opp)	
2007.08.22 09:23:39	M3R	EFA	Fag: Avløp(Vann)	
2007.08.22 09:31:21	M3R	EAN Endret ansvar	Ansvarlig: Albert(Edgar)	

Figure 27: A view from Gemini Melding log

Gemini VA should include a function to calculate the failure growth rate based on material, year and dimension, to prevent time consuming analysis prior to a long term analysis.

8.4.4 Information localized on system and utility level not included in Gemini VA

A lot of information is missing in Gemini VA to include all information needed to run both the cost and the performance analysis in AWARE-P. In 9.1 ERSAR data , an overview is completed after going into the performance indicators given by the Portuguese regulator, ERSAR, and comparing them to what is available in Gemini VA.

8.5 Suggestion for setting up statistics in Gemini VA

To get an overview of the condition of the network, some easy statistics for the network can be made. For example:

- Length of pipe and distribution on installation year, dimension and pipe material. Unfortunately everything in Gemini VA must be copied to Excel, or another software, for further visualization. A better visualization tool would be favorable in Gemini.
- Failure rate depending on year of failure
- Failure and weights is summarized and condition classes calculated. In Gemini VA the classes should be from 1-4. Class 3 and 4 should be rehabilitated.
- Cost (budget or total capital value) in total for each of the last years, average age of network in years.

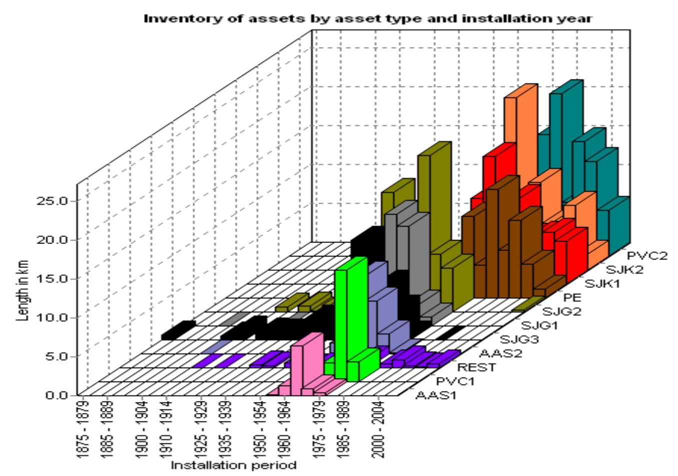
In Kristiansand there was taken out a prediction of the system. How it was done is described below (3).

<table>
<tr><th>What was done</th><th>Example</th></tr>
<tr><td>Grouping of pipe assets

Dividing all pipes into groups depending on material and diameter. Every group was given a number, a name and a material code</td><td>
<table>
<tr><th>Group number</th><th>Group name</th><th>Material code</th></tr>
<tr><td>1</td><td>AAS1</td><td>AAS up to 150 mm</td></tr>
<tr><td>2</td><td>AAS2</td><td>AAS > 150 mm</td></tr>
<tr><td>3</td><td>SJG1</td><td>SJG up to 100 mm</td></tr>
<tr><td>4</td><td>SJG2</td><td>SJG > 100 up to 150 mm</td></tr>
<tr><td>5</td><td>SJG3</td><td>SJG > 150 mm</td></tr>
<tr><td>6</td><td>SJK1</td><td>SJK up to 150 mm</td></tr>
<tr><td>7</td><td>SJK2</td><td>SJK > 150 mm</td></tr>
<tr><td>8</td><td>PVC1</td><td>PVC until 1980</td></tr>
<tr><td>9</td><td>PVC2</td><td>PVC after 1980</td></tr>
<tr><td>10</td><td>PE</td><td>PE pipes</td></tr>
<tr><td>11</td><td>REST</td><td>Unknown, MCU, MGA, MST, RDEL, REM, GUP og RSM</td></tr>
</table>
</td></tr>
<tr><td colspan="2">Length distribution depending on groups</td></tr>
<tr><td>Distribution of pipe classes per year

Length

Installation period

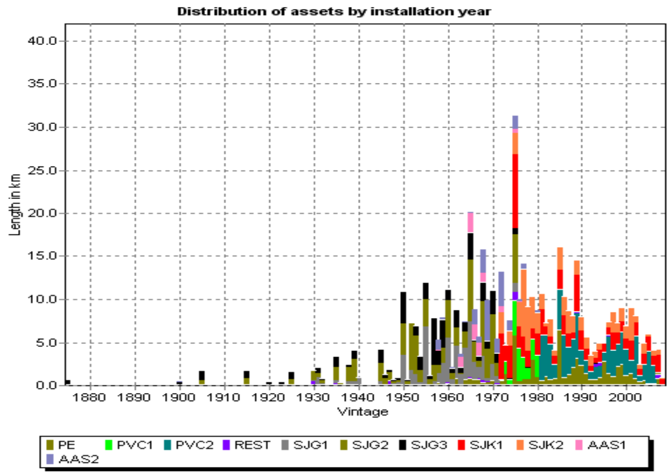
Material</td><td>
</td></tr>
</table>

Age distribution of groups

Length

Year

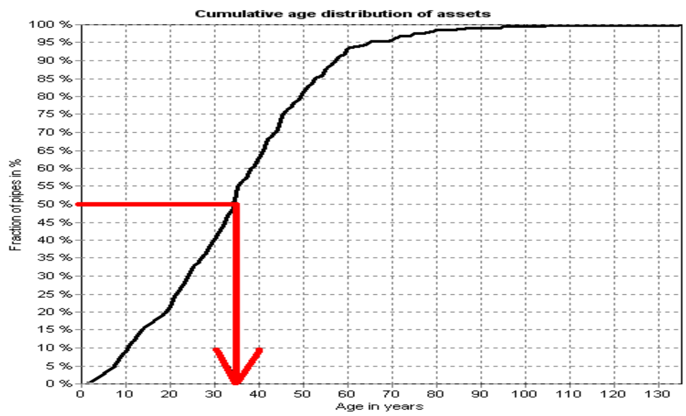
Material



Cumulative age distribution net

Graph showing the age distribution

steeper curve gives younger net



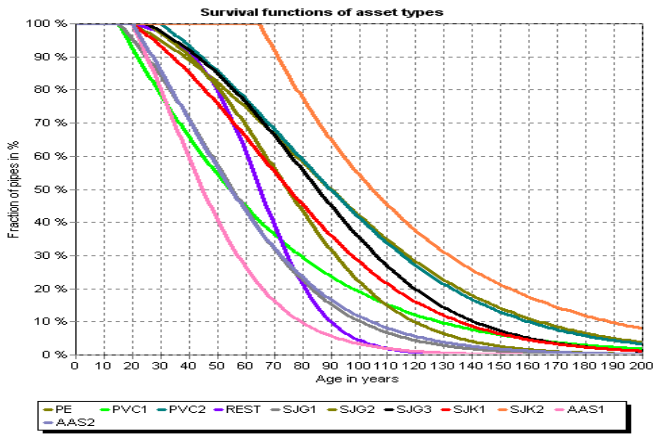
Estimation of service life giving the pessimistic and optimistic curve.

Dividing the system

Estimation of service life – pessimistic, optimistic, (years)

Group	100 %	50 %	10 %
PE	10-30	80-100	150-170
PVC1	10-20	50-60	120-140
PVC2	20-40	80-100	150-170
REST	10-30	60-70	80-100
SJG1	10-20	50-60	90-110
SJG2	20-30	70-80	110-130
SJG3	20-40	80-90	130-150
SJK1	20-30	70-80	120-150
SJK2	60-70	90-120	180-200
AAS1	15-25	40-50	70-90
AAS2	20-30	50-60	90-120

Example of survival curve



Renovation

In a table:
give 3 main renovation techniques,
divide in how big part of the network(in %) that is being renovated this way,
include the unit cost for each

a. Used here is No-dig rehab, Trench with W/WW pipes, Trench with single pipe

Method	***Part (%)***	***Unit cost [€/m]***
Rehabilitation No-dig	*10*	*300*
Excavation of trench, common	*60*	*400*
Excavation of trench, single pipe	*30*	*700*

Different graphical estimations:

