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TITLE

Ageing of Water and wastewater networks
International status and responding strategies

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ABSTRACT

The Scandinavian water works associations Svenskt Vatten (Sweden) and NORVAR (Norway) are exploring experiences related to the ageing of drinking water and wastewater networks. This information will be used by Swedish and Norwegian municipalities in the long term resource allocation for rehabilitation of water and wastewater pipelines and for the decision support to rehabilitation plans.

The report deals with the following main questions in a European (World) setting:

- What is failure rate and rehab rate for cities in Europe/world?
- What are the strategies applied for practical rehab planning?
- Does national publications and guidelines exist that can support rehab planning?
- What kind of software tools is applied for rehab planning, and what kind of input do they require?

The information is collected by a specially designed questionnaire, a general literature survey, the review of relevant papers from international conferences, direct contacts and interviews with colleagues representing main countries of Europe and also abroad.

The general condition measured as failure rates show large variations among cities and is due to construction practises, pipe material quality and level of operation and maintenance. Analysis of condition requires performance data which very often is not available in an appropriate format. *The application of standards for information about water and wastewater networks should therefore have the highest attention*. Several software systems have been developed to support rehabilitation planning. Some of them are dealing with specific problems, water loss management, prediction of failures, but some have a general approach to support the selection and ranking of project as well as long-term needs. These should be applied to enhance the value of information collected.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Network	Ledningsnett
GROUP 2	Rehabilitation	Rehabilitering
SELECTED BY AUTHOR	Water	Vann
	Wastewater	Avløp
	International review	Internasjonal kartlegging

PREFACE

This report presents the results of a project initiated by Svensk Vatten (Swedish organisation of water companies) and NORVAR (Norwegian organisation of water companies) with the aim to create an understanding of international state of the art on water and sewer network rehabilitation. It includes as well strategies (long-term planning) tactics (project selecting and ranking) and technologies (repair and renovation methods). This overview should serve as an input to national projects meant to support local water companies in their water and wastewater network management.

Originally it was planned to base the report on results from a broad questionnaire. This was developed and distributed to contacts worldwide. However, the feedback was meagre, only three countries, namely Hungary, Italy and Netherlands (drinking water only) gave significant information back. Therefore the information received by the questionnaire was supplemented by a literature review. The amount of literature relevant to ageing water networks is tremendous, and it has been necessary to select just a small amount to provide a “taste of the art” on water and wastewater network rehabilitation outside Scandinavia

A reference group has followed the projects. It had the following members:

Trond Andersen, NORVAR
Hands Bäckman, Svenskt Vatten
Ivar Kalland, Bergen kommune
Kjell Kihlberg Borås kommune.

The work has been conducted by Sveinung Sægrov, SINTEF Byggforsk supported by Jon Røstum, SINTEF and Rita Ugarelli, Bologna university,

Dora Laky, Budapest university, Gabriele Freni, Palermo University, Rita Ugarelli, Bologna university and Miriam Blokker, KIWA has given valuable support by filling in questionnaire from users in their respective countries, while Annie Vanrenterghem Raven, New York Polytechnic University, Ingo Kropp, Dresden and Eliane Algaard, Veolia London have provided important information, points of view and literature on the topic.

Trondheim, June 2007
Sveinung Sægrov

TABLE OF CONTENTS

Summary

Scope

This report comprises a discussion of some basic questions for management of water distribution and wastewater collection systems, namely:

1. What is current condition and rehab frequency?
2. Which strategies are applied for practical rehabilitation planning, and what is needed input information for this?
3. Which technologies are applied?
4. Which decision support is applied?
   - Software tools?
   - National guidelines?
   - Publications on rehab planning performance

Originally it was planned to base the report on results from a broad questionnaire. This was developed and distributed to contacts worldwide. However, the feedback was meagre, only three countries, namely Hungary, Italy and Netherlands (drinking water only) gave significant information back. Therefore the information received by the questionnaire was supplemented by a literature review.

The report deals with the technical issues, focussed on networks materials and main networks. Main challenges here are reduction of water leakages, which stands for a significant percentage of the produced water for supply. The provision of a stable water quality is another important issue. On the wastewater side local floods and cracking foundation of city roads due to erosion around water pipes are reasons of concern. The report gives some examples of data showing condition internationally and ways to meet the challenge that urban water networks approach.

Current condition and rehab frequency

Leakage

Statistics on water losses show large variations. Typical national values differ from 10-30%, some cities reporting even higher leakages. Best practise seems to be in the order of 5% For example city of Las Vegas, situated in the desert with scarce water resources report 4% leakage. In Europe, Berlin that also have limited water resources, reports an unbilled volume below 5%.

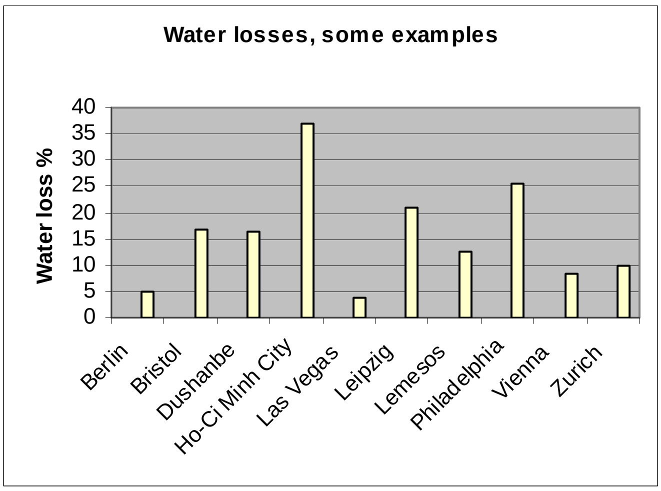

Figure 1 Water losses in some cities world wide

According to IWA Specialist Group on Efficient Operation and Management, presentation of water losses as percentage may not always give the right picture of the real situation. An infrastructure leakage index (ILI) is therefore proposed as the relationship between current annual real losses and unavoidable annual leakage losses. ILI values typically vary from 1-7 in developed countries, while for example African Water Systems have ILI from 1 to 35. Free software is available for water balance calculations (Liemberger et al 2007).

Burst frequencies: The structural integrity of water mains is often quantified as the number of breaks pr 100 km and year. Burst frequencies of water distribution networks are analysed by recent literature supported by the questionnaires. Some results are presented in table 1.

Table 1 Burst frequencies, results form some investigations

<table>
<tr><th>City/area</th><th>Bursts pr 100 km/year</th><th>Reference</th><th>Comment</th></tr>
<tr><td>32 European cities</td><td>58</td><td>Alegre (2002)</td><td>Includes pipes, alves, fittings, service connections</td></tr>
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<tr><td>Bristol</td><td>17</td></tr>
<tr><td>Leipzig</td><td>93</td></tr>
<tr><td>Lisbon</td><td>48</td></tr>
<tr><td>Zurich</td><td>24</td></tr>
</table>

These results show that conditions are different, depending on network age, materials used and intensity of maintenance and rehabilitation. They demonstrate that best management practice may reduce the failure frequency to less than 10 pr 100 km/year. Whereas there is an increase in break frequency in winter time in North Europe and Canada, the opposite is the fact in south Europe, i.e Italy. It is assumed that temperature is the main reason for the situation in North and the increase of pressure because citizens are leaving cities during summer months is the main reason for the Italian situation.

Pipe materials and age

There are large variations regarding the use of and experiences with pipe materials. The older parts of networks in cities world-wide consist of grey cast iron, steel and asbestos cement pipes and modern part of ductile iron, PVC and PE. In general, an old network creates more failures and repair needs. However this is not consequent. In some countries, e.g. Netherlands, a major part of the networks are old, but they do not have correspondingly high failure rates. In Italy, high failure rates are documented on modern pipes (e.g. PE). There are local reasons for this, such as non-appropriate material quality during the first years of use of a new material, operation and maintenance practises.

Failure frequency has also been reported from Canada (Rajani 1993) and UK (MacKellar and Pearson, 2003). A summary is given in Figure 3. The UK figures are from the national official statistics for the period 1998-2003. The Canadian report brings results from an inventory in 21 cities representing 11% of Canada’s population. The main conclusion is that materials representing old pipes have a higher burst rate than younger pipes.

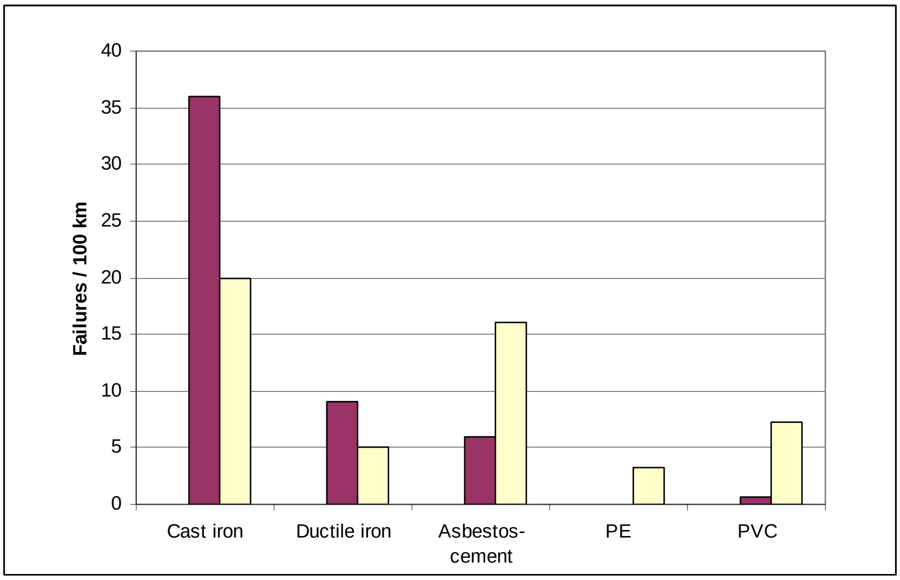

Figure 2 Failures related to pipe materials, reports from Canada (Rajani 1993, dark) and UK (MacKellar and Pearson, 2003, light)

Whereas about 1/3 of the networks in average are older than 30 years in Sweden and Norway, the situation is opposite in other major European countries. Italy, for example, 60% of water and wastewater networks are older than 30 years. The challenge on maintenance and rehabilitation, therefore, is even higher in many countries outside Scandinavia.

<u>Distribution network rehabilitation</u>
The European benchmark study in 2002 (Alegre 2002) included mains rehabilitation of 25 cities. The mean value of the results collected were 0.91% of mains rehabilitated. 50% of the cities have a rehab rate in the range between 0.25 and 1.3. The Techneau study in 2006 (Sægrov, 2006) gave some results from four European cities, namely Berlin 0.9%, Leipzig 0.9 % Bristol 0.3%, Zurich 1.9%. It seems like a yearly rehabilitation rate of about 1% of total mains length is an average value. However, there are large variations depending on local situation, and many countries practise a modest rehabilitation of existing networks.

<u>Wastewater collection systems</u>
The project questionnaire also included repairs/100 km for sewer network, with results varying from 14 to 211. The results can give an indication that sewer problems are not less than for water mains, but is in general too scarce to make solid results. Wastewater networks are normally controlled by CCTV inspection. Until recent years this method was used to check if problems exist, however, CCTV inspections are now being used more systematically for rehabilitation planning. Recently new commercial products form f ex IBAK and WINCAN have been applied for storing CCTV data. Earlier data can often not be tracked due to missing storing standards.

