Evaluation report on operational methods and maintenance schemes - Applied in praxis and compared to best practice

D 5.6.1 + D 5.6.2  WP 5.6
TECHNEAU

Evaluation report on operational methods and maintenance schemes - Applied in praxis and compared to best practice

D 5.6.1 + D 5.6.2

WP 5.6
Colofon

Title
Operation and maintenance of water network - Best management praxis

Author(s)
Sveinung Sægrov, Axel König (SINTEF);
Robert Pitchers, Paul Conroy (WRc);
Helena Alegre (LNEC);
Andreas Korth (TZW)

Quality Assurance
Stein Wold Østerhus, SINTEF

Deliverable number
D 5.6.1. and D 5.6.2

This report is:
PU = Public
Summary

TECHNEAU work package 5.6 deals with operation and maintenance of urban water networks. Focus is on water quality issues. A BMP framework and procedures is developed under this work package, based on sensor measurements and water quality models. Sensors and models are possible input from other work areas and packages (WP3.5, WA4 and WP5.5). This work package develops the practical applicability of those results by showing how sensors and models can be implemented in the operational and maintenance management of drinking water networks.

Deliverables D5.6.1 and D5.6.2 have the objective to summarize the status on water quality related problems of networks and the management practice of some selected end-users. Based on this status, a sketch of best management practice is given.

Hygienic threats in the network that do not origin from the water treatment are ingress of pollution and chemical, physical and microbiological in-pipe processes. Ingress is mainly related to low pressure, pipe condition and repairs. All potential situations are described in this report. In-pipe processes depend on water characteristics of the processed water, travel time to consumers, hydraulics in general and pipe materials.

In-pipe processes and risks of ingress are difficult to assess in a water network. There are established operational routines to maintain water quality and to avoid deterioration. These routines are mostly established from experience and in many cases only re-active measures are applied due to lack of knowledge.

This report analyses the operational measures and maintenance schemes of 7 European utilities to map the current status and practice in these fields. There are huge differences in the conditions and challenges those utilities are facing and how they deal with them. Discussions and questions of the effectiveness of their measures are rised and there is a general interest in increasing knowledge and verification of methods.

The last chapter of this report addresses possible O&M solutions to water quality related problems, including risk management and models. This is the basis for the further work in this work package where all O&M solutions are mapped, evaluated and further developed.
# Contents

Summary 1

1 INTRODUCTION 4
  1.1 General approach 4
  1.2 Definition of terms 4
  1.3 Water quality as driver for rehabilitation 5
  1.4 Project deliverables 5
  1.5 Objectives 6

2 HYGIENIC THREATS AND AESTHETICAL PROBLEMS IN DRINKING WATER NETWORKS 7
  2.1 Introduction 7
  2.2 Contamination of drinking water due to ingress 9
    2.2.1 Intermittent pressurised systems 9
    2.2.2 Large demand 9
    2.2.3 Network repair 10
    2.2.4 Pressure variations/water hammer 10
    2.2.5 Ingress from storage tanks 10
    2.2.6 Ingress via valves 11
    2.2.7 Analysis of ingress vulnerability 11
    2.2.8 European Standard for protection 11
  2.3 Contamination of drinking water due to physical in-pipe processes 12
  2.4 Contamination of drinking water due to chemical in-pipe processes 14
  2.5 Microbiological water quality 17
    2.5.1 Main types of microbiological contamination 17
    2.5.2 Microbiological processes in the network 18
  2.6 Disinfection agent degradation 21
    2.6.1 Chlorine decay 21
    2.6.2 Disinfection by-products 22

3 CURRENT PRACTICE IN O&M TO REDUCE WATER QUALITY RELATED PROBLEMS 25
  3.1 Berlin 29
  3.2 Bristol 29
  3.3 Leipzig 32
  3.4 Lisbon 34
  3.5 Oslo 36
  3.6 Trondheim 37
  3.7 Zürich 38
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>O&amp;M SOLUTIONS TO WATER QUALITY RELATED PROBLEMS</td>
<td>41</td>
</tr>
<tr>
<td>4.1</td>
<td>Operation</td>
<td>41</td>
</tr>
<tr>
<td>4.1.1</td>
<td>Documentation, data collection and record keeping</td>
<td>41</td>
</tr>
<tr>
<td>4.1.2</td>
<td>Water quality monitoring, sampling and analysing</td>
<td>41</td>
</tr>
<tr>
<td>4.2</td>
<td>Risk management</td>
<td>42</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Safe Water Framework</td>
<td>42</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Risk management approach</td>
<td>44</td>
</tr>
<tr>
<td>4.2.3</td>
<td>Risk management implementation</td>
<td>48</td>
</tr>
<tr>
<td>4.2.4</td>
<td>Discussion</td>
<td>48</td>
</tr>
<tr>
<td>4.3</td>
<td>Maintenance</td>
<td>49</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Inspection and regular maintenance checks</td>
<td>49</td>
</tr>
<tr>
<td>4.3.2</td>
<td>Repair procedures</td>
<td>51</td>
</tr>
<tr>
<td>4.3.3</td>
<td>Flushing and cleaning</td>
<td>51</td>
</tr>
<tr>
<td>4.4</td>
<td>Models</td>
<td>59</td>
</tr>
<tr>
<td>4.4.1</td>
<td>Hydraulic simulation models</td>
<td>59</td>
</tr>
<tr>
<td>4.4.2</td>
<td>Water quality models</td>
<td>59</td>
</tr>
<tr>
<td>4.5</td>
<td>Monitoring systems</td>
<td>62</td>
</tr>
<tr>
<td>4.6</td>
<td>Integrated method for water quality driven rehabilitation</td>
<td>63</td>
</tr>
<tr>
<td>I</td>
<td>Interview answers from end-users</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Berlin</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Bristol</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>EPAL</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>Leipzig</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Oslo</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>Trondheim</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Zürich</td>
<td>105</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