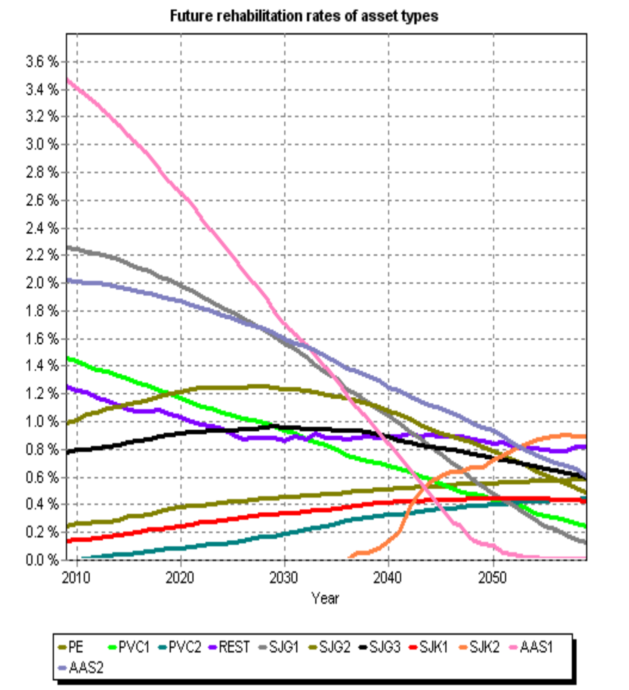


Figure 28: Rehab needs divided in classes. % of group length

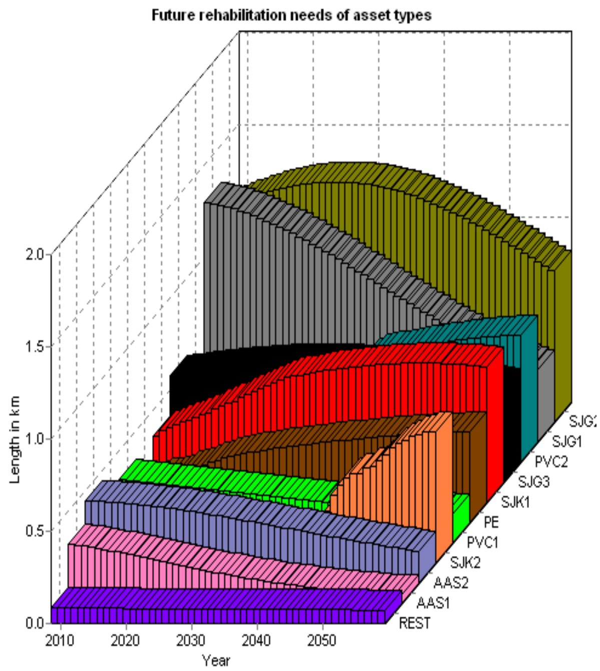


Figure 29: Group rehab need, km/yr

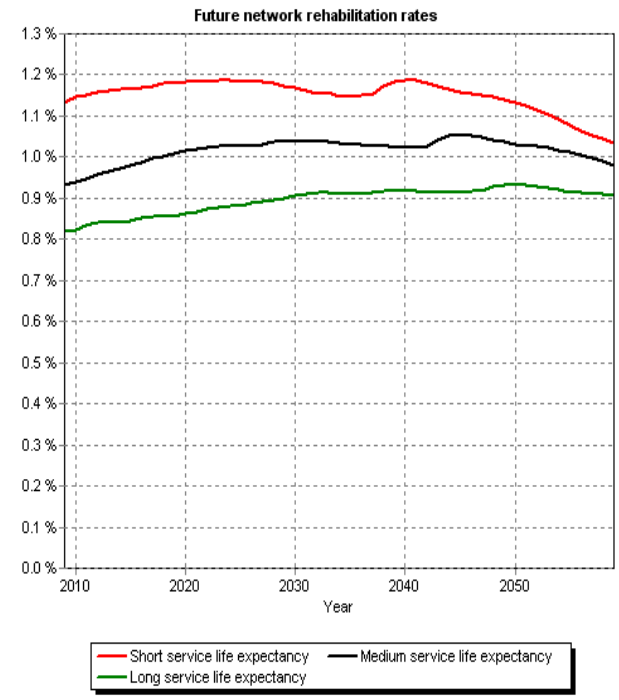


Figure 30: Future rehab need, % of total length

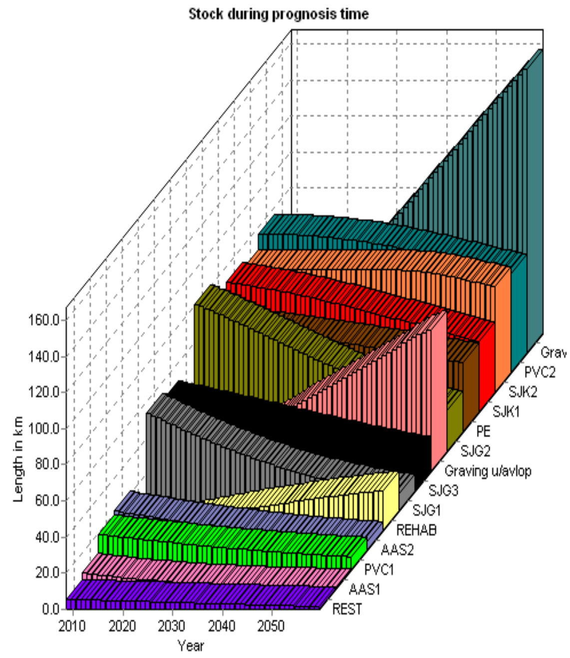


Figure 31: Future length of groups

Depending on materials to be used for rehabilitation (replacement, renovation)

9. Principles for establishing a database from scratch

Some municipalities, often the smallest ones, lack a great deal of information digitally. Often a lot of information is stored in the employees heads, and disappear with them. A problem can be where to start with what information, some municipalities might not even have a digitized map of their system.

9.1 ERSAR data specification

In AWARE-P there are 119 performance indicators/indices included from ERSAR. ERSAR is the regulator of Portugal, and gives guidance and rules to the utilities to follow. Since a lot of the water supply and wastewater system is privatized, it's important to follow up the companies to make sure the service is run for the best of the inhabitants. The PI's are in AWARE-P divided into main areas as environmental, financial, human resources, operational, physical and quality of service. Less than 25% of the given indicators, in total, are available in Gemini, among them are mostly operational, structural (length, material, etc.) or geographical (number of service connections, properties etc) data. The whole specification used by AWARE-P is available in Attachment 11.

When comparing these indicators for implementation in Gemini, it's possible to see how much of these performance indicators the Norwegian municipalities can use in the software of AWARE-P, and what they can do to improve their data collection.

To avoid spending unnecessary time doing reports manually, achieving easy performance reports can possible, and as automated as possible, if the right amount of data is collected and stored in a linked database. The right collection of data and the accuracy of the information of the data, will present a time and cost efficient solution. Out of 118 PI and UI's for both water and wastewater, 29 is possible to automate out from Gemini today. The main areas the Gemini databases lack information is on the areas of financial information, energy consumption and employee information. If connection to other databases of the municipality, such as within the financial department, the treatment facility's database and the billing system (includes energy consumption), the automotive collection might increase. Information from monitoring of pumping stations can make the database more complete. The ERSAR's indicators are converted to the way the Gemini database is structured is shown in Table 9.

Table 9: ERSAR PI system converted to Gemini structure

PERSONELL INFORMATION		ERSAR code	
nr; (No./100 km - year); (No./(10^6m3 - year); (No./1000 connections/year);	Employee ID Area: sewer/water Employee engagement: Full time; part time Job service: External (outsourced); internal Activity done: Operation, Maintenance, rehab Activity area: waste water, water	Aww073 Aww072 Aws063 Aws062	dAww104 dAww103 dAws084 dAws085
ENERGY AND POWER INFORMATION		**ERSAR code**	
kwh/yr; (kWh/hour.year); (kWh/(m3-100m); (kWh/m3/100m;	Energy link ID (area:pumps) Energy amount Consumption: average total, average peak hour, average annual Meter registration	Aww063 Aww072 Aws069 Aws061	dAww096 dAws082 dAws083
COST		**ERSAR code**	
(€); m3/yr; (€/year); (€/m3);	Cost Link ID (Water/wastewater) Cost / revenue Operating revenue Service	dAww085 dAws066 dAws073 dAws077	dAww087 Aws056 Aww057 Aww056

	Work in progress Cost of self constructed assets Operation & maintenance cost Volume of billed wastewater Internal manpower Average charge water supply Non-revenue Unit operation cost Operating income Running cost Consumption Exported water	Aws060	Aww055
		dAww086	Aws055
			Aws054
FACTORS		ERSAR code	
m3*m;	Standardisationfactor pumps volume of pumped m3 * head m period	dAww089	
PUMPING STATIONS		ERSAR code	
Nr;	Amount of emergency discharge Amount of non monitored discharges Type of recipient/ receiving environment: (sensitive, insensitive, recreation use, water activity use) Head Water pumped Volume	dAww011	dAww012
CUSTOMERS, PROPERTIES (32% of coverage in Gemini VA)		ERSAR code	
(€/year); Nr; %; (No./1000 connections/year); (No./ delivery point /year);	Income : average Connections:(House, area, property) Connections asset: (sewer system, septic, drainage, treatment, water) Service connections (water, wastewater) Available system: (Sewer, drainage, treatment) Service acceptable, y, n Operational service (y/n) Type of supply (distribution, bulk supply system,) Satisfactory wastewater handling (goes to treatment) Link to Cost of service (water; wastewater) Supply interruptions Number of house connected to each service connection	dAww059	Aws021
		dAww058	Aws022
		dAww057	Aww038
		dAww056	Aww037
		dAww048	Aww048
		dAww047	Aws048
		dAww034	Aww006
		dAww022	Aws029
		dAws038	Aws028
		dAws039	Aww040
		dAws040	Aww039
		dAws041	Aws041
		dAws042	Aws040
		dAws043	Aww040
		dAws015	Aww002
		dAws067	dAww081
		dAww001	Aww031
SLUDGE INFORMATION (8% of coverage in Gemini VA)		ERSAR code	
ton/yr; ton DS;	Dry weight Stored (at final destination,) Managed by: other utilities, undertaking Date in Date out Delivered to desired destiny Density Amount incoming from other systems/utilities		dAww079
		dAws126	dAww078
		dAws127	dAww077
		dAws128	dAww076
		dAws129	dAww075
		Aws101	dAww060
		Aww052	dAws125
TREATMENT (6% of coverage in Gemini VA)		ERSAR code	
m3; %; -/yr;	Water/wastewater Capacity Days below (lower acceptable level)% of capacity Days exceeds 95% Emergency discharge Exported water (raw water, treated water) Amount of water (w= out, Ww=in) Population equivalent served Requirements fulfilled (y/ n) Consumption Quality test (approved: Y/N) Wastewater reuse	dAws075	Aws003
		dAws076	dAww017
		dAww003	dAww016
		dAww004	dAww015
		Aww008	dAww012
		Aws005	dAws008
		Aww066	dAws009
		Aww060	dAws010
			dAws074
WASTEWATER (83% of coverage in Gemini VA)		ERSAR code	
Km;	Treated	Aww013	dAww049