Strategies applied for rehab planning
An overall strategy for rehab planning may comprise three levels; strategic, tactical and technological. The <u>strategic</u> planning takes place on a “network level” and incorporates level of service, overall condition, needs for rehabilitation and corresponding financial needs. The strategic planning will support master plans. The <u>tactical</u> plan refers to the single pipes and deals with ranking of rehabilitation projects. It supports the rehabilitation plan. The <u>technological</u> level deals with the selection of adequate technologies for specific projects. Results from literature and questionnaires are analysed in context of this three-level approach

Strategic planning, level of service.
Level of service is discussed in different contexts, and some examples will be given here. In Europe, level of service is developed as targets given by national regulators or other practises, for example OFWAT in UK and IRAR in Portugal. In Italy, the 1994 directive “principi sull’erogazione dei servizi pubblici”, defined rules to be followed by municipalities while providing the service to customers.

Several cities all over Europe apply performance indicator systems developed by international projects, for example IWA, CARE-W and CARE-S. These systems comprise several indicators that measure service level, for example number of complaints and interruptions.

Asset management plans are made for many cities world-wide. For example in Wellington, New Zealand, an AM plan covering the 10-year planning period includes four general service goals (EPA year unknown):

- Safeguard public health and environment
- Provide a network with a level of reliability that meets the customer and regulatory needs
- Ensure the network has sufficient capacity to serve all customers
- Improvement of the quality of capital investment strategies.

The project questionnaire asked for drivers for rehabilitation. They were mainly structural condition, water losses, water quality, reliable service and coordination with other service. For wastewater networks “water quality” was replaced by flooding and pollution. These drivers also reflect criteria for service level. The corresponding financial needs are sometimes analysed by methods addressing the life cycle of groups or clusters of pipes, aggregated to system level (i.e rehab need for entire city).
Needed input for strategic planning: Aggregated data on network level (material, age, diameter), performance indicators on service levels and condition.

Tactical planning
Rehab projects are in general defined from analysis of structural or hydraulic condition. Hydraulic models are quite common for drinking water networks. Reliability analysis has been conducted by a few utilities. They assess the hydraulic consequence of pipe failures. The structural condition is normally decided from failure records, where pipe break rates are the most relevant failure for water mains managers.

From the questionnaire, some information exists from Italy and Hungary, which appears to be quite representative for all developed countries. In Italy, condition measurement consists of location of breaks on city maps, monitoring leakage by district meters and pressure management. The network databases comprise network topology, thematic maps, failures, intervention reports and for sewers: CCTV data. Hungarian cities uses a standard Technical information System (MIR) with structured digital data including x,y coordinates, material, age of pipe and failure history.

From the literature, Wellington in New Zealand appears as an important case (EPA, year unknown). Wellington has its own asset management system that is integrated across sewer maintenance, storm water, transportation, properties and parks department. This includes an asset register (age, location, condition, function, material), customer service etc. Condition analysis is done regularly and includes statistical methods and computer modelling.
Needed input for tactical planning: Data on single properties, failures, hydraulic situation, inspection

Technical planning

Technical assessment includes the application of the right technology to a certain rehabilitation project. A first step of technical planning may be the detailed technical condition analyses that may be conducted non-destructive by inspection or by taking opportunistic test samples. In general, main water supply lines and main wastewater trunks need to be inspected without long-term service abruption. For this purpose some technologies have been developed for water supply systems, such as Hydroscope (www.hydroscope.com), Sahara (www.wrcsahara.com) and BIT (www.breivoll.no.). Wastewater networks are normally inspected with CCTV camera. During recent years the cameras have been improved and do now present results as digital pictures. Smaller pipes for drinking water distribution may not need a non-destructive inspection, since they are less vulnerable with regard to service abruptions.

A detailed database and an application tool have been developed for technical planning of wastewater network rehabilitation as a part of the CARE-S method. A Canadian report appoints the importance of using renovation methods. In UK a major part of rehabilitation until recently has been driven by water quality issues, and the isolation of pipe walls to avoid corrosion has been a major issue. Epoxy resin and recently PU-lining is a major method. In south and east Europe cement lining seem to be a major method still. For structural relining slip-lining and pipe bursting remain as major technologies. The CARE-S database demonstrates that a number of renovation products exist. Apart from cement mortar lining, renovation of water and wastewater pipes is not common in South and East of Europe.

Needed input for technical planning: Rehabilitation technologies, project description

Legal framework

An appropriate legal framework regulating the ownership and safeguarding the customers' rights seems to be a necessity for an effective maintenance and rehabilitation of the urban water networks. There are some good examples of various approaches from the European water industry.

As the UK water industry was privatised in 1989, a new legal framework was developed. This include the establishment of a control agency, OFWAT, who act as a "contract partner" of the water utilities and follow up service levels compared to pricing system. The water companies make 5 year plans that are negotiated and have to be accepted by OFWAT. In Germany the water supply and sanitation is left to the competence of the local authorities; their right is fixed in the Federal basic law (Grundgezetz). The local authorities belong to the "service of general interest" (in the term used in Brussels). The local authorities decide upon the form and structure how to organize the service. In Italy the Galli Law (no 36/1994) and the 2000 Government rules forced local authorities towards a partial privatization, changing the municipal firms into limited companies. Small water companies were merged in order to reduce costs and improve service quality. A major problem, however, is the level of bureaucracy of the large companies. In Portugal a national state-independent regulator (IRAR) has been established that has its power from integrity and competence. In New Zealand the local government Act Amendment no3 prohibits cities from delaying needed replacements to avoid rate increases for current users, thereby passing the infrastructure crisis on to future residents.

Lessons learned

The lessons learned in this project may motivate the Swedish and Norwegian Water Associations to direct the management of the urban water networks. This may include the utilising and improving of the existing data collection system and to start using tools that can enhance the information given in data collection. Thereby, a more efficient water and wastewater network maintenance can be obtained.

1 Introduction

Background: The global problem

Globally, the shortage of water and urban environment threatened by pollution are main concerns. In the developed countries, the main challenges for urban water systems are connected with migration/urbanisation, ageing of existing networks and impact of climate change. The urbanisation leads to a higher pressure on water resources and environment, while ageing networks causing increasing loss of water and capacity to transport storm water, and climate change causing as well droughts that hamper water supply as concentrated storms that lead to the increase local flood events. Consequently, national as well as local authorities, universities and research institutions and water utilities are giving more attention to the need for a sustainable management of urban water systems. This includes operation, maintenance and rehabilitation of existing water and wastewater networks. The letter presented below was received from a research colleague in Latin America, and it gives a quite representative description on how the problem approaches in many countries worldwide:

"Most of NN country cities have systems that are becoming old. However, it is happened due mainly to institutional problems (absent of laws, corruptions, and others). Water, sewer and storm systems didn't receive effective investments during 30 last years. Consequently, such systems are deteriorating have presented several operational problems. For instance, the average rate of water losses in water distribution systems is around 40%. Specifically, some cities have presented until 70% of losses. On the other hand, in January of 2007 President NN signed a new federal water and sanitation law that outlines federal policies in the sector. The law aims at increasing investments to provide universal access to water and sanitation. It has been estimated that investments in water and sanitation infrastructure in the order of US$ 4,5 billion ($24 per capita) per year, or almost three times the level of 2005, would be needed to achieve universal access.
From this situation, my question is: how could we (researchers) contribute for better allocation of such investments? Thus, I saw that Care tools could aid to identify critical systems in order to prioritise such investments."

This situation is handled organisationally as well as technically. From a national and legal point of view it is important to safeguard that the customers get adequate services to a reasonable price. Many countries have established national control agencies to avoid overpricing of services. Another way is the development of national independent control and support agencies. The Portuguese IRAR, for example, act as a "soft" regulator since it has its power based on independence and integrity. The IRAR control of the efficiency and effectiveness of the local water and wastewater service providers combined with their offer of knowledge support to those companies seems to be a major key to improvements both organisationally and technical.

The report deals with the technical issues, focussed on networks materials and main networks. Main challenges here are reduction of water leakages, which stands for a significant percentage of the produced water for supply. The provision of a stable water quality is another important issue. On the wastewater side local floods and cracking foundation of city roads due to erosion around water pipes are reasons of concern. The report gives some examples of data showing condition internationally and ways to meet the challenge that urban water networks approach.

Ageing networks

The older part of water and wastewater networks do often not fulfil modern demands on condition and performance. The pipelines were not built with materials and according to standards for strength, durability and performance that apply today. The designed hydraulic capacity may not comply with modern standards and to-days demand. Construction weaknesses make the network vulnerable to external load. Some materials are exposed to degradation mechanisms and will over time loose strength and tightness. This is the background why leading water authorities world-wide like USEPA, AWWA-WERF, UKWIR and WSSTP have reported great concern and worry about ageing networks.

Malfunctioning pipes has many impacts. Burst and leaks of water mains may lead to pressure loss and thereby service abruptions, as well as loss of water. There are several mechanisms that may lead to water quality degradation; for example corrosion of metallic pipes, re-suspension of settled particles, biologic growth on pipe-walls. Leaking water pipes combined with non-pressure may lead to ingress of contaminated water to the water system. Similarly will blockages, bursts and leaks of wastewater pipes lead to service abruption, leakage of polluted water into the ground or increase of pollution loss from overflows

The scope of this report

This report aims to give an international state of the art on water and wastewater network problems and rehabilitation practises. The status is made from a questionnaire specifically developed for this project, a scanned survey of recent reports and papers of international conferences and information from forefront researchers and experts of several countries. We have aimed to describe problems that may occur, the reasons of those and how they are solved.

VA-forsk in Sweden is planning a major project activity on approaches for planning and technologies for rehabilitation of water and wastewater networks. In Norway there is a discussion ongoing on real needs for rehabilitation. This report is meant to give an input to the Swedish development as well as future Norwegian projects to analyse rehabilitation needs and technologies. Main questions to be answered are:

- What should Swedish and Norwegian municipalities do and what should the branch organisations do?
- How can we prove that existing quality of network is sustainable?
- What are rehab needs in coming 40 years and how can this further concretise?

According to the customer, this report should include practical information to be used by municipalities and branch organisations, for example:

- Criteria for rehab planning
- How are plans and strategies anchored in operation organisation
- Definitions of Performance Indicators for rehabilitation
- Definition of “pipe age”
- Principles for planning implemented in practical rehabilitation

In other words; what is the problem? What is done to solve the problems? What does exist of guidelines for doing this? Obviously there is a problem if the water network does not fill its expected performance, namely stable deliverance of water at correct pressure and water quality. Additionally, the water distribution should not cause any external hazard to the built environment, such as flooded buildings and road damage. The wastewater service should be regular, it should be sufficiently designed to bring away runoff from large intensity rainfall, blockages should not cause damage to buildings and urban waters should not become polluted. Therefore, this report will start with a short description of expected functionality and the main reasons why this performance is not obtained. This includes wrong design, poor materials, poor construction practise and lack of operation and maintenance.

The gap between requested service and the actual situation will drive the rehabilitation needs, and the planning should bring the best possible strategy to bridge the gap. Several strategies have been developed for planning, one common problem is that all strategy work depends on thorough information about the assets. This is a main problem today and, together with security constraints on network data, a limitation for using advanced methods for strategic and tactical rehabilitation planning.

2 Condition of water distribution and wastewater collection network

2.1 Failures of drinking water network

2.1.1 Ageing water infrastructure

Drinking water systems are designed to deliver constantly sufficient water at adequate pressure and quality to customers. The main shortages reported are service abruptions due to bursts and due to extreme consumption at some nodes of network (fire-fighting, leakages). Service abruptions may lead to a non-pressurized network in some areas, and subsequent ingress of polluted water. Sedimentation of particles and subsequent re-suspension may lead to poor water quality, this is often observed when flushing/cleaning pipelines.