1.1 General approach

TECHNEAU work package 5.6 deals with operation and maintenance of urban water networks. The package is divided into two parts, namely 5.6.1 Operation and 5.6.2 Maintenance. Focus is on water quality issues and a BMP framework and procedures based on sensor measurements and water quality models is developed under this work package. Sensors and models are possible input from other work areas and packages (WP3.5, WA4 and WP5.5). This work package shall develop the practical applicability of those results by showing how sensors and models can be implemented in the operational and maintenance management of drinking water networks.

The aim of this report is to summarize a status on water quality related problems of networks and the management practice of some selected end-users. Based on this status, a sketch of best management practise is given. The need for knowledge and technologies is described, in particular models and sensors for monitoring. The report contains the deliverables D5.6.1 and D5.6.2 of the TECHNEAU project.

1.2 Definition of terms

Operation and maintenance is defined differently from country to country and even between utilities. In the UK, maintenance is defined as a general term and the distinction is made between operational and capital maintenance. In this project, the definitions of operation and maintenance comply with IWA’s system, as shown below (table 1.1). In general, operation can be regarded as the daily routine efforts to secure the water supply, while maintenance is the intermittent efforts to maintain the performance and serviceability.

Table 1.1: IWA’s system for definition of operation and maintenance

<table>
<thead>
<tr>
<th>Operation</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Supervision of source protection areas</td>
<td>☐ System inspection</td>
</tr>
<tr>
<td>☐ General system monitoring and control</td>
<td>☐ Regular maintenance checks or service activities</td>
</tr>
<tr>
<td>☐ Standby duties and risk management</td>
<td>☐ Repairs of failures and other defects</td>
</tr>
<tr>
<td>☐ Documentation, data collection, record keeping and data processing (including management and operation of information systems)</td>
<td>☐ Cleaning</td>
</tr>
<tr>
<td>☐ Water quality monitoring, sampling and analysing</td>
<td>☐ Refurbishment</td>
</tr>
<tr>
<td>☐ Water loss management</td>
<td>☐ Regular meter replacement and maintenance</td>
</tr>
<tr>
<td>☐ Operational acceptance of new plants, networks and equipment</td>
<td>Maintenance and repair of fire fighting assets (whenever this is a responsibility of the undertaking)</td>
</tr>
<tr>
<td>Re-commissioning of systems after shut down</td>
<td></td>
</tr>
</tbody>
</table>
It should be noted that according to this definition, flushing and cleaning of pipe networks are defined as maintenance.

On the following work, operation and maintenance will be treated as one term, one type of action, parallel to building and rehabilitation.

1.3 Water quality as driver for rehabilitation

Some hygienic and aesthetical related problems can only be solved by rehabilitation of the pipelines. Ingress of water can only be completely eliminated if all leaks or defect joints are replaced or renovated. If renovation is selected, a fully structural or semi structural method should be selected.

Interaction between bulk water and pipe material can be stopped by lining the pipe with a material that is inert to reactions with adjacent material. For example corrosion of iron pipes are often stopped by epoxy or polyuretan lining. Water quality has for many years been a main driver for rehabilitation of water mains in the UK. This is normally not the reason of rehab works on for example Norwegian networks.

1.4 Project deliverables

The table 1.2 below gives an overview of project deliverables of this work package during the first 18 month period of TECHNEAU. This report complies with deliverable 5.6.1 and 5.6.2.

Table 1.2 Overview of contract deliverables of this work package

<table>
<thead>
<tr>
<th>Deliverable no</th>
<th>Deliverable</th>
<th>Deadline month</th>
<th>Deliverable type</th>
<th>Publicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>D5.6.1</td>
<td>Evaluation report on operational methods applied in praxis and compared to best practise</td>
<td>10</td>
<td>Report</td>
<td>Public</td>
</tr>
<tr>
<td>D5.6.2</td>
<td>Evaluation report on maintenance schemes applied in praxis and compared to best practise</td>
<td>10</td>
<td>Report</td>
<td>Public</td>
</tr>
<tr>
<td>D5.6.3</td>
<td>Modelling framework for improved hydraulic model</td>
<td>18</td>
<td>Report</td>
<td>Restricted</td>
</tr>
<tr>
<td>D5.6.4</td>
<td>Catalogue of improved operational models</td>
<td>18</td>
<td>Report</td>
<td>Restricted</td>
</tr>
<tr>
<td>D5.6.4</td>
<td>Modelling framework for WO driven maintenance</td>
<td>18</td>
<td>Report</td>
<td>Public</td>
</tr>
</tbody>
</table>
1.5 Objectives

The following paragraphs describe the objectives of WP 5.6. It is based on the contract text, but slightly amended and clarified. Operation and maintenance are combined and used as one term.