yr; (No./100 km sewer/year); (%/year);	Rehabilitation date Length Service line, normal Year Collapse Rehabilitation	Aww030 	dAww046 dAww045 dAww019
STORMWATER		ERSAR code	
nr/yr; (No./1000 service connections/year); (No./100 km sewer/year);	Flooding on private properties, on roads, streets Source of flooding	Aww011 Aww009	dAww021 Aww012
WATER		ERSAR code	
m3/yr; km; (No./100 km/year); (%/year);	Amount from legal capitations year Valve failure Amount to supply system Rehabilitation Fitting failure Length Rehabilitation date Main failure	dAws070 Aws033 Aws051	dAws004 dAws005 dAws069
RESERVOIRS (67% of coverage in Gemini VA)		ERSAR code	
Days;	Volume Consumption		Aws008
DIARY INFO (29% of coverage in Gemini VA)		ERSAR code	
((No. Failures - No. Properties) / (delivery point - year); no/yr; no;	Supply interruptions (total, above an hour limit (6h), Water quality test carried out (on the network, on the TP, user tap)	dAws037 dAws049 Aws031	dAws029 dAws030 dAws036 dAws048
ASSET MANAGEMENT		ERSAR code	
Physical;	Index level	Aws044	Aww025

9.2 Establishing a database

Some water and wastewater networks are poorly digitalized and the long term planning is difficult to perform. Some municipalities doesn't even have the network digitalized, which make it even harder to collect and maintain the data at a good asset management level. When there's no data available in a municipality, the question is "how to start building a database". This chapter will suggest easy ways to complete a digital survey of the network from a paper based level.

Most municipalities maintain their digital network in a GIS system and have a separate workorder program. Linking these two might be time demanding and complicated. Using Gemini VA as a base for the infrastructure, establishing a database both for localization, structural information and operational information makes the overview easier.

9.2.1 Digitalizing the network

Digitalizing the network is a time demanding work as there are a lot of assets to be registered. To do a basic digitalization today, is not too much of an effort as there are many digitalization tools available at the market. Some of the GPS's available can give a accuracy down at 2,5 cm. Running over the network with a GPS, localizing the manholes from a air photo and link them together or digitalizing a paper map are all different ways to locate the network.

Norway, with the use of Gemini VA, differs from most countries for not having their water and wastewater network registered in a GIS software. All pipes are linked to a node with coordinates, so the system is Geo-referenced, but the GIS tools are not available. The important part of a water and wastewater system is that the utility can locate the network, where it is, what it consist of and how the condition of the system is. A GIS software is not necessary the ultimate solution to handle these areas.

On the strategic level, for future planning and rehabilitation, the most important issue is to know the condition, and to know how big of a part of the network is in the different conditions. This way the long term planning can be done regarding the financial needs and include this in the master plans. That means that all assets must be known and what condition they are in. Each utility usually have a person that knows the system very well, after gradually getting the map into the Gemini VA software, this person can point out where each asset are, going from asset to asset, through the data block function. With this function, all marked pipes, can be given the same value. Age is usually dependent on location and can be data blocked by housing areas, diameter is usually dependent on type of net (main, transmission, etc), material is usually dependent on construction year and diameter.

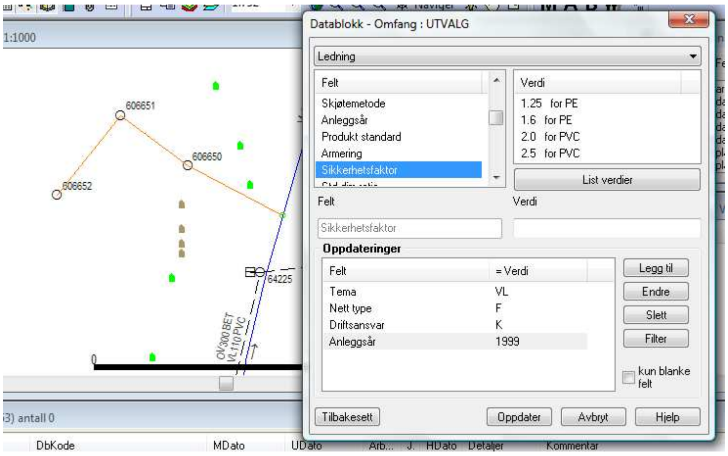


Figure 32: Example on data block function in Gemini VA

The data block can also be used on diary happenings, date of inspections, troubled pipe etc can be added easily. The problem with this type of registry is that the database will not be 100% consistent, and as mentioned earlier, it is better to have short term and consistent data.

On the tactical level, the most valuable information is the asset distribution and location. This way it's possible to manage and decide what kind of projects should be initiated and rank the different projects by importance. It's beneficial to know what the history of the pipes, to make the right decisions.

On the operational level they need to know detailed information of the assets, usually structural information, and where the location is.

9.2.2 Diary registrations

Important registrations to include in the network is breaks and inspections. Rehabilitation and condition is also important and should be included to the best possible degree. The diary recordings are often preserved and organized in ring binders organized by year in municipalities. If similar recording, this information can be scanned through an optical character recognition devise, sorted, and implemented in the database. When organized in a database such as Gemini, a factor should link the note to the pipe ID (street name, etc.). All information had to be run through a manual analysis, which is a very time consuming job. The information could possibly be used for statistical purposes.

9.2.3 Summary of base data input

Basic information should be:

- Location (for information on operational basis)
- Type of asset
- Structural information
    - construction year,
    - pipe material,
    - diameter
- Failure record (as consistent as possible)

10. Conclusion

Gemini VA provides several of the base data needed for rehabilitation planning. An Asset Management approach balance the risk, cost and performance assessments at the three planning levels: strategic; tactical; and operational, and Gemini VA can be used to a certain extent on all levels. Using the five core questions of the Asset Management framework, Gemini VA can be used as a tool to give information within the current state and the criticalities of the assets. Here, assets are defined as the key attributes of the water and wastewater network: pipes and manholes and the historical data linked to these. Other assets such as buildings, machinery, equipment, and other tools do not have the same amount of data available, and information on the operators is excluded.

Analysis on critical assets can be done by evaluating the structural function of each pipe as all occurrences in the network (breaks, leaks, burst, cleaning, etc) is linked to each pipe ID. Some pipes are also valued with technical functional score. This is shown in Figure 33.

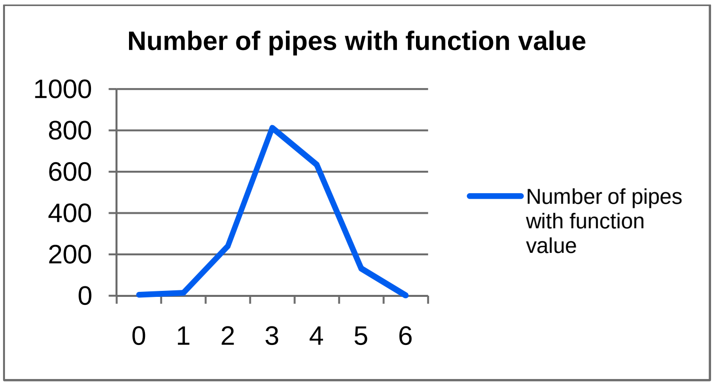


Figure 33: Number of pipes registered with a function value

Risk factor for damage is also available, and this is registered as low, high or not evaluated. The function in Gemini VA to convert the network into .inp files which can be used to evaluate the hydraulic performance, is valuable as bottlenecks and other hydraulic deficiencies can be discovered. No function of reporting the result of hydraulic analysis back to the pipe ID is available. The HCI could be included in the pipe description, and a script to do a datablock on the specified pipes should be available. This feature would enable the user to run analysis giving pipes with low hydraulic and low condition score, and would be a useful tool for planning purposes.

Information on important customers or areas with critical service in the network is not included as input data. In wastewater it is possible to include information given on extra additives to the wastewater, but no information, such as hospitals or high demand buildings, is included in water supply.

Data indicating power use or hours in service of pumping stations are not available in Gemini VA. An extract from the live data could be included as a diary report, as this information is interesting for other assets of the network as well, such as treatment facilities, water tanks, booster stations, etc. Other live data such as hours and amount in overflow and peak demand at the water treatment plant could also be included to get historical data easy accessible. With all the focus on environment and power use today, statistics towards

"ENØK" (energy efficiency) for the whole system, should be included, since a goal at the strategic level in AM could be to reduce the power use in the utility.

By the use of Gemini Melding, the area "level of service" can be estimated and evalued. If the interaction between the utility and the customers is good (if all customers complaints if they are not satisfied), the total number of complaints can represent the utility's goal on the strategic level on customer satisfaction. Other examples on how to use the information in Gemini Melding are the number of complaints in one area, time from receiving a complaint until the problem is taken care of, etc. Gemini Melding can be linked to the GAB database, as is Gemini VA, this way a script can be made to link the two together to use priorities.