24 US mayors were asked to identify which of 24 water resources issues is either a current or future issue of priority for their cities. The top three list from this exercise was (USEPA 2002):

1. Ageing water resources infrastructure 61% of cities
2. Security and protection of water resources infrastructure 55%
3. Water supply availability 46%

The ageing infrastructure was identified as a priority by 40% of small cities, 34% of medium cities and 26% of large cities. The USEPA has estimated a water and wastewater infrastructure “needs gap” of over $500 billion in investment in United States to comply with water laws by 2019. Scaled by population of Sweden and Norway this amounts to ca 100 bill SEK/NOK.

2.1.2 Failure indicators

In general literature burst frequency and water loss (%) are the most frequently referred indicators. The burst frequency represents a measure of the structural condition, and also the vulnerability with regard to drinking water contamination. The water loss also brings general information about the network condition, and is in particular important in regions suffering from droughts.

<u>Water losses</u>

Statistics on water losses show large variations. Typical national values differ from 10-30%, some cities reporting even higher leakages. Best practise seems to be in the size of order 5% For example city of Las Vegas, situated in the desert with scarce water resources report 4% leakage. In Europe, Berlin that also have limited water resources, reports an unbilled volume below 5%.

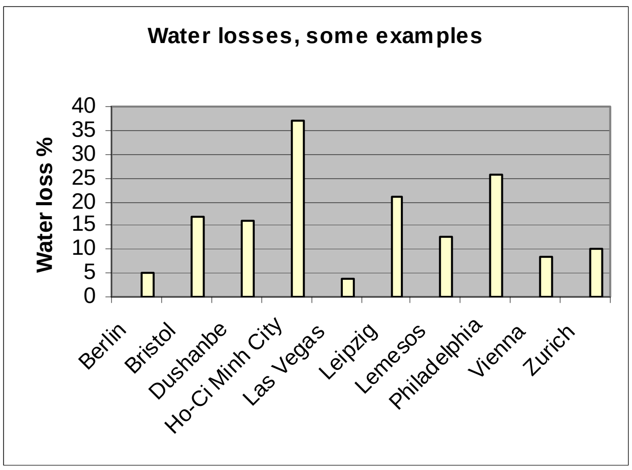

Figure 2.1 Water losses in some cities world wide

In general, national authorities are careful in publishing benchmark on leakage, since background data often are limited, and the number presented more a rough estimation than an accurate number and the results depends on the definition used. A few countries have published national surveys. For UK, OFWAT has brought 27% as average leakage over the country. An Italian survey shows a general water loss in distribution system of 22%, more in the south than the north. In Germany average leakage is 15%.

According to IWA Specialist Group on Efficient Operation and Management, presentation of water losses as percentage may not always give the right picture of the real situation. An infrastructure leakage index (ILI) is therefore proposed as the relationship between current annual real losses and unavoidable annual leakage losses. ILI values typically vary from 1-7 in developed countries, while for example African Water Systems have ILI from 1 to 35. Free software is available for water balance calculations. (Liemberger et al 2007)

A European project (TILDE) analysed practise of leakage control. 11 European cities were asked about methods, tools and instruments used to detect and pinpoint leaks. Technologies mentioned were step test, DMA with data loggers, leak noise correlator, listening sticks, ground microphones, flow data loggers. Several used leakage activity database developed in-house. The TILDE project comprises such tools (www.waterportal.com, see also www.leakageforum.org). A free tool for initial check if the leakage level is appropriate is available at the water portal. It helps the user to answer questions like

- How can the leakages be managed?
- What are the components of non-revenue water?
- How much leakage is occurring in my system?
- How can I compare my performance?
- What is the economic level of leakage of my system?

Burst frequencies: The structural integrity of water mains is often quantified as the number of breaks pr 100 km and year. Burst frequencies of water distribution networks are analysed by recent literature supported by the questionnaires. Some results are presented in table 2.1.

Table 2.1 Burst frequencies, results form some investigations

City/area	Failures pr 100 km/year	Reference	Comment
32 European cities	58	Alegre (2002)	Includes pipes, valves, fittings, service connections
3 cities in Netherlands	5	Questionnaire 2006 (Blokker, Ugarelli, Laky)	Average values for Netherlands and Hungary
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These results show that conditions are different, depending on network age, materials used and intensity of maintenance and rehabilitation. They demonstrate that best management practice may reduce the failure frequency to less than 10 pr 100 km/year. Whereas there is an increase in break frequency in winter time in North Europe and Canada, the opposite is the fact in south Europe, i.e Italy. It is assumed that temperature is the main reason for the situation in North and the increase of pressure because citizens are leaving cities during summer months is the main reason for the Italian situation.

2.1.3 Pipe materials and age

There are large variations regarding the use of and experiences with pipe materials. The older parts of networks in cities world-wide consist of grey cast iron, steel and asbestos cement pipes and modern part of ductile iron, PVC and PE. In general, an old network creates more failures and repair needs. However this is not consequent. In some countries, e.g. Netherlands, a major part of the networks are old, but they do not have correspondingly high failure rates. In Italy, high failure rates are documented on modern pipes (e.g. PE). There are local reasons for this, such as non-appropriate material quality during the first years of use of a new material, operation and maintenance practises.

Failure frequency has also been reported from Canada (Rajani and Makar 1993) and UK (MacKellar and Pearson, 2003). A summary is given in Figure 2.2. The UK figures are from the national official statistics for the period 1998-2003. The Canadian report brings results from an inventory in 21 cities representing 11% of Canada's population. The main conclusion is that materials representing old pipes have a higher burst rate than younger pipes.

Reduction of strength and perforation of pipe wall due to corrosion of metallic pipes are the most important failure reasons. Asbestos-cement pipes have a high failure rate, too. This is probably due to cement degradation and to poor bedding condition. These pipes were mainly laid from 1950. First generation PVC pipes have an increased burst frequency. The reason for this lie in failures of the manufacturing processes. In Italy, high failure rates are documented on modern pipes (e.g. PE). There are local reasons for this, such as non-appropriate material quality during the first years of use of a new material.

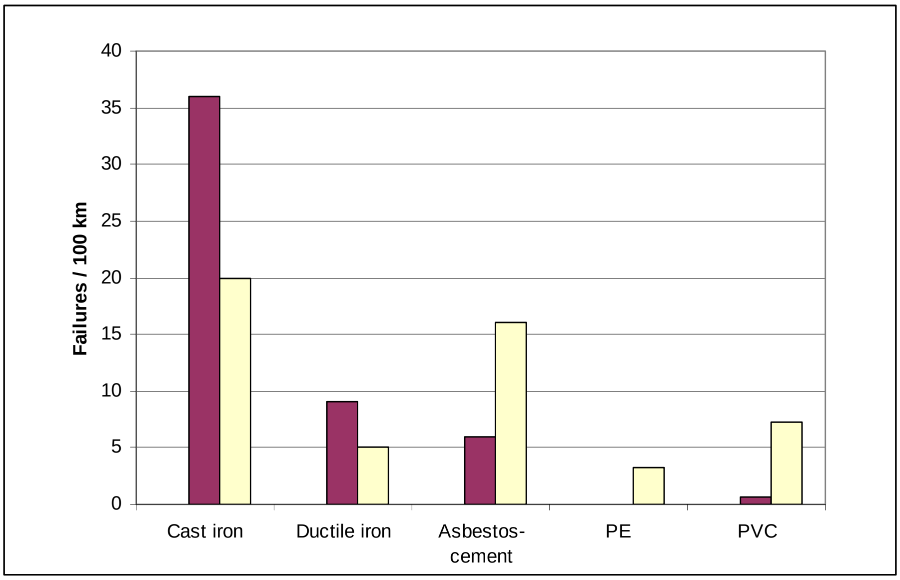


Figure 2.2 Failures related to pipe materials, reports from Canada (Rajani and Makar 1993, dark) and UK (MacKellar and Pearson, light)

Whereas about 1/3 of the networks in average are older than 30 years in Sweden and Norway, the situation is opposite in other major European countries. Italy, for example, 60% of water and wastewater networks are older than 30 years. The challenge on maintenance and rehabilitation, therefore, is even higher in many countries outside Scandinavia.

Cast iron water mains

Rajani and Makar (2000) presents a methodology to estimate the remaining service life of water mains affected by corrosion. The methodology combines the residual resistance capacity of grey cast iron pipes, anticipated corrosion rates and the measurements of corrosion pits by direct inspection or non-destructive evaluation technology to predict when the factor of safety of an individual pipe segment will fall below a minimum acceptable value set by the utility owner, i.e remaining service life. The estimate of remaining service life may then be used to schedule appropriate maintenance or replacement of grey cast iron pipes.

In Australia CSIRO has conducted a study to find a methodology for analysing external corrosion on cast iron mains (P Davis, M Moglia, S Burn, M Farlie). Although there is a known connection between surrounding soil and external corrosion, it is widely acknowledged that pitting corrosion is inherently random. To account for this uncertainty in the corrosion process, data from the condition-sampling program was represented by a probability distribution function. This function defines the probability of a particular corrosion rates occurring within a particular soil environment. A physical probabilistic failure model (Montecarlo model) was then developed, which combined the probability distribution function for a corrosion rate with pipeline operating conditions to estimate the time-dependent failure probability of a set of critical mains. Results from this condition assessment and failure modelling process can be used to prioritise critical mains for scheduled future actions.

The Ductile Iron Pipe research Association (DIPRA) recommends a 10-point scoring system based on (but not limited to) soils properties such as resistivity, pH, sulphides and moisture content. However, in order to apply this system to a pipe network, the relevant soil properties must be known. Whilst field measurements are possible on small projects, the number of measurements required to assess corrosive environments across an entire network is impractical

An effective alternative is to undertake regional soil mapping projects and represent relevant soil properties on GIS: This can then be used to identify potentially corrosive areas across the entire network Investigate conducted in Australia show that mapping of DIPRA scores is a valuable asset management tool.(P Davis, I Allan, S Burn, R vd Graaff)

Plastic pipes failures

The failures of plastic pipes have been broken down to failures connected with crack growth, resp. joint failures. Crack growth failures represent to slightly less than half of failure numbers. For PVC this corresponds to 3.5 failures pr 100 km due to crack growth, see table 2.3.

Table 2.3: Failure mode breakdown from UKWIR national failure database (MacKellar and Pearson, 2003)

Material group	**Pipe fracture %**	**Joint failure %**	**Other %**	**Unknown %**	**Total %**
PE	39.1	18.8	3.9	38.2	100
PVC	49.3	19.6	3.7	27.4	100

These failures include circumferential fractures, longitudinal fractures and pin holes, which correspond to short cracks which penetrate the pipe wall before becoming unstable and propagating along the pipe. In many cases, these fracture failures occur from stress concentrations at defects in the pipe wall. However, in other cases third party damage such as impact from a stray pick axe or backhoe will also result in a fracture. Unfortunately, water authority failure databases do not usually distinguish between fracture under normal operating loads and third party damage (P. Davis and S Burn 2004).

Failures on pressurized PVC pipes are rare, but may occur. Some failures can be attributed to poor installation, excessive operation conditions and third-party damage. In contrast, others are attributed to poorly manufactured pipes. First generation PVC pipes were produced with low gelatination level, making them more brittle. For all generation pipes minor surface cracks may occur, that can initiate cracks.

They can be analysed by using linear elastic fracture mechanics (LEFM) to predict time to failure. The brittle fracture process can be envisaged as a balance between an applied stress intensity factor (SIF) and the plane strain fracture toughness of the material. The process is split into three stages:

- An incubation period between load application and crack initiation
- A period of slow crack growth
- Fast brittle fracture, when the applied SIF exceeds the material fracture toughness

The applied SIF is determined by the in-service loading conditions and the “installed condition” of the pipe. Serviced loading can be split into contributions from internal pressure, diametrical deflection and residual stress. A critical Stress Intensity Factor (SIF) can then be calculated that should be compared to the material fracture toughness. If SIF exceeds the toughness, then there is a probability of slow crack growth.