1. Study and document practice at case sites on water quality based maintenance, discuss BMP by criteria for service level, sustainability and economy. Describe current practise, problems, solutions, sensors, BMP and need for knowledge.

2. Support the development of a framework for an improved hydraulic model to simulate operation and maintenance actions and strategies. Develop strategies based on an improved hydraulic model - cleaning (flushing, pigging), detention (valve operation), pressure safety (valve operation, valve type).

3. Develop methods for contingency plans based on an improved hydraulic model (assure water quality by flushing, pigging, valve operation. Create a catalogue on problems and corresponding potential measures for prevention or acute solutions.

4. Develop a method for management of water quality in networks, including a formulation of a model for corrosion on metallic pipe materials.

As can be seen from this description, WP 5.6 comprises (i) the investigation of current practise on operation and maintenance in example cities, (ii) discussion on requirements for on-line and off-line sensors, (iii) requirements of water quality network model (event based on hydraulic model) and (iv) the formulation of a corrosion model for metallic pipe materials.

The detailed understanding of processes causing water quality changes in network is meant to be carried out in other Techneau work packages. This work package shall link to the practical application of knowledge and methods. Knowledge is applied in three steps:

1. Registration of a poor water quality event, or a situation that can develop poor water quality (complaints, sensors, models)

2. Estimation of customers influenced by poor water quality (automatic mapping of influence area from registration assisted by model)

3. Intelligent action (attach the source of problem)

This work package leads to a framework of BMP for water network management, related to water quality. The final outcome handles “what to do - if”-questions and action plans. The understanding of what to model and what to measure by sensors from an application point of view is transferred to work packages dealing with method development (WA3 and WP 5.5) at an early stage in the project to ensure its implementation.
2 HYGIENIC THREATS AND AESTHETICAL PROBLEMS IN DRINKING WATER NETWORKS

2.1 Introduction

Several water quality related problems may arise in water networks and poor water quality may create health hazard or aesthetical problems. Several technologies exist to protect the water, but very often they are not utilised. Existing technologies are sometimes not brought to a stage where they can be easily implemented technically (sensor and data transfer to monitoring systems). Table 2.1 below gives some examples of problems that may occur, currently applied mitigation actions and potential opportunities for sensor measurement or model calculation.

Table 2.1: Current technologies for monitoring and maintaining water quality in the network

<table>
<thead>
<tr>
<th>Water quality related problems</th>
<th>Sensor measurement</th>
<th>Model (software program)</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration of contaminated water</td>
<td>X</td>
<td></td>
<td>Pressure control Disinfection routines</td>
</tr>
<tr>
<td>Formation of bacterial film</td>
<td>X</td>
<td></td>
<td>Flushing, pigging *, Disinfectant increase, nutrient removal</td>
</tr>
<tr>
<td>Sedimentation</td>
<td></td>
<td>X</td>
<td>Flushing, pigging, water treatment</td>
</tr>
<tr>
<td>Corrosion, iron substance dissolution</td>
<td>X</td>
<td></td>
<td>Flushing, pigging, (coating) Water treatment</td>
</tr>
<tr>
<td>Calcium dissolution, pH increase</td>
<td>X</td>
<td></td>
<td>Water treatment</td>
</tr>
<tr>
<td>Smell, odour</td>
<td>X</td>
<td></td>
<td>Flushing, pigging, water treatment</td>
</tr>
</tbody>
</table>

* The effect of remedial effect of pigging is questionable. Experiences show that pigging will lead to increased bacteria concentration in the bulk water.

Results from EU study Microrisk:
The nature and extent of waterborne illness in Europe was extensively reviewed within the EU study Microrisk (Risbero et al. 2006). The outbreaks were detected by examining electronic databases and personnel contacts amongst Enter-net (an international surveillance network). Only well documented and characterised outbreaks were included in the assessment. On this basis 86 enteric disease outbreaks associated with public drinking water supplies in the EU were identified to have occurred between 1990 and
2004. Other potential outbreaks that were considered to be attributable to drinking water were excluded from the study as there was insufficient information available to make a proper assessment. The strict criteria used by the authors to define an outbreak meant that the data on the number of detected outbreaks was confined to those countries with better surveillance systems for detecting and recording incidents of waterborne disease through drinking water. Consequently, this data is likely to be un-representative of the range and extent of the actual number of outbreaks across the EU.

Each of these well characterised outbreaks was examined in more detail in an attempt to establish epidemiological, ecological and environmental factors contributing to the causes of waterborne disease. The number of outbreaks and cases associated with implicated pathogen and source of supply were determined for each of the ten EU countries in which the outbreaks were detected. Most of these outbreaks were identified in England (34%), followed by Finland (14%), France (8%) and Sweden (8%). The most predominant micro-organism in all these outbreaks was Cryptosporidium (32%) and the majority occurred in England (61%). The majority of the Campylobacter and Norovirus outbreaks (82%) were identified in Finland and Sweden.