To carry out a life cycle cost assessment cannot be completed by the use of the data from Gemini VA today. A minimum life cycle cost assessment or a long-term funding strategy will not be accurate unless the cost can be directly linked to the work done, on each asset. Gemini should therefore implement a unit cost at the unit asset level (on the pipe or node ID). It's important not to take too many variables into account when analyzing the network. This will result in too many variables getting mired in complexity at the expense of effectiveness. It's important to think strategically, on how cost effective it is for the utility. To implement good asset management, it's important to know where to spend the right money to achieve the best results. When collecting data, it's important that the meaning of the parameter is true, parameters used in the system should be related to a standard, e.g. an ISO system of data collections. When every parameter is decided, it's easier to make statistics, and at the same time, ensuring that the statistics are reliable.

In Gemini VA, the service connection are included in the map, but the municipality doesn't register any information on these, because they are private property of the customer. This represents a field of error for the failure statistics as the service connections usually represent the assets with a higher failure rate than the rest of the network. To make the best possible failure prediction, all recordings should be recorded.

For municipalities lacking historical information, it would be effective to collect data nationally, to give the possibility to collect general failure statistics. Since Gemini is used by a big number of municipalities, a national registry of errors, failure rates, blockages, life expectancies, etc, be feasible. Descriptive and explanatory manuals on Asset Management, data collections, and rehabilitation planning, should also be available, preferable available from Norwegian authorities.

Gemini VA is a software mainly used for operation and maintenance, and it is not an Asset Management tool. Asset Management is also an approach and not a software, but Gemini VA can be a tool for easy supplying data and statistics for future predictions of the network. The rehabilitation strategies are very important as these influence both the future performance of the network and are a big part of the long term cost prediction.

The cost of collecting data vs. what you make on collecting them is the most important part of the data management. By validating Trondheim municipality's data, the consistency is good, but here is also a lot of information not collected. A registration with error is not easy discovered, and Gemini VA should implement several validation functions for different assessments such as historical, structural and input data. Analysis and statistics done in the software are dependent on the data consistency of the municipality. A general summary of topics Gemini VA should include to be a good data providing tool for Asset Management, is listed in table 10.

Table 10: Summary of improvements in Gemini VA

DATABASE	COLUMN	EXAMPLES	
STRUCTURAL DATA	Reliability	HCI input	
	Patrimonial code	current book value of assets	
	Treatment plant info	Sludge, connections, amount	
	Pumping stations		
		Overflow (event + frequency)	
		CSO input	To make the software compatible with SWMM. Risk areas for sewer flooding.
	Pipe roughness		
	End of service year		
	Critical delivery points	Hospital, areas with big demand	
DIARY	Overflow	Event and frequency, damage	
	Patrimonial code	Cost of investment for specific rehab methods, Cost of water losses, repair cost of breaks	unit repair cost, unit inspection cost, unit cleaning cost, unit construction cost of manholes etc.
	Water quality	Water samples from network	
	Power use, energy efficiency	Peak hours	
DIARY DETAIL	Leakage reports	Leakage control data	
HMS	Health and protection		
	Human resources		
REPORTS	Validation of structural data	Length≠0, Node≠0	
	Validation of historical data (diary)		
	Failure rate	Individually	(by material, age, dimension)
	Statistics with graphical information	Condition, breaks, combination of score from inspections, modeling and breaks, etc	User defined statistics, where user mark the data collection to be used in the statistics, a graphical view of the combined data is shown directly.
	Pre analysis module to LTP		
	Condition assessment	Automatic generated and highlighted in the map	
	Network analysis	Number of CSO, Number of drinking water samples gathered (and quality)	
REGISTRATIONS BY MUNICIPALITY	Pumping stations		
	Risk	Available in software but not used by Trondheim	
	Condition registry on all assets		
GUIDES	Links to internet or better information in the software	Wiki-page	

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Attachments

1. Total overview Care-W

activity	belonging set id	depth of installation	length (a,o,p)	sector applicability
aq_availability	br poisson	description	level	Sensitive customer
aq_frequency	failnet stat	desired pressure	log id	set id
arp	break type	desiredhead	maintenance type	start date
arp_annual repair costs	carew material	detail date	material	start year
arp_annual unit cost of rehab	annual unit cost of rehabilitiation	diameter	max flow rate	status
arp_co-ordination score	annual unit cost of repair	discrete name	max pressure	street,road,locality
arp criterias	co-ordination score	discrete type	max waterlevel	subgroup
arp_damage caused by traffic	expected durarion of repair	display map	minor loss coefficient	tail node name
arp_damage of infrastructure	intensity factor	ei_ui_pi_code	min pressure	tank diameter
arp_damage owing to flooding in housing areas	parallel infrastructure factor	el	min supply pressure	tank volume
arp_damage owing to flooding in industrial areas	risk of landslide	emitter flow	min tank volume	target maximum (default)
arp_damage owing to soil movement	rrt	end date	min waterlevel	target minimum (default)
arp_hs_annual repair costs	sensitivity of housingareas due to flooding	end year	mttr	text
arp_hs_annual unit cost of rehab	sensitivity of industrial areas due to flooding	event id	name	to year
arp_hs_co-ordination score	street category factor	existing asset type	network applicability	traffic in street
arp_hs_criterias	vulnerable values in housingareas factor	external lining	node id	ttr95
arp_hs_damage caused by traffic	vulnerable values in industrial areas factor	failure (a,o,p)	node name	type
arp_hs_damage of infrastructure	waterlosses index	failure date	node type	type of repair
arp_hs_damage owing to flooding in housing areas	waterquality deficiencies index	ff belonging set id	number of people supplied	type of soil
arp_hs_damage owing to flooding in industrial areas	cat length	file name	number of service connections	unit
arp_hs_damage owing to soil movement	cause of failure	file spec	objective	user id
arp_hs_hydraulic criticality index	cluster applicability	file version	official code	value
arp_hs_predicted critical water interruption	code	flow	official processing rule	variables
arp_hs_predicted frequency of water interruption	comment	fr poisson	(a,o,p) {10%, 100%, 50%}	version
arp_hs_predicted water interruption	concept	fr failnet stats	pattern	vertex count
arp_hs_water losses index	confidence factors	from year	pattern code	vertex id
arp_hs_water quality deficiency index	corrosivity	group	pavement	visit
arp_hydraulic criticality index	cost - average, optimistic, pessimistic (a,o,p)	head	percentage replacement	vol curve id
arp_predicted critical water interruption	costing category	head node name	pessimistic10	water level
arp_predicted frequency of water interruption	costing material	hr aquarel	pessimistic100	window type
arp_predicted water interruption	creation date	hr failnet reliab	pessimistic50	x (max,min)
arp_status	criterion1 - 5	hr relnet	pipefailureid	y (max,min)
arp_water losses index	crown depth	hr belonging set id	pipeid	year
arp_water quality deficiency index	data type	id	pipetype	year laid
arp project name	date of cement mortar lining	id_dataset	probability in service	z
asset description	date of epoxy lining	importance	prognosis name	rsd category
asset type	date of rehabilitation	index	project name	rsd key
average working pressure	date of sliplining	internal code	replacement asset type	ruler ow
backfill	date abandoned replaced	internal processing rule	roughness of the pipe (colebrook formula)	savings (a,o,p)
background maps	date of repair	internal lining	roughness of the pipe (hazen-williamsk formula)	rehab year
band colour	default label	iwa code	legend title	rehab method
band id	demand	joint type	length	rehab rate (a,o,p)
band limit	layer name	label	last edit date	rehab cost
bedding type				