There are three possible variables for a SIF analysis in practise, namely pipe size (wall thickness), fracture properties of pipe material, in-service loading conditions and inherent defect size. The inherent defect sized may be measured by Scanning Electron Microscope (SEM) and analysed by Weibull distribution functions. A Monte-Carlo simulation can now be used to generate failures in hypothetical PVC pipeline. This has been done for a UK pipe failure database (UKWIR) for pressures 0.7-0.9 MPa. Figure 2.3 below shows an example of model compared to failure data. Note that failure rate within the first 40 years of service is less than 1 pr 100 km/year.

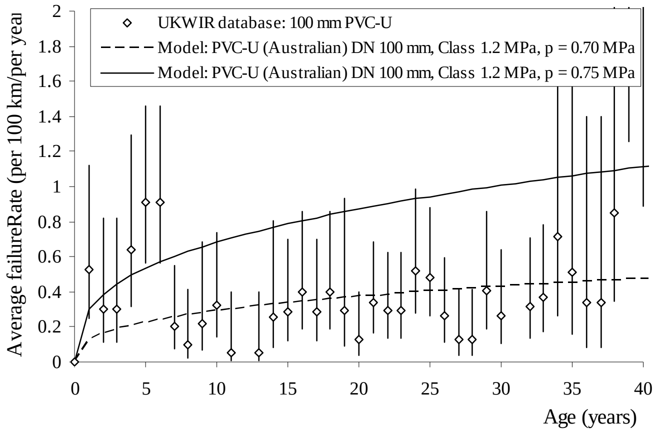


Figure 2.3: Failure model of PVC (Davies and Burns,CSIRO)

2.2 Wastewater

According to OFWAT (2002) 45% of sewage derived flooding is derived by hydraulic overload, and 40 % (>5000/year) by blockages (OFWAT 2002). Blockages are thus a major reason for local pollution and backflow flooding basements.

The questionnaire of the current project included a paragraph on repairs/100 km for sewer network, with results varying from 14 to 211. The results can give an indication that sewer problems are not less than for water mains, but is in general too scarce to make solid results. Wastewater networks are normally controlled by CCTV inspection. Until recent years this method was used to check if problems exist, however, now being used more systematically for rehabilitation planning. Earlier data can often not be tracked due to missing storing standards. Therefore systems for saving digitized information form CCTV inspection has now been developed, and is also supported by various commercial systems.

CCTV inspection dominates as a method to determine the condition of sewers and is applied worldwide. The US WERF (Water and Environment Research Foundation) has developed a method for identifying pipelines at risk of structural and operational failures so that inspections can be prioritized. Prioritization involves consideration of the consequence of failure. The method presented is based on a broad understanding of the variables leading to a failure. Those variables are typically internal and external corrosion, material degradation, infiltration and operational defects. This information is treated in a model based on the statistical method Simple Bayesian Belief network. The purpose is to allow agencies to strategically focus on inspection programs on areas most likely to need attention. The CCTV is considered as a necessary step to in the next term obtain plans for rehabilitation. As such this method can be compared to the European method CARE-S (Computer Aided Rehabilitation of sewer networks, see chapter 3)).

CCTV inspections are just the first step of rehabilitation planning. The aim is to classify pipes according to condition grades. Condition grades give a feeling on structural performance of the asset but in order to apply asset management, including economical strategies of rehabilitation, condition class of pipes has to be linked to other pipes attributes that explain pipes vulnerability, like, location in sensitive areas, or impact of failures and rehabilitation works on customers (indirect social costs).

3 Strategies for rehabilitation planning

An overall strategy for rehab planning may comprise three levels; strategic, tactical and technological. The strategic planning deals with the "network level" and incorporates level of service, overall condition, needs for rehabilitation and corresponding financial needs. The strategic planning will support master plans. The tactical plan refers to the single pipes and deals with ranking of rehabilitation projects. It supports the rehabilitation plan. The technological level deals with the selection of adequate technologies to specific projects (Vanrenterghem-Raven, 2006). Results from literature and questionnaires are analysed in context of this three-level approach

3.1 Strategic planning, level of service

Asset management plans are made for many cities world-wide. For the example in Wellington, New Zealand, an AM plan covering the 10-year planning period includes three general service goals:

- Safeguard public health and environment
- Provide a network with a level of reliability that meets the customer and regulatory needs
- Ensure that the network has sufficient capacity to serve all customers

The current project questionnaire asked for drivers for rehabilitation. They were mainly structural condition, water losses, water quality, reliable service and coordination with other service. For wastewater networks "water quality" was replaced by flooding and pollution. These drivers also reflect criteria for service level.

The corresponding financial needs are sometimes analysed by methods addressing the life cycle of groups or clusters of pipes, aggregated to system level (i.e rehab need for entire city). In New Zealand, the current asset value is calculated as the replacement cost minus the depreciation plus any capital improvements added since last evaluation
Information needed of strategic planning: Network data on pipe clusters (material, age, diameter), performance indicators on service levels and condition.

3.1.1 Achievement of service goals

Overall strategies for rehab planning comprise understanding of current state of the art and expected future development. Level of service is discussed in different contexts. Performance Indictors are widely used to assess the achievement of service goals, compared to the resources spent for this. The USEPA has compared service indicators from several countries (USEPA 1999). The recommended indicators for drinking water distribution networks deal with:

- Customer complaints (odour, taste, colour, pressure, interrupted service), total complaints pr geographic area, pr 1000 customers
- Service interruptions (time/customer, planned/unplanned
- Pipe condition grade by type and section
- Breaks pr pipe length, year, area type of pipe
- Leakage, average rate, total volume, pr unit length, pr total produced
- Metered water, % of produced
- Projected water demand in 5 years/current capacity
- Pr capita water consumption
- Percentage breaks, leaks etc repaired within x hours of notification

The corresponding indicators for wastewater collection systems are:

- Pipe condition by type and section
- Number of days volume of influent exceeded treatment plant capacity
- Blockages, stoppages pr year and pipe length
- Collapses pr year and pipe length, by pipe material, age, diameter and date of occurrence
- Projected needed capacity in 5 years/current capacity
- Properties flooded internally by sewage, caused by blockages, sewer collapses, equipment failure, capacity
- Sewer overflows, incidents due to blockages etc
- Sewer overflow/pipe length, /1000 consumers

World-wide, the IWA Benchmarking system or the World Bank Benchmarking system for water resources (IBNET) is widely used. Models and software are developed for this purpose. In Europe, level of service is developed as targets given by UK OFWAT and other national practises. Several cities all over Europe apply the Performance Indicator System for CARE-W and CARE-S. These systems comprise several indicators that measure the achievement of planned service levels.

During the projects CARE-W and CARE-S, a number of indicators were developed to analyse pipe condition and rehabilitation needs. In general these indictors are aimed to measure the extent of problems and efficiency of measures. By combining indicators of service quality and financial indicators, the cost-efficiency can be expressed. Still these results must be used with care, since it is not possible to include all variations and complexities into a limited number of indicators.

The performance indicators can be divided into

- Operational indicators
- Financial indicators
- Quality of service indicators
- Water resources indicators
- Physical indicators

A benchmark study, carried out as a part of the CARE-W project in 2002 compared 18 cities (35 case studies) from 9 European countries, representing south/north east/western regions of Europe (Alegre et al 2003). They were asked to present data for 49 indicators. Some data, for example failures of mains and service connections, water losses, distribution system and storage capacity, mains and service connection rehabilitation were presented from the vast majority of the cities. Other indicators, like power failure, annual investments for new and upgrading mains and for mains replacement were seldom reported. A similar benchmark for wastewater pipelines were conducted by CARE-S in 2004, comprising 20 cities and including 40 performance indicators.

The illustration below show mains rehabilitation of cities included in the survey. In average 0.91% of network has been rehabilitated pr year. 50% of the cases had a rehab rate between 0,25% and 1.3%/year. This could be considered as a currently normal rehab rate for cities.

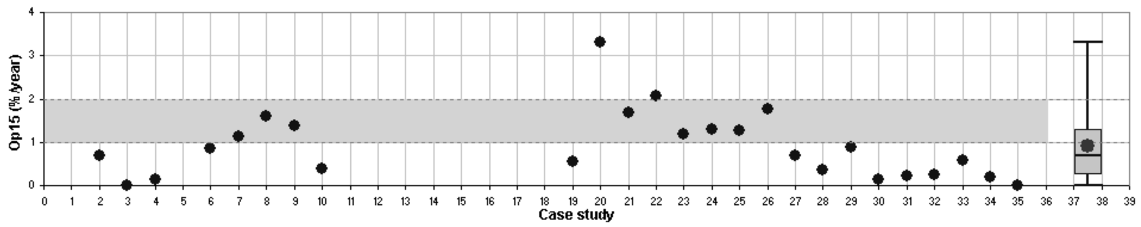
Op15 - **MAINS REHABILITATION** (%/year)	
Concept: Length of transmission and distribution mains rehabilitated during the year / total mains length x 100 Processing rule: Op15 = D18/C6 x 100 Variables: D18 – Mains rehabilitation (km/year) C6 – Mains length (km)	
	
Comments:	The mean value of the results collected is 0.91% of mains rehabilitated per year and 50% of the case studies are situated in the range from 0.25 to 1.3% of mains rehabilitated per year. As it might be expected, a significant number of case studies present relatively low rehabilitation rates, corresponding in average to a mains lifetime of 110 years.
Difficulties:	A few end-users had difficulties with D18 (Mains rehabilitation). This difficulty seems to be due to the lack of records, not to the complexity of the variable itself, and nobody recommended abandoning this PI due to assessment difficulties.
Relevance:	This PI is considered essential or important by all end-users.
PI guidance range: At this stage, a tentative recommended guidance range seems to be 1.0-2.0% of mains rehabilitated per year, representing a global network renovation within a period of 50 to 100 years.	

Figure 3.1. Example of a PI form.

3.1.2 Risk based Asset Management

The level of service thinking should be extended by the risk dimension. This includes the probability that the assumed functionality can not be reached, and the consequence of it. A risk based management includes a description of potential hazards, e.g. so-called event-trees or fault trees and the corresponding impact. The second step is an analysis of preventive measures and their corresponding costs. Finally acceptable risks and costs are analysed and a strategy proposed.

The planning should include an analysis of different financial strategies for rehabilitation and the corresponding development of risk levels and value of the network. The sewer inspection priority tool discussed in section 2 comprises analysis of likelihood of failure as well as consequence, where consequence is discussed as economic, environmental and socio-economic. The CARE-W and CARE-S approach also incorporates the likelihood and consequence perspectives.

Risk assessment is becoming more and more fundamental for asset management, and numerous books and articles has been written on this topic during recent years. The current project TECHNEAU (www.techneau.org/), for example, contains a section on this issue, comprising assessment of risk and risk reducing measures and the development of a database for risk assessment of drinking water networks. As an example of recent articles, one on “Risk and opportunity in upgrading the US drinking water infrastructure system” published in Journal of Environmental Management, Elsevier 2007 (Rogers and Louis, 2007) could be mentioned. This paper presents a practical risk assessment methodology to provide drinking water infrastructure (DWI) decision makers with an objective risk assessment tool. The purpose of it is to maintain the desired level-of–service or systems reliability while managing the financial uncertainty of the expected budgetary impact within the capital improvement program.