Overall an equal number of surface water and groundwater supplies were implicated in the outbreaks. The majority of groundwater outbreaks occurred in Finland (31%) and the majority of surface water outbreaks in England (44%) and this probably reflects the predominant nature of water sources used in these countries for producing drinking water.

Of these 86 outbreaks, 61 had sufficient information available regarding contributory failures to be utilised in the development of a generic outbreak fault tree. Outbreaks with surface water supplies were most often associated with some form of failure at the treatment works. In these situations temporary interruption to the filtration process was seen to have the greatest effect and appears consistent with the finding that most surface water outbreaks were associated with Cryptosporidium.

It was reported that, although the probability of occurrence was less, the magnitude of the effect is greater for distribution system incidents. It was stated that awareness of the public health hazard associated with illegal cross-connections for example could help to reduce waterborne illness from drinking water.

Reference:
2.2 Contamination of drinking water due to ingress

Ingress of water into a pipeline can only happen if external pressure is higher than internal pressure. Additionally, water contaminated from a faecally polluted source must stay in contact with a pipe from outside and there must be an opening for contaminated water to intrude the pipe (corrosion penetration, defect joint, open valve etc). However, there are still many situations that may lead to ingress of contaminated water to the network.

This is supported by several international investigations. Outbreaks of waterborne illness were comprehensively reviewed in Mircorisk, see previous chapter. Some examples:

- In one city, UV disinfection was installed at some customer properties. They had significant lower frequency of water-related diseases compared to customers without UV. It was concluded that water in this city represents a hygienic risk that is due to ingress (Payment 1997, Colford 2002, 2005)

- A study in Sweden (Nygård 2003) concluded that the longer the distance from water treatment system, the higher the probability of campylobacter disease. This was linked to increased potential for ingress.

- In Norway a significant number of such incidents have been reported, some of them are linked to fire-fighting, some by pumps installed by customers may push polluted water into the main network system

The risk factors should therefore be identified for each network and appropriate protection measures completed. Pressure loss in pipelines may happen at certain situations as elaborated in the following chapters.

2.2.1 Intermittent pressurised systems

This is a major problem in many regions with water scarcity (Middle East, South Africa,....) The source capacity may only admit temporarily pressurised systems, for a few hours per day. During periods without pressure, contaminated water may intrude due to high ground water table, sewage filled trenches, river crossings etc via leaky joints and perforations. Conversely, intermittent supply is frequently associated to poor condition of the assets, which increases the risk of contamination. Practice demonstrates that in intermittent supply systems it is not feasible to assure that the water delivered is safe to be used as drinking water, although it may be used for other human consumption uses. However, some risk mitigation measures can be implemented in order to mitigate the risk of contamination associated to intermittent supply, such as leakage control.

2.2.2 Large demand

This is a common reason for temporarily non-pressurised systems everywhere. Network capacity may not be sufficient to cope with an extreme
water abstraction, due to fire-fighting, major leakages or extreme domestic/industrial consumption. Since ground water table may exceed pipe level along the line and since leakages or joint failures probably exist, this represents a hazard to drinking water contamination.

2.2.3 Network repair
Due to safety and for practical reasons, most repairs are conducted at non-pressurised systems. Operative procedures exist to protect water supply and normally, disinfection is desirable before pressurizing the system again. However, practice shows that disinfection in many situations is unfeasible to carry out in the distribution mains because utilities must prevent that high concentrations of disinfectant reach the consumer tap. Effective isolation of every service connection is often difficult to assure and too time consuming. There are several examples of pollution origin from network repairs. An investigation in USA (Besner, 2004) concluded that 1/3 of customers influenced by a network repair got microbiologically contaminated water. A Norwegian (2006) investigation concluded that there is a significant increase of water supply related diseases among customers living in areas downstream after repairs have been conducted. This demonstrates that even when precautions are taken, the risk of drinking water contamination associated to pipe repairs is high.

2.2.4 Pressure variations/water hammer
Low pressure can also occur due to pressure variations and water hammer. This may occur when water volume is accelerating, typically start/stop of pumps and valves. The effect can be calculated by computer software (e.g WATHAM (SINTEF), HAMMER (Bentley)). Studies (measurements) in USA (LeChevalier 2002) and in Norway (Tveit 2003) demonstrated that short-lasting pressure-less episodes may occur by start and stop of pumps.

2.2.5 Ingress from storage tanks
Storage basins are an important component of the drinking water network. They are built of steel, concrete, plastic or as rock basins. Interaction between environment and water is an issue and the construction should be sealed. Basins should be designed with appropriate circulation, detention time and ventilation and cleaning routines should be conducted. They should also be constructed in order to avoid insects, dust and pollen to enter. The roof must be constructed to protect tanks form intrusion of rain or surface water. Some countries (e.g Netherlands) are disconnecting storage basins since they may affect bio-stability of the drinking water. They are substituted by pumping systems. However, this option has also to be analysed from the reliability of supply point of view.

In some cities, in particular in Common Wealth countries, influenced by the UK, and in developing countries with intermittent supply systems, domestic tanks at the customers are quite common. Other examples of adjacent cells are integrated systems including the network, local wells and tank cells intended for fire-fighting. If these tank cells are interconnected with the water supply network, pressure variations may lead to suction of water from the adjacent
basins and thus threaten water quality. The adjacent cells are not subject to control in the same way as main sources. Some investigations on fire-fighting tanks where water has not been renewed have revealed a large content of fungi. Buildings subject to fire-fighting with water from these tanks have been damaged by fungi. It is therefore extremely important to ensure that water from non-potable water tanks cannot intrude the public water system.