2. Total overview Care-S

24hour mean dwf (m3/s)	ds_invert level (m)	Loss of trade	Pipe layer to colour code	Surcharge level (m)
Code a -e	ds_node_id	noise	Pipe order	Surface
activity	duration	pollution of ground water	Pipe static id	Surface sealing
Analysis type	dust allowed (y/n)	road traffic disturbance	Pipe type	Surface water type
Area type affected	ei_ui_pi_code	service interuption	pit damage allowed (y/n)	System type
Arp project name	End date	id	planning horizon	target max, min
Asset type	Event id	id_dataset	predicted condition grade	Technology id
average basement level above pipe (m)	exfiltration rate class		Predicted probability of collapse	Techonolgy order
Average water consumption	Failing overflow	Impervious urban area	Predicted probability of structural failure	temperature (c)
back water valves (y/n)	failure prediction	Incident date	Prediction year	Traffic flow(/day)
Background maps	Ff belonging set id	Incident type	presence of difficult soil	Transition matrix roughness
Base flow (cu m)	File date stamp	inflow (cu m)	presence of hard rock	trench depth (m)
basements exist (y/n)	File name	inhabitants	Pressure class	trench width (m)
Belonging set id	File version	Inspection date	priority pipes file name	Unit
bod (mg/l)	Filling material	Inspection file id	Priority for condition inspection	us_invert level (m)
bod (strength)	First node grid reference	Installation year	probabilityof reaching water level 2&3	us_node_id
Catchment id	First node reference	internal code	project unit cost (€/m)	Use of receiving water
Catchment name	First rainfall event which causes flooding upstream	internal processing rule	Project name	user
Catchment type	Flooding volume (m3)	Internal corrosion risk	propertyconnections	value
cause	Flow capacity(m3/s)	interuption of work (y/n)	Property count	variables
Cctv id	Flow file date stamp	iwa code	Protection zone	version
City	Flow file name	Joint type	pu length (m)	Vertex count
cluster applicability		Land use	Public transport	Vertex id
cod (mg/l)	Gis pipe label displayed	Last edit date	reinstatment of surface	volume of cracks (m3/m)
cod (strength)	Gis pipe label field	length (m)	Resultset id	Vulnerability (several)
comment	Gis set label displayed	level	Risk	Wall thickness (mm)
concept	Gis set polygon displayed	Line number	road type	width (mm)
Config and plant layout	ground water impact allowed (y/n)	link_suffix	Roughness type	Window type
cost(euro)	ground water type	Log id	Score	working space available (y/n)
Creation date	Ground level (m)	Long term	Sdr	Ww tp (y/n)
Critical level (expressed as ratio to diameter)	groundwater level class	manentry (y/n)	sealing required (y/n)	X (min, max)
cso (y/n)	Groundwater level (m)	Manhole energy loss (m)	Second node grid reference	Y (min, max)
current 24 hour exfiltration volume (m3)	Group	material	Second node reference	Year start month
current 24hour infiltration volume (m3)	Hci	max time for possible interuption (h)	sector applicability	Zone layer to colour code
current blockage factor	Heavy traffic(y/n)	max time for rehab (days)	service connections cut of possible (y/n)	Wall thickness (mm)
current chemical corrosion rate (mm/y)	height (mm)	Max wwt pinflow (cu m)	Setid	width (mm)
current condition grade	Hrbelonging set id	Medium term	Sewer id	street
current endangered zone	hydraulic reliability	min temperature at rehab time (c)	shape	structural rehab (y/n)
current environment probability	Hydraulic catchment area	Modell id	slope	subgroup
Current external corrosion rate (mm/y)	Hydraulic model	name	Soil id(runoff)	permeability class
Current hydraulic probability	Hydraulic results id	network applicability	Soil type	Pipe failure id
Current operational probability	Hydraulic set id	Night or day (n/d)	spill duration (h)	Pipe id
Current risk for groundwater on soil type		Node grid reference	spill frequency (per year)	waste water overdropping on street
Current roughness	intangible damage to population	Node id	Spill volume (m3)	dust
Current trend for exfiltration	material damaage and loss of trade	Node name	Start date	loss of trade
Dataset id	road traffic distrubance	Node reference	Start year of analysis	dewatering
Data type	odurs rodents insects	Node type	Storm duration	dig/trenth allowed (y/n)
Date of survey	polution of groundwater	noise allowed (y/n)	Storm frequency	Display background maps
Date stamp	polution of receiving waters by overflow	Number of lanes	Storm id	Straight curved
density of non residents	service interruption	objective	Storm name	strategic
description	soil depression	official code	Original hydraulic modell id	
Detail date	waste water overdropping in basement	official processing rule		

3. Data Available in Gemini on Sewer link

AWARE-P INPUT SEWER PIPE	GEMINI COVERAGE, TRONDHEIM MUNICIPALITY [GIVEN IN NUMBERS NOT LENGTH]
IDENTIFICATION CODE	100%
PATRIMONIAL CODE	n/a
UTILITY DESIGNATION	-
SYSTEM DESIGNATION	-
SUBSYSTEM DESIGNATION	-
NODE ID	100% 99,9% right coordinates
INSTALATION DATE	99,8%
PHYSICAL CONDITION (CONSERVATION STATUS)	0 55 % 1 16 % 2 21 % 3 6 % 4 2 %
OBSERVATIONS	28,4% of the pipes are registred with observations
PIPE HEIGHT	44,5% of pipes has a /fallretning/
SHAPE OF CROSS-SECTION*	2,1% of all pipes with stormwater
SIZE OF CROSS-SECTION**	61,1%
PIPE LENGTH	99,9% (5 pipes = 0; 23 pipes < 1m)
PIPE DIAMETER	99,7%
PIPE MATERIAL	99,1%
PIPE ROUGHNESS	n/a
PIPE SHAPE	2%
PIPE VERTICAL DIMENSION	79% out of pipes marked with a shape different than sircular. (98% of pipes are not marked with shape)
PIPE REINFORCEMENT	82%
PAVEMENT TYPE	*n/a* *99,3% is registred with street code*
SOIL TYPE	93,2% ground material soil. 14,4% ditch filling material.

*Only pipes with stormwater are important for this. Water and pure wastewater are not included in the statistics.

**Only pipes with already registered other shape than sircular

4. Data Available in Gemini on Sewer node

AWARE-P INPUT SEWER NODE	GEMINI COVERAGE, TRONDHEIM MUNICIPALITY
IDENTIFICATION CODE	100% registred
PATRIMONIAL CODE	N/A
NODE COORDINATE X	100% registered
NODE COORDINATE Y	100% registsered
UTILITY DESIGNATION	-
SYSTEM DESIGNATION	-
SUBSYSTEM DESIGNATION	-
INSTALLATION DATE, CONSTRUCTION YEAR	98,6% registered
PHYSICAL CONDITION (CONSERVATION STATUS)	-
ELEVATION OF MANHOLE COVER	21,6% registered
ELEVATION OF MANHOLE INVERT	35,5% to the bottom of manhole {pkt z(bunn)} are registered
OBSERVATIONS	[597 out of 24086] 2,5%
TYPE OF JOINTS	-
TYPE OF INLETS	All inlets in manhole included.
DENSITY OF INLETS	All inlets in manhole included.
MATERIAL	96,8% registered
DIAMETER	0,2% registered
MANHOLE COVER TYPE	N/A

5. Data Available in Gemini on Water link

Identification code	**Y**
Patrimonial code	N
Utility designation	-
System designation	-
Subsystem designation	-
NODE ID UPSTREAM	Y
NODE ID DOWNSTREAM	Y
Measuring controlling zone	96,2%
Installation year	96,2%
Average installation year	As above
Physical condition (conservation status)	N
Observations	36,2% of the pipes are registered with an observation
Pipe length	100% (2 pipes L=0; 387 pipes L<1m)
Pipe diameter	98%
Pipe material	99,3%
Pipe pressure class	2,5% for PIPE,
Pipe roughness	Not available
Type of link	100% (main, transfer, etc)
Density of service connections (<= 1")	Not dependent on diameter: 99,96% registered of net. 0,01 pr tot. length 0,02 pr main length.
Average Length of service connections (<=1")	Not dependent on diameter: 18,7 m
Density of service connections (>1")	Same as above – 84% (length) and 87% (number) of the service connections are not registered with diameter (private property).
Average Length of service connections (>1")	Same as above
Demand type	Not applicable
Type of joints	91,1% are registered
Pipe ringstiffness (GEMINI)	1 pipe. 0%
Pipe protection external (GEMINI)	28,3%
Pipe protection internal (GEMINI)	19,8%
Pipe safety factor (GEMINI)	2 pipes has SF=2, rest SF=0.
Measuring controlling zone (GEMINI)	97% SYSTEM(trykksone)
Pavement type (GEMINI)	N/A. 95,9 % has registered street code.
HISTORY (GEMINI)	2,8% of the pipes has registered history
Product standard (GEMINI)	1,8%

6. Workorder registration, Diary registration Gemini

Intervention work identification	YES
Date of initiated work	YES – should also be hours - reported
Date of realized/ended work	YES – should also be hours - completed
Date of comunication	YES – should also be hours. Gemini Melding has hours.
Type workorder	YES, divided in codes, as shown in the table below. All numbers are on all pipes (including historical pipes).

CODE	WATERLINK	WWLINK	Manhole*
NO REGISTERED DATA	33 %	28 %	96 %
DAN, Other	0 %	1 %	0 %
DBR, Break/ Leakage	23 %	0 %	0 %
DLT, Unknown code, rehabilitation	0 %	-	-
DST, Blocking	0 %	4 %	-
K01, Unknown code, not specified	-	0 %	-
K02, Unknown code, not specified	-	0 %	-
K03, Unknow code, Advice to rehab pipe	0 %	-	-
QA3, Unknown code, not specified	0 %	-	-
QA4, Unknown code, not specified	0 %	-	-
QA5, Unknown code, not specified	0 %	-	-
QFT, Fuctional technical condition	8 %	0 %	-
QIN, Analyzis pipe inspection	-	6 %	-
QKO, Unknown code, replacement	0 %	-	-
R31, Inspection	0 %	-	-
R32, Pipe inspection	-	0 %	-
R41, Cleaning, flushing	-	0 %	-
R46, Root removal	-	0 %	-
R61, Repair, maintenance	0 %	-	-
R64, Unknown code, not specified	-	-	1 %
R72, Renovation	0 %	0 %	-
R76, Replacement	1 %	0 %	-
R77, Unknown code, Replacement.	-	0 %	0 %
U31, Inspection	0 %	0 %	-
U32, Pipe inspection	0 %	29 %	-
U33, Leak search	1 %	0 %	-
U34, corrosion survey	0 %	0 %	-
U40, Desinfection	0 %	-	-
U41, Cleaning, flushing	16 %	30 %	0 %
U42, High pressure flushing	-	0 %	-
U44, Plug flushing	6 %	0 %	-
U45, Cleaning – other methods	0 %	-	-
U46, Removal of roots	-	0 %	0 %
U61, Repair, maintenance	1 %	0 %	0 %
U62, Unknown code. Replacement of cones, firevalve.	0 %	-	0 %
U64, Repaired joint with corrosion protection	0 %	-	0 %