The water company Three Valleys Water in London has developed a risk based asset management model for water network. It is based on more than 4300 test samples which have been thoroughly investigated plus a statistical analysis of burst history and other parameters. They use this information to predict pipe failures and thereby prioritize rehab projects. The method applied includes a comprehensive analysis of operation expenditure (OPEX) and Net Present Value (NPV) of the water asset stock.

3.1.3 Example on asset information processing

Wood et al (2007) introduces an approach for constructing water main database that can be used to manage utility assets. They concentrate to main breaks, since this may also be a gateway to contamination of the water distribution system. A case study on constructing a database has been conducted at city of Marple Ridge, Canada, and some lessons were learned.

- *Data processing is the key to success*. For example, aggregating soil data improved the understanding of the relationship between soil type and the number of water main breaks. However, summarizing and aggregating data requires expertise and knowledge of the intended analyses.
- *Constructed databases do have some limitations.* Created data may not always be accurate or quantifiable. The limitations can be overcome by a program that verifies the data over time.
- *Future breaks must be recorded and verified.* Utility mangers should develop long-term strategies that improve and verify the breadth of data and the confidence in the database. Opportunities should be used to obtain physical samples and verifying the condition of pipe protection, bedding, backfill and pipe exterior.
- *Interviews can capture information that is known to staff but not recorded*. Staff members share more information when interviewers begin the session making observations and then asking about the validity of these observations. Staff seemed uncomfortable with making observations unless they could also note exceptions
- *The approach improved organisational communications and decision-making.* A dialogue of data use has developed, leading to knowledge discovery and information sharing across the organisation. Although utilities have traditionally focussed on collecting and storing data, the next step will be applying data mining and continue the knowledge discovery processes. As more data analysis tools become available, utility managers must consider the business intelligence that they should employ to wisely invest resources to meet future demands.
- *This approach can be successfully applied to water, sewage, drainage and other systems to improve asset management*. Operations and maintenance analysis, performance and public accountability
- *The district of Marple Ridge is making changes based on the study results.* The utility is now examining ways to improve the prioritisation of water main rehabilitations and the assessment of break risk factors. As a result of this study, the district has revised its data and retention practises. Data on replaced pipes are now retained, field data are now being collected when new pipes are installed and new water main break forms have been implemented. Communication about data is improving as different departments work together to collect and share data and to better understand departmental roles in achieving the common goal of effective asset management.

3.2 Tactical planning

Rehab projects are in general defined from analysis of structural or hydraulic condition. Hydraulic models are quite common for drinking water networks. Reliability analysis has been conducted by a few end users. They assess the hydraulic consequence if a pipe is taken out of service. The structural condition is normally decided from failure records, where pipe break rates are the most important failure for water mains

According to Wood et al 2007, four general approaches exist for prioritizing pipes for replacement:

- Deterioration point assignment
- Break-even analysis (augment analysis with predictive techniques for pipe breaks, such as failure probability)
- Failure probability and regression
- Mechanistic methods. Data collection efforts required to calibrate mechanistic methods may only be justified for larger-diameter mains with costly failure consequences, (Rajani 2001)

Current practise with regard to condition assessment was requested in this project. In general, GIS based databases comprise network topology, thematic maps, failures, intervention reports and for sewers: CCTV data are being developed and improved in countries worldwide. Some cities, for example in New Zealand, develop an asset register (age, location, condition, function, material), failure history, customer service etc. Condition analyses are done regularly and include statistical methods and computer modelling. It is a general challenge that many systems are rather an extension of a GIS mapping system than actually a decision support system. Therefore, there are limitations with regard to the opportunity to gain the maximum of relevant information from the data.
For tactical planning, the following information is needed: Pipe level data on properties, failures, hydraulic situation, inspection

The drinking water network should be object to analysis of hydraulic performance including hydraulic reliability, history and prediction of failures, water loses and water quality. These are main criteria for developing a detailed plan for upgrading network. CARE-W comprises a multi criteria method for selection and ranking of rehab candidates, utilizing the criteria mentioned above an also customer satisfaction and co-ordination with other infrastructure developments.

The WRc Sewerage Rehabilitation manual represents an advanced approach that is applied internationally. It is based on research and development programmes and hands-on experience spanning 20 years and incorporates current best practise and developments in UK and around the world. The manual comprises how to determine structural performance of sewers, to survey techniques and procedures for assessing deterioration and collapse mechanisms, to investigate and analyse the hydraulic performance, plan the maintenance and to maximise the use of existing assets. Finally it comprises a major section of structural design methods for sewer renovation. The analyses of hydraulic and structural performance is brought forward in CARE-S, and is supported by software tools. CARE-S comprises a rehab manager supported by 20 software tools.

3.3 Technical planning

Technical assessment includes the application of the right technology to a certain rehabilitation project. CARE-S comprises tools and databases for this application. However, many highly developed countries, like Italy and Germany, still do not use renovation methods to a large extent, but when used, cement mortar lining still seems to be the most important method.

In UK a major part of rehabilitation until recently has been driven by water quality issues, and the isolation of pipe wall to avoid corrosion has been a major issue a major issue. Epoxy resin and recently PU-lining is a major method. For structural relining slip-lining and pipe bursting remain as major technologies. Significant improvement on water quality has been achieved. Current trend in UK is to expand the number for criteria used for rehab planning, in particular predicted burst rates.

3.4 National rehabilitation guidelines

The water regulator Ofwat is determining the general condition for UK water companies, for example system expansion, rehab needs and the following water price. In a periodic review in 1999 they were critizised for backward looking approach to assessing maintenance requirements. Ofwat responded with UKWIR (UK Water Industry Research) by developing the Capital Maintenance planning Common Framework. This is a forward-looking risk-based approach that has motivated the water utilities to analyse investment requirements using risk based, performance focused, whole life costs based on data analysis. It is important to measure performance through Key Performance Indicators. The results is meant to be used in identifying why, when and how to invest in the asset.

The UK guidelines has brought forward more data. Water companies have invested in pipe samples which has been investigated for condition, corrosion. Therefore, it is the right time to the move to a risk-based approach as recommended.

As mentioned in chapter 3.2, the WRc Sewerage rehabilitation manual is the most comprehensive guideline on upgrading sewer networks. It introduces a procedure for planning and implementation, including:

- How to select sewers for examination
- Detailed description of survey and analysis methods
- When and how to consider upgrading and rehabilitation
- Identification of suitable rehabilitation options
- Preparation of detailed schemes of work
- Day-to-day maintenance programmes and long-term strategic planning
- European Standards harmonisation
- Operational investigation to European Standard EN752-7:1998
- Alternative prioritisation methods for inspection programmes
- Grading system compatible European Defect Coding Systems
- Improved design methods for new techniques

The current version is from April 2001. A new version is planned.

The UK Drinking Water Inspectorate (DWI) released a code of practise and operational requirements for in-situ lining of water mains in 2004. It provides practical guidelines for the lining of water networks with epoxy or polyethylene (PU)

EU is currently developing standards for all material and products in contact with drinking water through a common European Acceptance Scheme (EAS). EAS will consider materials and products defined as “building elements” and the complete acceptance scheme will describe requirements and corresponding test methods

3.5 Legal framework

As the UK water industry was privatised 1980s, a new legal framework was developed. This include the establishment of a control agency, OFWAT, who act as a “contract partner” of the water utilities and follow up service levels compared to pricing system. The water companies make five year plans that are negotiated and have to be accepted by OFWAT.

In Portugal, a different control agency has been applied, independent of the state and water companies, and having its authority based on competence and integrity. IRAR control the efficiency of each water, wastewater and solid waste company, and publish the results. The improvement is then not urged by IRAR, but decided by local political authorities that cannot accept unecessary limitations in water, wastewater and solid waste services. On the other hand, IRAR also provide assistance to the end users to improve their knowledge and the capacity of their technical systems, for example Portuguese guidelines to rehab planning.

In Italy the Galli Law (no 36/1994) and the 2000 Government rules forced local authorities towards a partial privatization, changing the municipal firms into limited companies. Small water companies were merged in order to reduce costs and improve service quality. A major problem, however, is the level of bureaucracy of the large companies. Following the Galli Law, the Decree n° 99/97 (Disposizioni in materia di risorse idriche: Decreto Ministero Lavori Pubblici n°99 del 8.1.1997) regarding water balance calculations was issued on January 8, 1997. According to the Decree, Italian Utilities are required to calculate the water balance for each of their water systems. The so called “carta dei servizi” (level of service document): was defined and found useful to connect service providers and customers. The directive defines four levels of service where quality indices have to be defined and reached and dealing with contractual conditions and availability of water supply, good quality and the right price.

In Germany the Federal basic Law (Grundgesetz) gives the right to provide water supply and wastewater services to local utilities. They belong to “services of general interest”. The institutional control is left to local parliaments. State control is restricted to supervise possible misuse of rights; there is no preventive regulation or direct interference into investment plans, financing, pricing or managerial issues. Detailed regulation concerns water catchment (needs state permission) and drinking water quality (supervised by public health authorities). In general the German water sector operates in a very transparent way and very near to the public. This creates an internal “control loop” that has generated a high quality of service to customers.

In New Zealand the local government Act Amendment no3 prohibits cities from delaying needed replacements to avoid rate increases for current users, thereby passing the infrastructure crisis on to future residents.

4 Decision support tools applied

4.1 Methods and software

A wide variety of software exists to support operation, maintenance and rehabilitation of water and wastewater networks. In general, they can process data from record databases and GIS systems into higher-level information to be used for analysis of condition and selection and ranking of operation, maintenance and rehabilitation projects. The necessary information as performance indicators is widely discussed, and tables have been developed by the International Water Association (IWA), American Water and Wastewater Association (AWWA), by international projects (CARE-W, CARE-S) and by national utilities (UK)

Some prominent examples of offered software are the Belgium Hydroplan, the UK Seams, the Italian TILDE, the German KANEW and the joint European CITYNET tools

4.1.1 Hydroplan

Hydroplan *(www.hydroplan-eu.com/)*supports sustainable water management programmes, including monitoring, maintenance, prioritise renovation and investment. It is build by modules so that surveys and studies can be spread over various years. The following stages are distinguished:

Preliminary study – collection and centralisation of available data. During this stage, all existing information of the sewerage infrastructure and its surroundings that may add to the inventory and evaluation of the functioning of the sewage system is collected and centralised. Any information sources will be used; municipality, public inquiry, plans, databases. This information is put into an initial sewerage management database. In addition, the frame of reference (structural, hydraulic and ecological is determined upon consultation with the municipality.

Defining the strategic components of the sewerage system. The sewers are classified according to the social, financial and ecological impact should they fail to work. The result is a strategic map, indicating which sewers have strategic importance for the municipality (red) and which have not (green)

Surveys and identification on "in-situ" bottlenecks. Within the strategic zones there is a need of accurate, reliable and more detailed data on the sewerage assets. Collection of these data is rather expensive. To save or spread the survey costs over years a specific survey programme is set up. Next to the strategic sewers, also the hydraulic main sewers are being measured. For surveys, GPS and data entry through dataloggers are used. Together with underground survey, the condition of each pipe is visually examined and preferably completed with camera survey of manhole camera. All data are registered in the sewerage management database. Through a reporting procedure, urgent interventions are immediately reported to technical service of the municipality and registered in a follow-up system

Risk analysis of hydraulic, structural and ecological failure. The current functioning of the sewerage is compared to a frame of reference agreed upon in advance. A risk analysis is carried out hydraulically, structurally and ecologically. All data from previous stages are used to this end. Based upon additional parameters, such as age of the sewers, root intrusion, presence of aggressive wastewater, number of connected PEs, connected impermeable surfaces, water quality of receiving water course etc., critical sewer maps are produced. Three coloured sewer maps give the municipal a total view of all sewers with a high hydraulic, structural and ecological risk.