2.2.6 Ingress via valves
Valves connected to service branches may be a vulnerable component if the system loses pressure. In Norway, particularly, valves for branches designed for fire-fighting have been considered, since a design error leaves the current valves open when external pressure exceeds internal pressure. Valve types that remain tight even when pressure drops are now introduced.

2.2.7 Analysis of ingress vulnerability
Normally, situations leading to ingress are known as a (potential) consequence of an action (e.g. a planned repair). However, some unplanned situations occur due to bursts and major leaks, and some situations leading to under-pressure due to large water consumption are never known. SINTEF has developed a methodology for using a hydraulic model to find the areas (nodes) in the network that are vulnerable for pressure loss. The model works by setting consecutively all nodes at large water consumption and measuring pressure at all parts of the network. The number of low-pressure situations for each node is thereafter counted and become a measure for network vulnerability (Hafskjold 2006).

2.2.8 European Standard for protection
A European Standard exists on “Protection against pollution of potable water in water installations and general requirements of devices to prevent pollution by backflow”. It is based on a methodology by Montout. This consists of an analysis of actual operational condition and contamination threats (risk that pressure at the local user exceeds network pressure, existence of added substances to liquid). Adequate protection equipment is proposed based on the analysis. Back-flow valves, ordinary valves, chamber with drainage and air gap are some examples of protection systems.

References:
- Besner et al 2004: “Do routine distribution system operations have an impact on water quality? Proceedings of AWWA WQTC.
- Tveit O A 2005: Strategy to avoid contamination of drinking water when repairing pressureless pipelines (in Norwegian)
2.3 Contamination of drinking water due to physical in-pipe processes

The most important physical processes that influence water quality are sediment transport and diffusion through plastic materials.

Particle transport
Sediments are common in water pipelines. The sediments may occur as suspended (transported in bulk phase) linked to pipe wall, loose sediments along pipe bottom. The sediments have several sources:

- Particles that were not removed in treatment process
- Particles coming from pipe materials
- Release of biofilm
- Particles intruded due to repairs or operations
- Dissolved agents that are transferred to non-soluble phase

A Finnish research project (Lethola et al., 2003) concluded that concentration of iron, bacteria and turbidity were at the highest at the time of the day when water consumption was at the highest. After cleaning, the day variations decreased. Another Finnish research project (Zacheus, 2001) concluded that sediments contained a large number of microbes. Pipe cleaning had a good effect on sediment removal, but one year later an equivalent amount of sediments occurred and also with a large number of microbes.

Sedimentation and re-suspension of sediments are caused by water flow variations. Variations in water consumption over a day and operations like flushing, burst repair, fire fighting and regulation of valves will change flow patterns, leading to sedimentation. Regularly pipe flushing is necessary to avoid this. Some criteria for cleaning of pipes are:

- Dead-end pipes
- Pipes with general low flow (=low velocity)
- Areas with customers complaints
- Areas with water supply from sediment rich source

In general three methods are available: flushing, pigging and scouring. They are described in chapter 5. The WHO report on “Safe Piped Water” comprises a general check list for network cleaning.

A method for evaluating the need for cleaning has been developed by KIWA (Liverloo et al 2002), Resuspension Potential Method (RPM). A controlled change in water consumption feature is made. Sediments will thereby resuspend and this will increase turbidity. This increase is a measure of the degree of sediments accumulated in those pipes where water velocity has increased. This is used as criteria for cleaning needs. The method is being tested in Bergen to learn where flushing is needed and how flushing can be operated without disturbance for customers (Sjøvold and Østerhus 2006).

In water supply systems, sediment can occur as suspended solids in the transported water, attached to the pipe wall (for example, as biofilm or a...
corrosion layer) and as loose deposits that accumulate at the bottom of the pipes. Input sources for these sediments are usually:

- Particulate matter that is not completely removed at the water treatment plant due to deficient operation (for example, incorrect filter operation or incorrect coagulation and flocculation)
- Particulate matter released from system materials in contact with the water (for example, from corroded metal pipes or from lined pipes)
- Biofilm release from pipe walls
- Particulate entering the system after pipe installation, maintenance or repair operations incorrectly performed
- Dissolved components (coming from the treatment plant or from the pipes) that transform to a non-soluble form during the transport of water. Examples are colloidal particles exiting the treatment and that flocculate downstream, microbiological conversion of dissolved organic matter still present in the treated water, the precipitation of iron either released from pipes or not removed in the treatment, the precipitation of manganese and calcium

All these sediments are subject to transport along the pipes. Though it has not been receiving adequate attention, system hydraulics plays a major role in this process as it conditions the accumulation and resuspension of the particles. Changes in flow characteristics (change in flow direction or increase in velocity) are the cause for sediment resuspension and increase in water turbidity at the consumers tap. In practice, this may lead to consumers’ complaints of “discoloured water”. Besides normal and seasonal variations, these flow changes may occur during pipe bursts, operation of valves or use of water for fire fighting and flushing. On the other hand, in zones with low velocities and high stagnation times, conditions are appropriate for the settling of sediments. If, after a period of low flow, the velocity increases, the previously accumulated particles will be resuspended and also cause discoloured water events.