<table>
<tr><td></td><td>
<table>
<tr><td>U65, Repair of joint</td><td>6 %</td><td>-</td><td>-</td></tr>
<tr><td>U71, Renovation</td><td>1 %</td><td>1 %</td><td>0 %</td></tr>
<tr><td>U72, Unknown Code, Leakage</td><td>0 %</td><td>-</td><td>-</td></tr>
<tr><td>U73, Unknown Code, dovre</td><td>-</td><td>-</td><td>0 %</td></tr>
<tr><td>U74, Unit replacement</td><td>1 %</td><td>0 %</td><td>0 %</td></tr>
<tr><td>U75, Replacement, /omlegging/</td><td>1 %</td><td>0 %</td><td>0 %</td></tr>
<tr><td>U76, Unknown Code, Replacement</td><td>0 %</td><td>0 %</td><td>1 %</td></tr>
<tr><td>U77, Unknown code</td><td>-</td><td>-</td><td>0 %</td></tr>
<tr><td>U78, Unknown Code</td><td>-</td><td>-</td><td>0 %</td></tr>
<tr><td>U79, Unknown code</td><td>0 %</td><td>-</td><td>0 %</td></tr>
<tr><td>U81, Pipes for new areas</td><td>0 %</td><td>-</td><td></td></tr>
<tr><td>U88, Unknown Code: not specified.</td><td>-</td><td>-</td><td>0 %</td></tr>
<tr><td>U89, Unknown Code: not specified.</td><td>-</td><td>-</td><td>0 %</td></tr>
<tr><td>U91, Function change/modification</td><td>-</td><td>0 %</td><td>-</td></tr>
</table>
*Theme=manhole, Type≠not in net
0% is registered on a few objects. 0% is <1%.</td></tr>
<tr><td>Type of work realized</td><td>Yes. Registered in Gemini Melding.</td></tr>
<tr><td>Cause of intervention work</td><td>Yes. Registered in Gemini Melding.</td></tr>
<tr><td>Cleaning Method</td><td>YES. U41, U42, U44, U45. Only the general U41 is used, though TK usually use plug flush.</td></tr>
<tr><td>Year of last inspection</td><td>YES, U32.
28% of WW, SW pipes are registered with a last inspection date, these are divided as shown in table below.
Sort: [tema≠VL, eier≠P, status=D, tema≠TV]
<table>
<tr><th>Combined Sewer Channel</th><th>0,20%</th></tr>
<tr><td>Combined Sewer pipe</td><td>45,07%</td></tr>
<tr><td>Combined Sewer Pressurized Pipe</td><td>0,07%</td></tr>
<tr><td>Drainage</td><td>0,04%</td></tr>
<tr><td>Overflow pipe</td><td>0,77%</td></tr>
<tr><td>Stormwater pipe</td><td>24,15%</td></tr>
<tr><td>Stormwater, channel</td><td>0,03%</td></tr>
<tr><td>Wastewater pipe</td><td>29,58%</td></tr>
<tr><td>Wastewater, Pressurized pipe</td><td>0,08%</td></tr>
</table></td></tr>
<tr><td>Failure ID</td><td>YES</td></tr>
<tr><td>Failure date</td><td>SAME AS REPORTED DATE</td></tr>
<tr><td>Type of failure</td><td>YES</td></tr>
<tr><td>Failure mechanism</td><td>As above.</td></tr>
<tr><td>Belonging L_ID/N_ID</td><td>YES</td></tr>
<tr><td>Signature</td><td>YES</td></tr>
<tr><td>Planned WO</td><td>YES</td></tr>
<tr><td>Status – completed, not completed, history</td><td>YES</td></tr>
<tr><td>Pipe failure</td><td>YES</td></tr>
<tr><td>Failure (burst) rate per unit length</td><td>61 registered breaks on 754844 meters of waterpipe</td></tr>
<tr><td>Growth of failure (burst) rate</td><td>YES. Very demanding calculations in excel.
1,15 in average since 1988. (VL in operation) (number of burst independent on length of network)</td></tr>
</table>

	3,47 in average since 1988 (WW in operation) (number of bursts independent on length of network)**
Collapses rate	Not differed from Burst (VL)
Blocages rate	YES 1,07 in average since 1988. (≠VL in operation) (number of blockages, not dependent on length of network)
Growth of collapses rate	NO
Growth of blockages rate	NO
PipeFailureID*	YES
UserReference*	YES
CreationDate*	YES
LastEditDate*	YES
EventID*	YES
FailureDate*	YES
MaintenanceType*	
X*	YES
Y*	YES
CauseOf Failure*	YES
Visit*	
confidence factor*	
Type of Repair*	YES
DateOf repair*	YES

* = CARE

**= In 2004 the failures increased with 55 times, this influences the rate.

7. Coding errors in Gemini V A

Error Codes	Pipe ID	Error
R64	12874	Invalid code. Registred in 3 november 1992 construction year 1952
R77	6429	Invalid code. The diary has an attachment which sais that the manhole is replaced at the same date as the code R77 was put in, manhole from 1868 is replaced with new manhole with construction year 1991
U62	7 nodes	1993. Details: T92 poor construction 1992. Comment: Cones replaced 1994. Details: T020 wide trench and T72 Wrong gradient 1992. No detailed information 1992. Comment: Cones replaced 1988. DBR (break/leakage) are given at the same date 1994. Details: B12 other, T020 wide trench
U73	2 nodes	1988. Comment: Replacement of cone 1996. Comment: Dovre
U77	28 nodes	1991 Details: Raise manhole 1988 Details: New manhole T-pipe with 3 locks 4". 1993 Details B12 Other and T020 wide trench 1989 Comment: Replacement of manhole crossings 1996 Comment: Manhole from 1873 replaced, etc.
U78	19934	Comment: New hydraulics in manhole
U79	15 nodes	1993: Comment: replacement of firevalve 1994. DBR (break, leakage same date. 1994. The same date reported on DBR code. 1994. The same date reported on DBR code. 1993. Replacement of fire vent. 1994. Details B14 Blockage and watersupply interruption 1993. Replacement of fire valve 1989 Replacement of fire valve, etc.
U88	1241	invalid code, DBR (break, leakages) registered at same date
U89	21085	Invalid code. No date, just year (1993)

8. ERSAR dataspecification

available in gemini or not	Comments regarding Gemini				
Y	Few data given on hours of interruptions	dAws030	Supply interruptions	Number of supply interruptions with more than 6 hours	(No./year)
Y		Aws021	Supply interruptions	Weighted average of supply interruptions per delivery point	(No./ delivery point /year)
Y	Interruptions is linked to pipe, not house.	Aws022	Supply interruptions	Number of households afected by supply interruptions per 1000 service connections	(No./1000 connections /year)
Y*	Number of service connections vs number for customers.	Aws028	Physical acess to the service	Percentage of households located in the undertaking intervention area for which the bulk supply system is built and operational	(%)
Y*		Aws029	Physical acess to the service	Percentage of households located in the undertaking intervention area for which the water distribution system is available	(%)
Y		Aws033	Mains failures	(Number of mains failures during the assessment period (including failures of valves and fittings) x 365 / assessment period) / total mains length x 100	(No./100 km/year)
Y*	Not much bulk supply in Norway	Aws040	Deficit in water system connections	Percentage of the total number of households located in the intervention area for which the bulk supply infrastructure is built and operational, but have no effective service	(%)
Y*	If registered as a problem in the diary	Aws041	Deficit in water system connections	Percentage of the total number of households located in the intervention area for which the water distribution infrastructure is built and operational, but have no effective service (by lack of service connection or lack of contract).	(%)
Y		Aws051	Mains rehabilitation	Anual average percentage of supply and distribution pipes with more that 10 years that have been rehabilitated in the last five years	(%/year)
Y	Number of serviceconnections to the wastewater network. Divide the result in owner.	Aww002	Compliance with the discharge legal parameters	population equivalent that is served by wastewater treatment plants complying with discharge consents / population equivalent served by wastewater treatment plants managed by the undertaking x 100, at the reference date	(%)
Y		Aww013	Sewer colapses	(Number of sewer collapses during the assessment period x 365 / assessment period) / total sewer length at the reference date x 102	(No./100 km sewer/year)
Y		Aww030	Sewer rehabilitation	Average anual percentage of sewer pipes older than 10 years that have been rehabilitated during the last 5 years	(%/year)
Y		dAws015	Service connections	Total number of service connections, at the reference date.	(No.)
Y		dAws029	Supply interruptions	Sum, for all delivery points, of the product between the number of failures in the delivery points with more than 6 hours and the number of properties depending on it.	((No. Failures - No. Properties) / (delivery point - year)
Y*	Link taxinformation on personal security number, to owner of house to service connection.	dAws067	Average income per household	Average available income per household in the systems intervention area.	(€/year)
Y		dAws069	Rehabilitated water pipes in the last 5 years	Length of water pipes older than 10 years that were rehabilitated in the last 5 years	(km)
Y		dAws070	Average pipe length	1/5 of the sum of water supply and distribution pipes (service connections are not included) older than 10 years	(km)