4.1.2 SEAMS

SEAMS (www.seamsltd.com) is a commercial software developed to support Asset Investment Planning to water, energy and utilities companies to achieve long-term, sustainable business performance The WILCO model approach captures asset relationship and links between cost, risk, servicability and performance. One objective with this software is to create a common language between finance and engineering, facilitating cross-communication throughout and organisation and with all stakeholders. In particulate the WILCO technology is developed to support asset managers in:

- Maintaining an efficient infrastructure whilst considering repair, renewal and rehabilitation options
- Balancing CAPEX and OPEX
- Managing risk
- Optimising performance
- Planning for best case scenario investment

4.1.3 Tool for Integrated Leakage Detection (TILDE)

TILDE (TILDE Water Portal, Internet, www.waterportal.com)
stands for Tool for Integrated Leakage Detection and supports leakage detection. The software tools comprise the Leakage Check-up, the Decision Support Tool, the Benchmarking and economic tools and the Data Management System.

TILDE Leakage Check-up: In an initial step the utility can gain an overview over the current leakage situation of its network by applying the Leakage Check-up through the Water Portal. The infrastructure leakage index (ILI) as the ratio between current annual real losses and unavoidable annual real losses provides a first classification for the performance of leakage management and the potential in recovering drinking water. The calculated ILI combined with the supply-demand balance allow the user to find himself placed in a matrix with areas of varying challenges. This benchmarking application makes use of a chosen set of IWA performance indicators and is one level in the TILDE methodology

TILDE Decision Support Tool (DST): is based on recommendations from IWA water balance table and include afacility for benchmaking.

TILDE Management System (DMS): The Tilde DMS enables users to manage all leakage control related data coming from flow, pressure and acoustic sensors. It also records leak detection and repairs. In addition, a calculation method for prioritising zones is embedded in the Tilde DMS. Tilde DMS includes: The TILDE DMS itself, a software for management of all leakage control related data coming from flow, pressure and acoustic sensors and a calculation method for prioritising zones for leak detection.

4.1.4 The CityNet software

The CityNet cluster (http://citynet.unife.it, Krebs et al 2007) consisted of six individual projects on urban water issues have been conceptualised and proposed independently of each other under the European Framework Program No. 5 (FP 5). They were running in the period 2001-2006 and are very briefly introduced in Table 4.1, where the website addresses are given for detailed information about the projects. The CityNet projects addressed ageing water in different ways, but they all dealt with the consequences of water network degradation.

Table 4.1 The 6 CityNet projects

AISUWRS (Assessing and Improving Sustainability of Urban Water Resources and Systems). Objective: develop an integrated contaminant flow and transport model for urban water systems (water supply, sewerage, drainage, groundwater) and a decision support system with guidelines and recommendations for the safeguarding and protection of urban groundwater resources against contamination. Project coordinator: University of Karlsruhe, Germany. → www.aisuwrs.de
APUSS (Assessing Infiltration and Exfiltration on the Performance of Urban Sewer Systems). Objective: develop new methods and techniques based on tracers (chemicals and/or natural radio-isotopes) to assess and quantify infiltration into and exfiltration from sewer systems. Project coordinator: INSA-Lyon, France. → www.insa-lyon.fr/Laboratoires/URGC-HU/apuss
CARE-W (Computer Aided Rehabilitation of Water Networks). Objective: develop an integrated suite of tools supporting municipal engineers to establish and maintain a cost-efficient system of maintenance, repair and rehabilitation of their water supply networks. Project coordinator: SINTEF, Norway. → http://care-w.unife.it
CARE-S (Computer Aided Rehabilitation of Sewer Networks). The main objective consists to provide a decision support system for a cost-efficient system of maintenance, repair and rehabilitation of sewer and stormwater networks ("rehabilitate the right pipe at the right time by using the right rehabilitation technique"). Project coordinator: SINTEF, Norway. → http://care-s.unife.it
CD4WC (Cost-effective Development of Urban Wastewater Systems for Water Framework Directive Compliance). Objective: provide guidance and support for optimising the efficiency of urban wastewater systems with regard to ecological consequences in natural water bodies and with regard to investment and operation costs. Project coordinator: TU Dresden, Germany. → www.cd4wc.org
DayWater (Adaptive Decision Support System (ADSS) for the Integration of Stormwater Source Control into Sustainable Urban Water Management Strategies). Objective: develop an ADSS for stakeholders involved in urban stormwater management, integrating technical information and tools for best management practices, methodologies for a comprehensive assessment of hydrological environmental risks. Project coordinator: ENPC, France. → www.daywater.org and www.daywater.cz

5 City examples

The project work comprises collection of information from a number of cities via a specific questionnaire. Answers were received from a number of cities, some more comprehensive than others. The following text presents information received from the project questionnaire and the Techneau project.

5.1 Analysis of questionnaire

State for the art

Figure 5.1 and 5.2 shows some main statistics developed from the questionnaire.

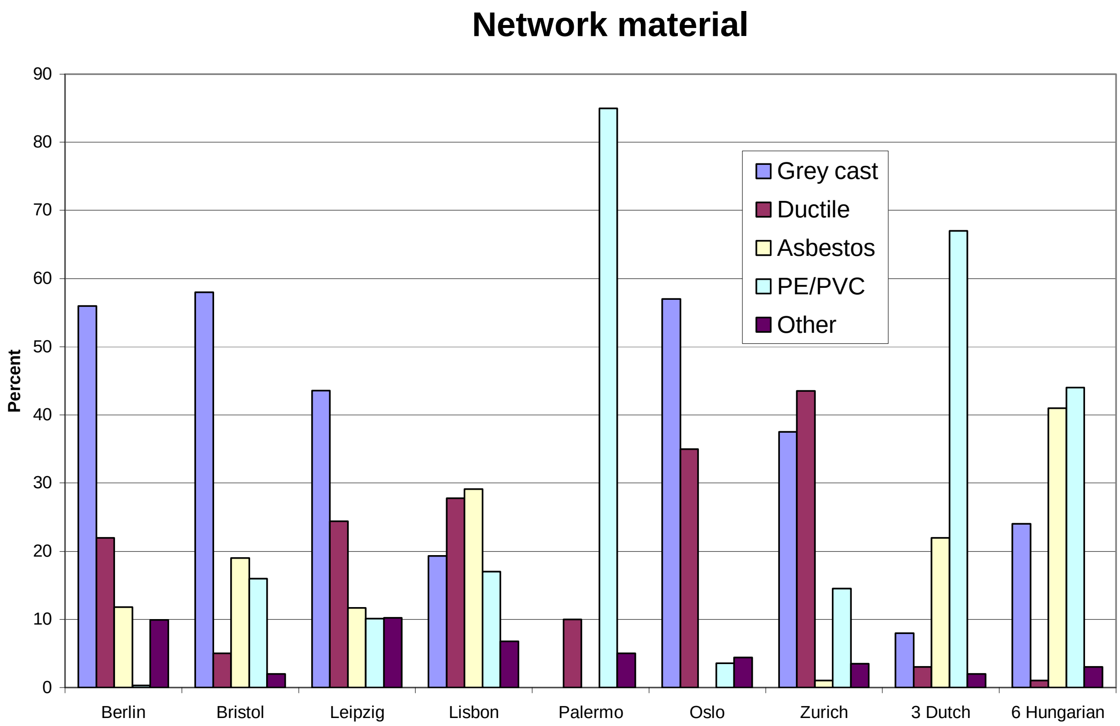


Figure 5.1 Network materials in some European cities

It can be seen that most of the analysed cities are using cast and ductile iron as the main material for water supply. However, in Dutch and Hungarian cities as well as in Palermo, plastic pipes have a dominating position. The material distribution also reflects the age composition of water mains, cities with a majority of plastic pipes have a reasonable new network, while cities with a significant amount of grey cast iron pipes have a comparatively older network. Where asbestos-cement pipes are significant, this is a sign that a major part of the network was constructed in the first two decades after the second world war.

The failure frequency will reflect the material composition of the network. In Hungary, where failure frequency is comparatively high, the most vulnerable materials cast iron and asbestos cement stands for 2/3 of the network and in Leipzig, a major part of network is unprotected cast iron pipes. On the other hand, Dutch cities and Palermo with a rather new and plastic-domitated network, the failure frequency is extremely low (figure 5.2)

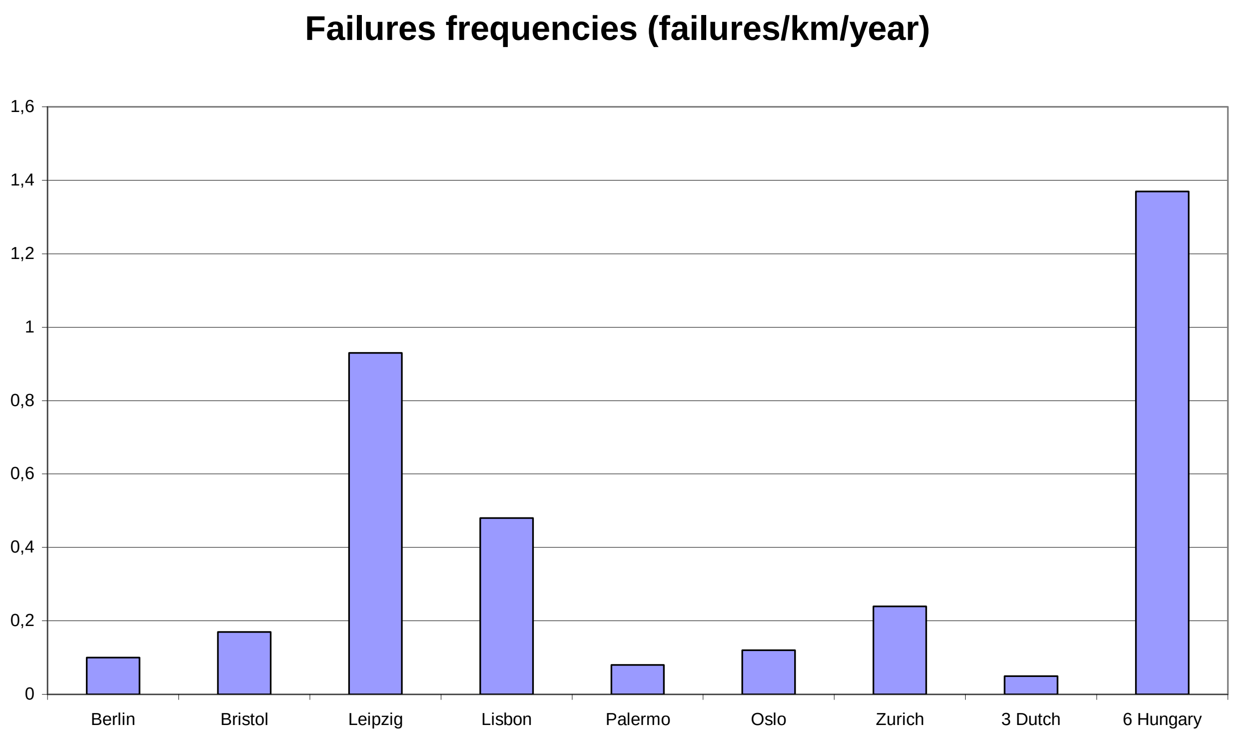


Figure 5.2: Failure frequencies in some European cities

Information was also collected for wastewater network in some of the cities. While concrete is dominating in Palermo and concrete + clay pipes in Lisbon (Oeiras et Amadora), the six Hungarian companies possess mainly plastic pipes in a network where only 30% is older than 35. Failure rate in Lisbon is three times larger than Hungary and ca 10 times larger than Palermo,which may stand as an example of the best cities in Europe. The reason is an old net (85% older than 35 years) and a large percentage of old clay pipes.