Also the physical characteristics of the sediments influence their transport: small and light particles are the type of sediments that most likely will cause high turbidity water because they settle very slowly and resuspend easily when flow changes.

Some studies on the nature of these sediments have been reported and the results are based on composition analysis of samples taken from fire hydrants during flushing and of samples obtained from reservoirs and from the pipes. The main conclusion is that the composition of deposits varies strongly with the sampling point in a network, with the quality of the source water, with the type of materials that are present and with the hydraulic characteristics (mainly, stagnation time) of the system.

The influence of hydraulic processes on the transport of sediments in supply systems is still a field for research, as it requires more insight and correlation between the hydraulics of the water itself and the hydraulic characteristics of the different types of sediments that occur in these systems. As “discoloured water” caused by the resuspension of particles is a major cause of customer complaints, it is predictable that it would be valuable for the water suppliers
to have modelling tools that simulate the water quality in terms of the parameter turbidity. This would help them, for example, in the definition of the areas of the network more subject to accumulation of sediments and, therefore, to discoloured water problems, in the planning of flushing and cleaning programs and in the evaluation of the efficiency of these actions.

**Diffusion through plastic pipes**
Diffusion may occur through polyethylene based plastic pipes. If they are used in polluted ground, a diffusion tight pipe should be attached to the polyethylene pipe. Products for this are available.

**References:**
- Lehtola M J et al 2003 “Removal of soft deposits from the distribution systems improves the drinking water quality”, Water research, October 2003

2.4 **Contamination of drinking water due to chemical in-pipe processes**
Several chemical processes occur at the interface of pipe materials and water body. Chemical constituents may have a significant long-term health effect (allergies, cancer), and should not be neglected.

Within the European Union the suitability of materials in contact with drinking water are governed by national standards in individual member countries. The European Committee for Standardisation (CEN) are gradually developing harmonised standards which will gradually replace these national standards. Eventually, these harmonised standards will form the basis of the European Acceptance Scheme (EAS).

One particular group, CEN/TC 164 is actively developing standards specifically for water supply systems. Within this group, Working Group 3 is developing suitable methods for assessing the effects of materials in contact with drinking water.

Currently six ad-hoc groups are active in working group 3, and these are:

AHG1 Organoleptic assessment
AHG2 Migration from non-metallic and non-cementitious materials
AHG3 Enhancement of microbial growth  
AHG5 Metallic materials  
AHG6 Cementitious products  
AHG7 Un-suspected organic substances from materials

These ad-hoc groups are at various stages of completeness regarding either the development of standard methods or applying suitable criteria to test the performance of a material.

The following paragraphs discuss the most important chemical reactions in water pipelines.

**Organic constituents**
Complaints have been observed as taste/odour from water stemming from epoxy-lined tanks and basins. Standard laboratory investigations of HDPE pipes revealed organic compounds in test water. Also test water from PVC contained small traces of volatile organic compounds (VOC) (Skjevrak, 2003). A careful analysis of water quality in Stockholm after relining with epoxy sleeve showed that several potentially cancer-generating constituents appeared in water body downstream the sleeve. Stockholm city, therefore, has reservations in applying this renovation method (Wahlberg et al 2003). The increases of TOC and colony counts were observed in a new HDPE pipe during stagnation (Korth and Wricke, 2004)

**Deterioration of cement based material**
Concrete, asbestos cementous and ductile iron pipes coated with cement mortar are commonly used for water supply. Several mechanisms can lead to release of cement constituents to the water body. Most important is Calcium hydroxide, which will increase pH in network. In dead end pipelines with few customers and consequently long detention time, pH may raise to 11-12. Methods for analysis of cement mortar linings are presented in Sægrov (1998) and Østerhus (1998). The latter concludes that alumina cement mortar is not appropriate in drinking water networks, since significant alumina concentrations are released.

**Iron corrosion**
Older pipes of grey cast and ductile iron were initially not protected by cement mortar linings. These pipe materials represent a large percentage of the stock laid before 1970. In Germany about 50 % of the pipes are still unprotected cast iron or steel pipes. They corrode which decreases the strength and increases the probability for burst or perforation. The corrosion process can build thick corrosion layers which lower the hydraulic capacity. Depending on the water quality and the hydraulic conditions high amounts of deposits of the corrosion products can be generated. The resuspension of these deposits may lead to coloured water and turbidity. In stagnation pipes with low oxygen concentration the reduction of iron compounds in the corrosion layer can lead to a enhanced release of Iron (II). Although no health consequence of high iron concentration has been found, the deposits may contain a high concentration of bacteria and small numbers of coliforms.
Furthermore the colourization may give non-aesthetic impression and limit usefulness for consumption. The introduction of hydro silicates or ortho-phosphate to the water body has been proved to reduce corrosion by creating a dense shell-like layer.