Y		dAww019	Total sewer length	Total length of sewers managed by the undertaking at the reference date.	(Km)
Y		dAww022	Sewer conections	Total number of service connections at the reference date.	(No.)
Y*	Number of service connections	dAww034	Connected properties	Number of properties connected to the sewer system managed by the undertaking, at the reference date.	(No.)
Y		dAww045	Rehabilitated sewer pipes in the last 5 years	Length of sewer pipes older than 10 years that were rehabilitated in the last 5 years	(Km/year)
Y		dAww046	Average sewer length	1/5 of the sum of sewer length older than 10 years, for the last 5 years.	(Km)
Y		dAww056	Connected properties	Number of properties located in the area that is the responsibility of the undertaking having the contracted transport and treatment service built, in operation and connected to the service	(No.)
Y		dAww059	Existing properties	Total number of properties located in the undertaking intervention area that manages the the sewage systems	(No.)
M	Number of GAB to service connections	dAws038	Properties with efective service	Number of properties located in the undertaking intervention area for which the supply network infrastuctures are buil, operational and in service	(No.)
Y*	Number of service connections	dAws039	Properties with efective service	Number of properties supplied by the public water service network	(No.)
M		dAws040	Properties with available non-efective service	Number of properties located in the undertaking intervention area where the water supply infrastructure networks predicted in contract are buil and operational, and for which there is not an water distribution system available or is not connected.	(No.)
M	Calculate the number of properties connected to an area where work is being done.	dAws041	Properties with available non-efective service	Number of properties located in the undertaking intervention area where the water supply infrastructure networks predicted in contract are buil and operational, but are not connected to the water public network (buy nonexistence of service connections or contract)	(No.)
M	Calculate the number of properties connected to an area where work is being done.	dAws042	Existing properties	Number of existing properties in the water service undertaking intervention area	(No.)
M	Calculate the number of properties connected to an area where work is being done.	dAws043	Existing properties	Number of existing properties in the water service undertaking intervention area	(No.)
N	TP information	Aws003	Compliance with abstraction allowances	Percentage of the volume of water abstracted which comply with legal or contractual allowance requirements	(%)
N	TP information	Aws005	Treatment capacity adequacy	Percentage of treatment capacity used in adequate design conditions during the assessment period	(%)
N	Information on point. Whole numbers. Important both for model and this.	Aws008	Treated water storage capacity	Total capacity of treated water reservoirs (private storage tanks excluded) / system input volume during the assessment period x assessment period	(days)
N	Tests on the network should be included as diary.	Aws031	Water quality	Percentage of the required water tests that comply with the applicable standards or legislation	(%)
N/A	-	Aws044	Infrastructure asset management index	This index is determined by the acumulation of the following points refering to classes A, B and C, being able to vary between 0 and 100: A - Existence of a network plant (in paper or GIS); B - Information registered oabout the network elements; C - Information registered relative to network interventions	(-)

N		Aws048	Service affordability	Medium charge weight with the water supply system in the average disposable income per household in the area of system intervention.	(%)
N	TP	Aws054	Unit running costs	Ratio between the the anual adjusted operational costs and the sum of the volumes of raw and treated exported water	(€/m3)
N	Meters and billingsystem merged will give answer	Aws055	Unit running costs	Ratio between the the anual adjusted operational costs and the authorised consumption (including exported water)	(€/m3)
N		Aws056	Operating cost coverage ratio	Ratio between the operational adjusted revenues and the unit operational costs	(-)
N		Aws060	Non-revenue water by volume	Non-revenue water / system input volume, during the assessment period x 100	(%)
N		Aws061	Use of energy in peak power hour	Ratio between the hour average electrical energy consumption in peak hours and the average annual energy consumption, in pumping stations.	(-)
N		Aws062	Human resources	Number of full time equivalent employees of the water undertaking / (water produced during the assessment period x 365 / assessment period) x 106	(No./10^6 m3/year)
N		Aws063	Human resources	Number of full time equivalent employees of the water undertaking / number of service connections x 1000	(No./1000 connections /year)
N		Aws069	Standardised energy consumption	Energy consumption for pumping during the assessment period / Sum of the volume elevated during the assessment period multiplied by the pump head /100)	(kWh/m3/100m)
N	TP	Aws101	WTP sludge disposal	Percentage of sludge from WTP adequately disposed	(%)
N	Number of readings in overflow database	Aww006	Satisfactory discharges of wastewater		(%)
N	TP	Aww008	Treatment capacity adequacy	Percentage of treatment capacity used in adequate design conditions during the assessment period	(%)
N	Number of readings in overflow database	Aww009	Flooding from sanitary sewers	(Number of flooding incidents related to sanitary sewers during the assessment period x 365 / assessment period) / total sewer length at the reference date x 100	(No./100 km sewer/year)
N	Number of readings in overflow database	Aww011	Flooding	Number of floodings in public streets and properties with source in the sewer public network / 100km of sewer length	(No./100 km sewer/year)
N	Number of readings in overflow database	Aww012	Flooding	Number of floodings in public streets and properties with source in the sewer public network / 1000 service connections	(No./1000 service connections /year)
N/A	-	Aww025	Index level for infrasructure asset managemen t		
N		Aww031	Sewer systems without WWTP	Percentage of properties located in the area that is the responsibility of the undertaking where the collection system is available and in service but not connected to any treatment instalation	(%)
N		Aww037	Service physical accessibility	Percentage of properties located in the area that is the responsibility of the undertaking having the contracted transport and treatment service built and in operation	(%)
N		Aww038	Service physical accessibility	Percentage of properties located in the area that is the responsibility of the undertaking having the contracted collection and treatment service built and in operation	(%)
N		Aww039	Deficit in sewer system connections	Percentage of properties located in the area that is the responsibility of the undertaking having the contracted transport and treatment service built and in operation but are not actually connected to the service	(%)

N		Aww040	Deficit in sewer system connections	Percentage of properties located in the area that is the responsibility of the undertaking having the contracted collection and treatment service built and in operation but are not actually connected to the service (nonexistence of service connection or lack of contract)	(%)
N		Aww048	Service Affordability	Average weight expenditure to the management of wastewater services in the average disposable income per family within the intervention area	(%)
N	TP	Aww052	WWTP sludge disposal	Percentage of sludge from WWTP adequately disposed	(%)
N	TP	Aww055	Unit operational costs	Ratio between anual adjusted operational costs and anual volume of collected wastewater	(€/m3)
N		Aww056	Unit operational costs	Ratio between anual adjusted operational costs and anual volume of billed wastewater	(€/m3)
N		Aww057	Operating costs coverage	Racio between adjusted operating income and adjusted running costs	(-)
N		Aww060	Wastewater reuse	Volume of reused treated wastewater / volume of wastewater treated by the undertaking x 100, during the assessment period	(%)
N		Aww063	Energy efficiency in pump stations	Average standard energy consumption in pumping stations	(kWh/(m3-100m)
N		Aww066	Wastewater quality tests carried out	(Total number of tests carried out during the assessment period x 365 / assessment period) / total number of tests required by applicable standards or legislation during the assessment period	(-/year)
N		Aww072	Human resources	Number of full time equivalent employees working on wastewater services management per unit of the volume of collected wastewater	(No./(10^6m3 - year)
N		Aww073	Human resources	Number of full time equivalent employees wroking on sewer system management per 100km of pipe length	(No./100 km - year)
N	TP information	dAws004	Water collected from legal captations	Volume of collected water from legal captations that complies with the respective legal requirements	(m3/year)
N		dAws005	Abstracted water	Volume of water collected for the supply system	(m3/year)
N		dAws008	Over use of treatment plants	Sum of the treatment capacity, for all treatment plants, corresponding to the days for which the diary treatment flow ir over 90% of the treatment capacity, trough the whole year of analysis.	(m3)
N		dAws009	Underutilization of treatment plants	Sum of the treatment capacity, for all the treatment plants,corresponding to the days on which the diary treattment flow is lower to Ɵ% of the treatement capacity, trough the whole year of analysis.	(m3)
N		dAws010	Total treatment capacity of treatment plants	Instaled treatment capacity in all treatment plants trough the whole year of analysis	(m3)
N		dAws036	Required treated water quality tests carried out	Number of treated water tests carried out during the assessment period that are required by applicable standards or legislation. Or D47 + D48 + D49 + D50	(No.)
N		dAws037	Water quality tests required	Number of treated water tests required by applicable standards or legislation during the assessment period. Or water tests required by applicable standards or legislation during the assessment period. Or D58 + D59 + D60 + D61	(No.)

N		dAws048	Treated water quality tests carried out	Number of treated water tests carried out during the assessment period. Or D53 + D54 + D55 + D56	(No.)
N		dAws049	Compliance with the water analyses	Number of analyses done to the water, collected from the users tap, in case of distribution systems, and on delivery points for supply systems.	(No./year)
N		dAws066	Average charge for the water service suply	Medium annual charge value for the supplied water relative to the consumption of 120m3 of water by household in the intervention area of the system, based on the approved fare	(€/year)
N		dAws073	Running costs	Total operations and maintenance net costs and internal manpower net costs (i.e. not including the capitalised cost of self constructed assets) during the assessment period, regarding the water supply service.	(€)
N	Treatment facility information.	dAws074	Exported raw water	Total volume of raw water transferred to other water undertaking or to another system from the same supply area during the assessment period.	(m3)
N	Treatment facility information.	dAws075	Exported treated water	Total volume of treated water exported to other water undertaking or to another system from the same supply area during the assessment period.	(m3)
N	Link to metered information	dAws076	Authorised consumption	Total volume of metered and/or non-metered water that, during the assessment period, is taken by registered customers, by the water supplier itself, or by others who are implicitly or explicitly authorised to do so by the water supplier, for residential, commercial, industrial or public purposes. It includes water exported. Or A10 + A13	(m3)
N		dAws077	Total revenues	Total operating revenues minus capitalised costs of self-constructed assets, regarding the water supply service, during the assessment period. Or G2 - G35	(€)
N		dAws082	Average energy consumption in peak power hour	Average hourly consumption of electric energy in pumping stations, trough the peak hours of the tariff.	(kWh/hour. year)
N		dAws083	Average energy consumption for pumping	Average hourly consumption of electric energy in pumping stations	(kWh/(hour .year)
N	Employee information	dAws084	Personnel afected to water supply service	Number of total equivalent of employees at full time in the water undertaking afected to the water supply system	(No.)
N	Employee information	dAws085	Outsorcing water system personnel	Number of full time equivalent personnel allocated to external services related to the current activities in a continuity perspective.	(No.)
N	Treatment facility information.?	dAws125	Sludge with proper destiny	Dry weight of sludge handled by the WTP to proper destiny	(ton/year)
N	Treatment facility information.	dAws126	Initial stored sludge	Dry weight of stored sludge in treatment facilities at the begining of the year	(ton/year)
N	Treatment facility information.	dAws127	Produced sludge in the system	Dry weight sludge producted in the system	(ton/year)
N	Treatment facility information.	dAws128	Sludge from other systems	Dry weight of sludge from systems managed by other utilities	(ton/year)
N	Treatment facility information.	dAws129	Final stored sludge	Dry weight of stored sludge in the system facilities at the end of the year (31st of December), they should be properly packed, so avoid any polution into the environment ou negative impacts within the surrounding population	(ton/year)