Drivers for rehabilitation

A request on driving forces for upgrading drinking water networks demonstrated that rehab reasons are multiple. In general, structural condition due to material degradation (ageing) is predominant, whereas water losses, water quality and reliability are secondary causes. There is obviously a connection between structural condition and leakage and reliability in deliverance and quality. The responsible engineers tend to analyse the general structural condition as a more important indicator that as a consequence may lead to the above named inconveniences for the customers. Particularly in Netherlands a large investment program has been finished. Further rehabilitation is based on decision models.

Information on drivers for wastewater network rehabilitation is available from Hungary, Italy and Portugal. Structural condition is the major driver for these pipes, too, together with flooding. The probability of flooding is affected by the original hydraulic design. Therefore it can be concluded from these very limited data that structural degradation as well as hydraulic design are the drivers for wastewater network rehabilitation. Pollution and service reliability are attached consequences. In particular in Portugal the utilities responding have a decided program for upgrading, based on empirical methods, whereas in Italy the respondent inform that the upgrading program will be carried out by a new service utility that will take care of the water and wastewater service from 2007 to 2037. An experimental plan defined via CARE-S approach in Palermo city centre is under examination.

In general the cities possesses digitized records, they apply performance assessment and hydraulic models and utilize CCTV for condition measurement and rehab project prioritizing. They need a better evaluation of real failure and rehab costs. In Hungary rehab decision thinking is supported by a national publication. In Portugal, the cities use guidelines from the national research centre (LNEC) and the regulator (IRAR).

5.2 Management practise

This section includes a brief explanation of experiences on operation, maintenance and rehabilitation of drinking water mains from selected cities representing different European regions and presented by Techneau (Sægrov et alt 2006).

5.2.1 Bristol

Bristol Water provides drinking water to about 500 000 customers with a total sales revenue of 110 million Euro. Total running costs are 90 million Euro, whereof 21 % is used for O&M functions. Capital costs are 42 million Euro, whereof 60 % are investments for asset replacement and renovation. One third of operation and maintenance is outsourced. In total 29 million m^3 of water are billed each year. Bristol Water has a total of 380 employees, with an O&M staff of 230.

Lowland surface water is used to 84 % as water source, the rest is groundwater. 18 conventional treatment plants consist of several processes, including DAF (dissolved air flotation) and ozone, slow sand filtration and de-chlorination and coagulation, filtration and disinfection. The demand for residual disinfectant at the consumers tap is 0,1 mg/l free chlorine.

The network has a length of approx. 6 600 km, with 133 service reservoirs and 10 towers. It is divided into 386 district meter areas and has 457 600 service connections. The majority of pipes consist of grey cast iron (58 %), a low number of ductile iron (5 %), 19 % of AC and 14 % of PE. Minimum demand for network pressure is 100 kPa, maximum is 600 kPa.

Non-revenue water is calculated to 16 % of the input volume. Main failures and repairs are about 1100 each year which corresponds to 0,17 failures per km and year. 150 km (2,3 %) of the mains are cleaned yearly, 17 km (0,26 %) replaced and 3,6 km (0,05 %) renovated. 821 service connections (0,18 %) are replaced each year.

Bristol Water had emphasized on increasing water quality over the last decade and face no longer problems with bacterial content, turbidity, taste or odour. Occasionally, the iron content still exceeds the threshold (approx. 15 times per year).

O&M work is carried out mainly by the Production and Network departments. Production are responsible for sources and treatment works with operation of the equipment undertaken by dedicated plant attendants and maintenance work undertaken by multi-skilled technicians. Network department is responsible for the distribution system. Operation is undertaken by District Managers and Inspectors. Maintenance is outsourced to an external contractor. Water quality support is provided by the Process Science department. Laboratory services are outsourced. External contractors are required to use properly trained staff and to follow Company procedures. Compliant records exist and can trigger O&M activities.

Procedures and practices for safeguarding water quality during O&M activities are generally performed through first assessing the risks and then applying appropriate precautionary and remedial measures based on general industry guidance in the UK and internal procedures developed over many years by Bristol Water.

The entire network is covered by computer records. These include mains attribute data, connectivity, boundary data, soil and contaminated land data, ACORN (socio-economic categories), national mapping (OS) background data, aerial photography, schematics and event data. SCADA is used within the Company. It provides a wide range of data including pressure, flow, operational status, various water quality parameters, control data, pump speeds, reservoir levels and schematics. GIS is extensively used.

A number of hydraulic models for all mains exists for the whole of the distribution network. They predict pressures and flows at various operating scenarios but their use for water quality modelling has been limited. The models are used to optimise flushing programmes, valving operations, assessing the impact of taking service reservoirs out of use and as part of active leakage control.

Operating of valves is actively used to avoid creating stagnant conditions in the network.

On-line water quality monitors are used. Data is recorded, monitored and stored via SCADA and telemetry. It provides real time monitoring and allows to react to alarms providing lead indicators against internal trigger points. The following parameters are monitored:

- turbidity - R, T, D
- pH - R,T
- chlorine - T,W
- conductivity - R,T
- particle counters - T
- ammonia - R,T
- nitrate - R,T
- aluminium - T
- colour - R
- dissolved oxygen - R,T
- streaming current detectors - T
- ozone - T
- TOC - R
- phosphate - T
- iron - T

where R = raw water, T = treatment works, D = distribution

Pipeline renovation is partly water quality driven. Other rehabilitation projects aiming at improving water quality have included upgrading treatment works, re-design of specific sections of the network, altering flow configurations at service reservoirs to create separate inflow and outflow, removing some small service reservoirs and installing booster chlorination in the distribution system.

Historically, mains were re-lined with epoxy resin but this method is now replaced by PU lining. Other applied rehab methods are structural slip-lining and replacement by pipe-bursting or conventional trenching. Rehabilitation had been historically triggered by sampling for iron failures downstream but currently burst data over the past 3 to 10 years is used. A GIS tool has been developed to prioritise individual mains. Currently, a strategy is being developed to look at both bursts and iron failures. Some limitations are due to missing data, including event data that is not linked precisely to its location, material data for the distribution system and age of certain assets.

A standard procedure for disinfection, based on risk assessment, is used for repaired or renovated mains and service connections. Flushing is carried out to remove sediment and debris from the distribution system, avoid future discolouration problems and in response to bacteriological problems. Flushing is carried out mostly in-house by Bristol Water. Pigging is occasionally performed but has limited benefit because of potential damage to the integrity of the mains.

Cleaning of service reservoirs is operated on a four-year cycle in accordance with written procedures. It involves draining, hosing down walls, disinfecting and re-instating into service. Flood tests are made to assess the integrity of the roof. Drop tests are used to assess the integrity of the structure.

Active leakage control is performed under consideration of water quality changes in the network – to avoid discolouration and to maintain adequate circulation in the network. A pressure of 15 m is tried to maintain at all times. There is no evidence that contamination had been caused by pressure management practice.

Concerning future research priorities, Bristol Water appeals to develop failure prediction, i.e. knowing when and where an asset is going to fail.

5.2.2 Leipzig

Kommunale Wasserwerke Leipzig provides drinking water to about 600 000 customers with a total sales revenue of 64 million Euro. Total running costs are 43 million Euro, whereof 61 % is used for O&M functions. Capital costs are 19 million Euro, whereof 90 % are investments for asset replacement and renovation. 80 % of operation and maintenance is outsourced. In total 26 million m^3 of water are billed each year. Kommunale Wasserwerke Leipzig has a total of 260 employees, with an O&M staff of 142.

Only groundwater is used as water source in Leipzig, which is treated conventionally by 5 treatment plants. There is no demand for residual disinfectant concentration at the consumers tap.

The distribution network has a length of 2 300 km, including 19 service reservoirs and 77 643 service connections. The network is divided into 30 district meter areas. 44 % of the pipes consist of grey cast iron, 24 % are ductile iron, 9 % steel, 12 % AC and 9 % PE. Half of the ferrous pipes are without adequate corrosion protection. Minimum demand for network pressure is 250 kPa, maximum is 650 kPa.

Non-revenue water is calculated to 21 % of the input volume. Main failures and repairs have been 2135 in 2005 which corresponds to 0,93 failures per km and year. 500 km (21,8 %) of the mains have been cleaned in 2005, 20 km (0,86 %) replaced and 1,7 km (0,07 %) renovated. 1 243 service connections (1,6 %) are replaced each year.

The thresholds for microbiological, chemical and physical parameters in the network have been exceeded at 159 samples in 2005, 20 of them on bacteriological parameters.

A crew of 49 people is dedicated to operation and maintenance of the network, equipped with 35 vehicles. O&M staff is regularly trained. Customer complaints are recorded in considered in O&M actions.

When repair and renovation is conducted guidelines for hygiene are applied. Infiltration of contaminated water has not yet been reported. To protect the network from infiltration a minimum pressure of 250 kPa in any point of the network is ensured. The reservoirs are closed from environmental influences and diffusion dense plastic pipes are used in polluted areas.

A computer based utility system of the complete network exists, including also water works, reservoirs and pressure stations. A SCADA system is used to register flow, pressure, water levels in reservoirs, operating hours and pH. Also a hydraulic model of the network exists for the analysis of pressure, velocity and travel time. The model is actively applied to define pressure zones, to optimize flow conditions and pipe diameters within rehabilitation actions and to optimise operating costs. Valves are regulated to adapt travel time and velocity.

For economic operation and maintenance planning the software SAP R/3 is applied, handling financial management, asset accounting, cost accounting and materials management.

On-line sensors measure pressure and pH at each input to a district meter area and further representative points in the network. The measurements are evaluated in case of a failure.

Pipes are specifically rehabilitated to improve water quality. These actions aim mainly to reduce pipe diameters and reservoir volume in an over- dimensioned network. Relining and burstlining are used mainly as renovation methods. The software OPTNET is applied to plan rehabilitation, considering the hydraulic situation and pipe condition. Rehabilitation actions have to comply with technical standards of the German Technical and Scientific Association for Gas and Water (DVGW).

Hygienic procedures exist for repairing and replacing mains and service connections, described in the DVGW Technical Standard W291. New mains are systematically flushed and disinfected with H_2O_2. After a repair, mains are also flushed but selectively disinfected. Water samples are taken always immediately after flushing and one day after the repair or renewal. When replacing service connection, disinfection can not be applied without affecting water quality in the main.

Flushing is applied extensively in Leipzig. End pipes are cleaned every second month to avoid stagnation and brown water events. The routines are based on experience, complaints and water sampling. Service reservoirs are inspected and cleaned once a year, followed by disinfection of the bottom with chlorine.

To conduct leakage control, pressure management is applied, but a minimum pressure of 250 kPa is maintained. There is no evidence of external contamination. Active Leakage Control is not taken into account for rehabilitation planning.

As a goal for the future, Kommunale Wasserbetreibe Leipzig has the ambition to have coordinated and concerted maintenance programmes of all municipal enterprises dealing with streets, gas, telecommunication and sewage. They would also like to link their economical software SAP with their utility GIS.

5.2.3 Lisbon

EPAL is a public company responsible for the water distribution to Lisbon, as well as for the bulk supply of around 3 million people in the greater Lisbon area and north of. This description and the interview refer to the Lisbon distribution system and not to the whole company.
In 2005, the business area responsible for the Lisbon water distribution had a sales revenues of 77,7 million Euro, corresponding to 61 million m^3 of billed water. From the 402 employees, 193 are affected to O&M functions.