**Copper corrosion**
Copper pipes are used for service pipes and in-house distribution of water. Copper content in tap water is therefore normal. The results of various research projects carried out in Germany showed, that the increase of the pH results in a decrease of copper release in the drinking water. The dosage of ortho-phosphate can result in both decrease and increase of copper release. The concentration and composition of natural organic matter plays a major role in copper corrosion mechanism whereas inorganic neutral salts have a minor influence (Dartmann et al, 2006). Copper gives tap water a bitter taste, and it is anticipated that it gives a reason for diarrhoea among small children and cirrhosis of the liver. Further, surface of sanitary installations may reach a green colour. Pit corrosion may occur in copper pipes.

**Other metallic corrosion** (zinc, lead, cadmium)
The metals zinc, lead and cadmium are used for fittings, service pipes, in-house installations and equipment. The EU standard sets threshold concentrations for these materials. Health impacts related to lead have been especially investigated and reported in the UK where still a high percentage of house installations consist of lead pipes and fittings. In general, stagnant tap water in contact with in-house network and fittings will contain increased metal concentrations and should not be used for drinking water.

**European standard**
EU is currently establishing the European Acceptance Scheme (EAS) to standardise acceptable limits for water/material interaction. One benefit of this system is that acceptance of a new product in one country is valid in the entire EU/EEA area. The standard is originally planned to be implemented in 2010, but is expected to be delayed.

**References:**
- Wahlberg C, Berg C, Melin B 2003: impact on drinking water by epoxy sleeve
2.5 Microbiological water quality

The microbiological situation in the network is determined by the water quality leaving the treatment plant, the ingress of bacteria and the growth of microorganisms in the network. In most countries the water is distributed with chlorine residual to kill remaining bacteria and to avoid regrowth problems. In some countries of Central Europe (Germany, Netherlands, Austria, Switzerland) the drinking water is distributed in most cases without any disinfectant residual.

The water quality in the network can be affected by different microbiological processes which are elucidated in the following paragraphs.

2.5.1 Main types of microbiological contamination

The ingress of virus, parasites and bacteria represents a significant health threat. This can be caused e.g. by insufficient treatment, leaks in the storage tanks, mains and service pipes or low pressure situation.

Virus
Norovirus is the most important source of water-borne diseases caused by virus in Norway. Over a 15 year period this virus was the main reason of 50% of all illnesses linked to drinking water (ca 5,000 persons).

Parasites
The most important parasites that can be transferred to humans via drinking water belong to the families Cryptosporidium and Giardia. The dose for an infection is very low (1-100 oocysts) and the oocysts are very resistant to chlorine. These parasites represent more than 20% of water-borne diseases in USA and more than 10% in UK and Sweden. They are detected in 25% of Norwegian water courses. Recently a major incident took place in Bergen, with up to 6000 cases of illness. Even two year after the outbreak 400 people have considerable health problems due to this incident (Røstum 2006).

Bacteria
Coliform bacteria may originate from faecal as well as aquatic environment, and are no obvious indicators for water contamination. These bacteria are of sanitary significance and not public health significance. The most common indicator used is Escherichia coli, which is a thermal tolerant bacterium that can survive up to 45°C. It is an indicator exclusively of faecal pollution.

Opportunistic pathogenic bacteria
Several opportunistic pathogenic bacteria may spread through drinking water. Some examples are Pseudomonas, Aeromonas, Bacillus and Burkholderia. They are associated with outbreaks of diarrhoea and wound infections as well as spoilage of food.
2.5.2 Microbiological processes in the network

The Microbiological quality of drinking water may change on its way from the treatment plant to the customer, due to:

- Detention time
- Pipeline condition
- Pipe materials and other system components
- Temperature
- Remaining disinfection agent
- Hydraulic conditions
- Physical, chemical and microbiological composition of water

Water quality normally does not create health hazards due to microbiological components. However, WHO has recently focused on opportunistic pathogenic micro-organisms as a possible reason to infections by persons with a weak immune system, though drinking water does not represent a major risk factor.

Fungi

There is an increasing concern about fungi as agents for allergies and infections. Norwegian water systems contain large quantities of fungi (Ormerod 1987, Warris 2001) and it is reasonable to believe that the situation is similar also in other countries. With the drinking water system, fungi can be spread that are introduced into the system. Drinking water may contain allergenic, toxic or pathogenic fungi. Typical effects are (Skaar, 2005):

- Skin irritation
- Infection
- Taste or smell
- Corrosion of pipe material

Fungi may initiate other biological growth that may influence the drinking water quality. In Norway, research continues to find out if fungi in drinking water can result in health hazards.

Coliforms

A study of the growth of coliforms in pipelines was conducted by Volk and LeChevallier (2000). They conclude growth in network may occur if:

- Temperature is over 15°C
- Available organic carbon (AOC) is over $100 \cdot \text{g/l}$
- Remaining chlorine less than 0.5 mg/l

The results of a current research project in Germany (DVGW W6/03/04) show that there is no growth of coliforms in drinking water with low nutrient content (AOC $< 20 \mu g/l$) in the presence of the natural bacterial population. However, coliforms can settle sediments of distribution systems in low concentrations.