N	TP information	dAww001	Population equivalent with satisfactory wastewater treatment	Population equivalent that is served by wastewater treatment plants complying with discharge consents at the reference date.	(p.e.)
N	TP information	dAww003	Population equivalent served by WWTP	Population equivalent served by wastewater treatment plants managed by the undertaking, at the reference date.	(p.e.)
N	TP information	dAww004	Population equivalent with satisfactory treatment (expired permit discharge)	Sum between the population equivalent, dAR14i, which is served with WWTP ensuring the expired permit discharge, for which as been made anatemped renovation request and mantains the compliance with the legal discharge parameters from the previous license, calculated the same way as dAR13ab.	(p.e.)
N		dAww010	Dischargers with poorly functioning	Number of emergency discharges, from pumping stations and treatment facilities, that have discharge monitoring and where the annual frequency of discharge to normal operation, is more than: 30 per year in case the receiving environment is is not sensitive; 10 per year in case the receiving environment is not sentitive but can be used for public recreation or contains public walk crossing areas; 6 per year in case the reveivng environment is sensitive and 3 per year in case the receiving environment is used for water activities	(No.)
N		dAww011	Non monitored discharges	Number of emergency discharges in pumping stations	(No.)
N		dAww012	Discharges	Number of emergency discharges located in pumping stations and treatment facilities	(No.)
N	TP information	dAww015	Over-utilization of treatment facilities	Sum for of all treatment facilities, of the installed treatment capacity corresponding to the days for which the daily treatment flows exceeds 95% of the installed capacity, during the assessment period.	(m3)
N	TP information	dAww016	Under-utilization of treatment facilities	Sum for of all treatment facilities, of the installed treatment capacity corresponding to the days for which the daily treatment flows are below Ɵ% of the installed capacity, during the assessment period.	(m3)
N	TP information	dAww017	Total capacity of treatment facilities	Sum of the instaled reatment capacities in every WWTP for the total assessment period	(m3)
N		dAww021	Flooding	Number of floodings that occured in private properties or public roads, with origin in the public sewer system.	(No./year)
N		dAww047	Properties with sewer system available without treatment	Number of properties located in the surrounding intervention area of the undertaking, for which the drainage networks are available and operational, but there is no wastewater treatment.	(No.)
N		dAww048	Properties with sewer system available	Number of properties located in the surrounding intervention area of the undertaking, for which drainage and treament systems are available and operational	(No.)
N	TP information	dAww049	Wastewater treated	Wastewater treated by wastewater treatment plants or by on site system facilities that are the responsibility of the wastewater undertaking, during the assessment period. Or wA2 = wA3 + wA5 + wA7 + wA9 + wA11	(m3)
N		dAww057	Properties without efective service	Number of properties located in the area that is the responsibility of the undertaking having the contracted transport and treatment service built, in operation and are not connected to the service	(No.)

N		dAww058	Properties with available but non-efective service	Number of properties located in the area where the colllecting, transport and treatment services are built and in operation but are not connected to the service	(No.)
N		dAww060	Properties with available sewage system but without and effective service	Number of properties located in the undertaking intervention area for which the public networks are available and operational, but have no effective service (by non existing service connections or non existing contract)	(No.)
N	TP information	dAww075	Sludge with proper destiny	Dry weight of sludge handled by the WWTP to proper destiny	(ton/year)
N	TP information	dAww076	Initial stored sludge	Dry weight of stored sludge in facilities since the beggining of the year (1January)	(ton/year)
N	TP information	dAww077	Sludge produced in WWTP	Dry weight of sludge produced in wastewater treatment plants managed by the undertaking during the assessment period.	(ton DS)
N	TP information	dAww078	Sludge from other systems	Dry weight of sludge from systems managed by other utilities	(ton/year)
N	TP information	dAww079	Final stored sludge	Dry weight of stored sludge in the system facilities at the end of the year (31st of December), they should be properly packed, so avoid any polution into the environment ou negative impacts within the surrounding population	(ton/year)
M		dAww081	Average disposable income per family	Average disposable income per family in the surrounding area of the utilities intervention calculated by …	(€/year)
N		dAww085	Running costs	Total operation and maintenance costs and internal manpower costs, excluding the capitalised costs of self-constructed assets, regarding the wastewater service, during the assessment period. Or wG6 = wG8 + wG9	(€)
N		dAww086	Billed wastewater	Wastewater volume which if billed to the users. For the utilities that manage sewer systems this value corresponds to the value of the volume of supplies charged to end users who also have the service of wastewater.	(m3/year)
N		dAww087	Total operating revenues	Total operating revenues, including service revenues (wG3), work in progress, capitalised costs of self-constructed assets (wG33) and other operating revenues, regarding the wastewater service, during the assessment period.	(€)
N		dAww089	Standardisation factor	Sum, for all the pumps of the system, of D2(i), D2(i) being: D2(i) = V(i) x h(i), where V is the total volume (m3) pumped by pump i during the assessment period and h(i) is the pump head (m).	(m3 x m)
N		dAww096	Pumping energy consumption	Total energy consumed in pumpin water facilities (excluding the particular pumping systems)	(kWh/year)
N		dAww103	Sewer system personnel	Number of full time equivalent employees working on sewer system at the reference date.	(No.)
N		dAww104	Outsorcing sewer system personnel	Number of full time equivalent employees assigned to external services related to the corrent activitie in a continuity perspective for sewer systems management.	(No.)

Y-yes, N-no, M-maybe, N/A-Not available

CCTV data

CCTV ID	Connected to NODES. Not searchable by itself.
Pipe ID / Node ID	YES
Inspection distance	YES
Inspection code	YES
Inspection rank	YES
Inspection type	YES
Inspection photo	YES
Inspection video	YES
Inspection text	YES
Inspection date	YES
Inspection Status	YES
Signature	YES
Weather	YES
Damage score/ score	YES
Inspection vertical point	NO
Direction of the location	YES
Method	-
Cleaned	YES
Type of location	YES
Name of employing authority,	ON INSPECTION SHEET
Name of town, village, district or sewer system,	LINKED TO THE NODE, MEANING YES
land ownership,	-
Original coding system (where older data is converted)	-
Name of inspector	YES
Job reference	YES
Purpose of inspection	NO
Cross section	LINKED TO NODE, MEANING YES
Lining details	YES
Pipe unit length	YES
Type of drain or sewer	YES
Type of effluent	YES
year of construction	YES
temperature	NO, BUT WEATHER
flow control measures	NO
Material	PIPE INFORMATION, YES
FileName	YES
FileDateStamp	YES

9. SWMM data

Descriptive information	Availabilty in Gemini
Precipitation	No
Channel characteristics	N
imperviousness	N
slope	Y
roughness	N
width (a shape factor)	N
Depression storage	N
Infiltration parameter	N
Coordinates_Subcatchment	Y
rain gauge (rainfall hyetograph)	N
Outlet	Y, coordinates
Area	N, but coordinates, can be calculated in other programs. But nowhere to put in at the drainage node.
Width	N
Slope (%)	N
Percent imperviouisness	N
Roughness	N
Infiltration parameter	N
Coordinates_ Pipe	Y
inflow	N
invert (bottom) elevation	27% of the manholes are registered with depth
maximum depth	N
Inlet node	See table above
Outlet node	See table above
shape (eg circular)	Y, see table above
maximum depth (diameter for sircular pipes)	Y, see table above
length	Y, see table above
roughness (mannings coefficient)	N
Offset	N
Time	Alternative information, not input
Temperature	No
Evaporation	No
Windspeed	No
Snow melt	No
Transects	No
Controls	No
Pollutants	YES. Additativ available, but 0% registered.
Curves (control, diversion, pump, rating, shape, storage, tidal)	Not available. Drawing are implemented as attachment.
Time (series and pattern)	NO.
Junctions	YES.
Nodes(manholes): [coordinates, inflow, invert (bottom)elevation, max depth]	
Outfalls	Yes
Dividers	No.
Storage units	Yes.
Conduits: [inlet node, outlet node, shape (e.g. circular), max depth (diameter for circular pipes), length, roughness (mannings coefficient),	Yes

offset.	
Pumps	Yes, but not satisfyingly
Orifices	Geographic placement, yes.
Weirs	YES, but should be improved
Outlets	Geographic placement.
Land use	No
Hydrology: [precipitation, channel characteristics, whatershed characteristics (imperviousness, slope, roughness, width (a shape factor), depression storage, infiltration parameters(horton or green-ampt))]	No
Rain gages	No
Subcatchments: [Coordinates, rain gauge (rainfall hyetograph), outlet, area, width, slope(%), percent imperviousness, roughtness, infiltration parameters]	No
Aquifers	No
Snow packs	No
Unit hydrograph	No
area depletion	No
NODE ID	Yes
LINK ID	Yes