The company has a whole has invested significantly in rehabilitation in the distribution system, the reason why the total costs of the distribution business area exceeded in 2005 the corresponding revenues: 71 million of running costs and 21 million Euro of capital costs. O&M functions represent 86% of the running costs. Investments for asset replacement and renovation correspond to 89,5 % of the total capital costs.

The main water source is a dam lake (86 % of total abstraction). The remaining sources are borehole water (12 % of total abstraction) and natural springs and wetlands (2 % of total abstraction). This impacts the treatment solutions adopted: 86% of conventional treatment and 14% of disinfection only.

The network size has 1427 km of mains, ranging from 80 to 1500 mm, 14 service reservoirs, and aprox. 90000 service connections, serving 341764 customers. The main pipe materials are asbestos cement (29,06 %), ductile iron (27,76 %) and grey cast iron (19,32 %). The remaining is mostly plastic materials (16,66 % of polyethylene).

In 2005, 692 mains repairs or 0,48 repairs per km and year were carried out (planned and unplanned), 6594 service connections (7,3 %) were replaced. 85 km (6,0 %) of mains were rehabilitated, most of which replaced. Trench digging continues to be the most used technology. Asbestos cement and cast iron is being replaced by HDPE and ductile iron.

Lisbon has no significant problems with water quality at the consumers tap. Only occasionally higher microbiological counts in end pipes occur. Most incompliances are caused by house installations.

Operation and maintenance are structured in two different departments. The activities are supported by computer-based information systems: maintenance IS (Maximo), GIS (Ginteraqua), a SCADA, and a Customers IS (SIGC) are the core ones. There is a recent hydraulic model of the network (EPANET-based), including the pipes ranging from the maximum diameter down to 200 mm. The integration effort between these systems started long ago and is a permanent challenge for the company. The procedures for automatic updates of the network model topology and demand loads are currently under development. Complaint records do exist and they are a reason for O&M actions (flushing, analytical tests, etc.). The major constraint for the use of water quality modelling (travel times and chlorine decay) is the fact that the model is still simplified. The company is looking forward to an “all of mains” model and is working in this direction.

There are well defined procedures for network interventions (e.g. repairs, flushing, storage tank cleaning, etc.), including naturally hygienic procedures. Although the results are satisfactory and there is not a matter of major concern, the company is most interested in sharing their practices, problems and difficulties with other utilities in order to be able to improve its efficiency and effectiveness. They recognise that the network is still very much a black box in terms of the water quality in the distribution and the company is most interested in the contribution of TECHNEAU with this regard.

On-line water quality sensors are used to monitor free residual chlorine, PH, turbidity, water temperature and conductivity. Sensors are mostly installed at the distribution network entry points and delivery points to bulk customers. Other are installed in service reservoirs and pumping facilities.

Flushing is routine practice successfully implemented. Traditionally it was carried out subsequently to a customer complaint, and in problematic points, such as dead end. Programmed flushing is currently being implemented by DMA. The company planned to split the network in 130 DMA. The implementation plan is on-going and 30 DMA are already fully operative. Whenever a new DMA is implemented, flushing is carried out and the results are monitored and recorded. Analytical tests are carried out prior and after cleaning, at the entry point and/or at potential critical points. Whenever a DMA is rated as more problematic, a periodic flushing plan is set up. The flushing sequence is made according to the current water flow, from upstream to downstream. Dead end valves, discharge valves, and fire hydrants are used.

During DMA planning, the number of new network dead-ends is kept to a minimum. Where this is not feasible, the length of main without consumption either side of the new DMA limit valve is minimised.

DMA are progressively being equipped to allow for a continuous real time monitoring. This is the core of the water losses active control, complemented naturally with leak location procedures and/or procedures to minimise apparent losses whenever appropriate.

There are written procedures for pressure management. The general procedure consists of setting pressure reduction devices to 300 kPa.

5.2.4 Zürich

Water supply Zürich provides drinking water to about 350 000 customers with a total sales revenue of 82,5 million Euro. Total running costs are 42 million Euro, whereof about 75 % is used for O&M functions. Capital costs are 40 million Euro, whereof 72 % are investments for asset replacement and renovation. Only 5 % of operation and maintenance is outsourced. In total 57 million m^3 of water are billed each year. Water supply Zürich has a total of 277 employees, with an O&M staff of 200.

Water sources in Zürich are to 70 % lake water and to 15 % each spring- and groundwater. 70 % of the raw water is treated conventionally by 4 treatment plants, 2 facilities consist of carbonizing and pH increase and 15 % is only disinfected. Details for all treatment plants can be seen in appendix 1. There is no demand for residual disinfectant concentration at the consumers tap.

The distribution network has a length of 1120 km, including 20 service reservoirs and 32 000 service connections. The network is divided into 20 district meter areas. 37,5 % of the pipes consist of grey cast iron, 43 % are ductile iron, 3 % steel, 1 % AC and 14,5 % PE. Minimum demand for network pressure is 350 kPa, maximum is 1100 kPa.

Non-revenue water is calculated to 10 % of the input volume. Main failures and repairs have been 264 in 2005 which corresponds to 0,24 failures per km and year. Only 1,5 km (0,13 %) of the mains have been cleaned in 2005, 21 km (1,9 %) replaced, but none renovated. About 500 service connections (1,6 %) are replaced or repaired each year. Zürich has no problems with water quality deterioration in the network, only occasionally higher microbiological counts in end pipes. Most complaints are caused by house installations.

The O&M organisation is divided into several departments. The production department is responsible for operation and maintenance of the plant and the reservoirs, the network department for maintenance and repair of the network, the quality control department for sampling and laboratory analysis. Regular training in hygienic aspects for all people is involved as a part of the ISO 9001 management system. Complaints are recorded, but practically all technical complaints are due to house installation problems and not to the network.

The network has at any location a minimal pressure of 350 kPa. Hygienic precautions are made for pipes under construction (closed pipes). No infiltration of contaminated water has been detected over the past 10 years. Guidelines are applied for cleaning and disinfection of drinking water pipes after rehabilitation.

Zürich Water Supply has a SCADA system for managing treatment plants, reservoirs and pressure zones, measuring flow at strategic places of the water supply system. Technical data of the complete network is available through a utility GIS. A hydraulic model called “EC-Netz” is applied for the network, measuring velocities, flow time and pressure. The calculation of travel time age is not realized yet. No water quality parameters are modelled. Valves between water works and service reservoirs are operated to ensure a mean travel time of about 24 hours.

Zürich Water Supply has experienced bacterial problems due to relining with a textile tube. Those pipes where thereafter replaced. Otherwise, relining or pipe in pipe systems with PE is used. Software tools from SAP (PM- and PS-Modul) and Guidelines from the Swiss Association of Gas and Water Works are applied for rehabilitation planning. The goal is to rehabilitate 1,5 to 2,0 % of the network yearly (2005: 1,9 %).

Operational procedures after repair and replacement of mains and service connections are applied. Microbiological testing is performed and in case the threshold is exceeded, disinfection is undertaken. Flushing and if necessary disinfection is repeated until the water meets the microbiological limits. Disinfection is made by the network staff together with the quality control department. Except sodium hypochlorite, no cleaning agents are used

Cleaning of mains is performed by flushing with water to remove sediments, organic materials and biofilms. Once a year, service reservoirs are cleaned with water and in case of constructions in the reservoir also disinfected by spraying floors and walls with diluted sodium hypochlorite.
Preventive leakage control is performed once per year of about 50% of the network by flow measurements and acoustic systems. Pressure management is not applied to reduce leakage. Water quality issues are discussed in the weekly coordination meetings with the network staff.

Stray current is the main reason of failure. This is due to tram lines running alongside unprotected cast iron pipes. When damaged the pipes are replaced by ductile iron pipes with electric isolated joints.

Concerning research needs, Zürich Water Supply asks for an advanced hydraulic model, capable of modelling complex ring systems, including the calculation of travel time, flow direction and velocity and temperature. They are also requesting a maintenance software considering pipe age, hydraulic situation, leakage and bursts. Finally, they are interested in modelling bacterial growth as a function of temperature, assimilable organic carbon and travel time.

6 Discussion and recommendations

Based on the discussion on some introductory questions, the Swedish and Norwegian water associations require recommendations for their further national activities related to network ageing. Besides ageing of network, the urbanisation and effect of climate change will also become important drivers for operation, maintenance and rehabilitation of water and wastewater network.

In general the current condition of the water and wastewater pipelines varies from country to country, city to city and within cities, by material, age, diameter bedding and soil conditions. The failure frequency statistics most commonly are made based on material use. Material use can also reflect other factors determining the condition, for example construction practise and age. A European benchmark conducted in 2002, and investigation by TECHNEAU in 2006, an investigation by NRC, Canada in 1993 and statistics collected to this project show a general range of failures from 30 to 50 pr 100 km/year. However, while some cities have more than 100 failures/100 km year, other may have as little as 10 failures/100 km/year. There are large differences from country to country, where for example Netherlands represents low failure rates and Central European countries represents comparatively high rates. Different practise and materials selection between countries strongly contributes to this difference.

In general, it can be seen that the materials of highest failure are also the oldest materials. However, this picture is not completely representative. In UK and in Italy, there have been a number of breaks of PVC and PE breaks, probably due to brittleness and construction practises (shallow pipelines). Pipe material is probably the most important parameter for the assessment of future failures.

Pipe failures cause several problems, like abruption of water supply or sanitary services, contamination of drinking water due to repair, flooding of basements or surface, pollution of local waters. Therefore international water engineers require methods to predict failures. Several methods are offered to obtain this, from classification based on former complaints and break rates and engineering judgement, to advanced stochastic methods or mathematical optimisation based on artificial intelligence (neural networks). Research has shown that a major part of future failures can be predicted, and when rehabilitated thus avoided. This will make a considerable improvement to the customer service.

When discussing strategies for rehabilitating water assets, the quality of data and plans for collection of such data is very often the topic. Data management is expensive, and a strategy is needed how to develop a data management plan. The long term goals should be complete sets for data needed for operation, maintenance and rehabilitation including GIS, records and on-line monitoring that on appropriate database format, easy accessed by the actual processing tools. In short term, it may be the best to use non-qualified data that are scanned form various sources.

A management strategy that seems to embed many current approaches are the three-tier approach on a) long term planning and financial need assessment; b) rehab project selection and ranking and c) selection of adequate technologies for the actual project.

<u>Long term planning and financial assessment.</u>
This comprises a general investigation of current condition based on failure records and customer complaints, analysed in terms of Performance Indicators. The future rehab needs and effects of various rehab strategies can be analysed on network level based on past experiences on rehab needs and future predictions, through the programme CARE-LTP (KANEW) or similar. The analysis is on a network level.

Methods for estimating capital investment needs associated with growth of the system and changes in service standards have to be applied. Rehabilitation strategies can be regarded from different point of view: evolution of performance, consequences of failures, investments requested. An optimal balance between the different strategies should be identified, because a strategy that is efficient for one criterion, can be inefficient if the criterion changes; as result an Economic Level of Service can be selected, based on information gathered on risk, cost and benefit.

Selection and ranking of rehab projects
This analysis is performed on pipe level, and comprises hydraulic bottlenecks, structural failures and consequence for customers if a failure should occur, as well as coordination with other works. Multi-criteria tools are applied for the ranking of projects.

Technology support
Databases and guidelines exist that can support the user when selecting the right technology for a concrete project. Additionally, the general knowledge about degradation of pipes and the knowledge of the actual situation at the project site is important for the selection of technology.

Lessons learned
This report was meant to describe the situations in some cities based on interview. The developed questionnaire was sent to cities in many European and abroad countries. The result was meagre, in spite of several reminders. It can be concluded that the responders will need a personal reward to convince them to work. Alternatively, a committee travel to selected cities in Europe might have been more useful.

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