Bacteria (heterotrophic plate counts, HPC)
In distribution systems, working without or with low chlorine residual the main part of the bacteria in the network is fixed within biofilms on surfaces of pipes and in sediments (Servais et al., 1992, Flemming et al., 2003). Therefore, the portion of bacteria in the bulk water is relatively low under usual conditions. Due to the consumption of nutrients by the biofilm the biostability of the water increases with residence time. Regrowth problems are mainly caused by the increase of bacteria release from the biofilm. As the experiences in e.g. Germany or the Netherlands show there is no need for chlorine residual to avoid bacterial regrowth. Under stable conditions in the network (particularly nutrient and disinfectant concentration) the release of bacteria from the biofilm and the growth of bacteria in the water body is very low. This results in a low bacteria concentration in the network. The disturbance of the biofilm by changes in the nutrient or disinfectant situation causes an increase of bacteria release from the biofilm resulting in regrowth.

If the water is distributed with higher disinfectant concentration, the bacterial degradation of nutrients is lowered. Additionally, there can be a formation of low molecular easily assimilable substances by the reaction of the disinfectant with humic substances. Because of the high nutrient concentration regrowth problems occur in parts of the network where the disinfectant concentration is not high enough to suppress bacterial growth.

Growth and biofilm

Biofilms are found in any drinking water distribution system. If there is no nutrient release from the pipe material the thickness of the biofilm is exclusively determined by the nutrient content of the drinking water, besides sheer stress from water velocity. Investigations in different networks in Germany were conducted within a research project. The cell numbers found in biofilms were in a range of $10^6$ to $10^8$ cells/cm² (Flemming et al., 2003). That means that there is only a monolayer of cells. A correlation of the bacterial density in the biofilm and the water quality in the network was not found. Hygienic relevant indicators were predominantly not detected in the biofilms. In case of a nutrient release from the material (e.g. rubber materials) the bacterial density can be much higher and coliforms in high concentrations may be found (Wingender et al., 2003). The bacterial density of the biofilm is considerably affected by the disinfectant concentration. Investigations of Große et al. (2005) showed the lowest cell number of the biofilm in pipes with the highest chlorine concentration.

The colonization of biofilm with faecal indicators is described by different authors (Camper, 1994, Robinson et al 1995, Macherness et al. 1993). Investigations of Fickel and Schwarz (2005) showed that hygienic relevant bacteria can be found in a drinking water biofilm after a contamination. But there was no growth of these bacteria in the biofilm.

In general, the development of a thick biofilm has to be prevented because:

- Micro-organisms may create toxic substances
- The biofilms can create more biological reactions
- Smell and odour problems may occur
• Pipeline roughness increases (hydraulic capacity decreases)

The characteristics of a biofilm may be an indicator that water treatment is not appropriate. Biofilm is discussed in more detail in WP 5.5.

References:

• Eikebrokk B, Røstum J: The outbreak of Giardian in Bergen SINTEF report (in Norwegian)
• Flemming H.C. (2003): Growth and contaminations potential of biofilms in drinking water networks, IWW series of publications, 36
• Fickel, J., Schwarz, T. (2005): Ensuring drinking water quality during distribution and consumers plumbing as well as management of distribution systems. Report BMBF research project 02WT0274
• Große, D., Korth, A., Wricke, B.: Optimisation of distribution system operation using high disinfectant concentrations. Report BMBF research project 02WT0276
• Skaar I, Fungi in drinking water systems, Tekna, Norway 2005
• Skjevrak I, Lund V, Ormerod, K, Due A and Herikstad H 2004 Biofilm in water pipelines, a potential source for off-flavours in the drinking water (Wat. Sci. Tech. 49, no9, pp211-217)
2.6 Disinfection agent degradation

2.6.1 Chlorine decay

Distribution of water for human consumption free of pathogens is, in this domain, the chief objective of water suppliers. Chlorination has been a current treatment practice to achieve this goal by destroying those organisms and preventing waterborne contamination. The most widely used disinfectant is chlorine, either in its gaseous form or as a hypochlorite compound. The maintenance of a residual quantity of chlorine throughout the system, in order to ensure the microbiological safety of distributed water, is current practice in many countries worldwide. The purpose of this chlorine residual is the prevention of regrowth of micro-organisms that have eluded treatment or entered the distribution system due to external contamination caused by pipe failure, maintenance works, intrusions (driven by negative pressures), entry of animals or contaminants in tanks, etc.

However, the residual chlorine concentration added to the treated water at the entrance of a distribution system does not remain constant during the transport to the consumer tap. This value gradually lowers as the chlorine reacts and decay may lead to the total disappearance of the disinfectant, thus increasing the probability of microbiological contamination. This issue becomes more relevant in network zones with high travel times, such as network ends with low consumption.

The chemical species that result from chlorine dissolution in water – hypochlorous acid (HOCl) and hypochlorite ion (ClO\(^{-}\)) – participate in several reactions with compounds of organic and of inorganic nature. These reactions are usually grouped in two components, relating to the decay within the water body – bulk decay – and to the decay that occurs through contact with the container (pipes and reservoirs) wall – wall decay.

![Figure 2.1 – Chlorine decay components in distribution systems](image)

Figure 2.1 – Chlorine decay components in distribution systems
The contribution of each chlorine decay component is specific to each distribution system because it strongly depends on the water that supplies the network and on the physical network itself. In summary, wall decay is a function of pipe characteristics – material, inner coating, age, condition (degree of corrosion, presence of attached biofilm, etc), diameter – and of hydrodynamic flow characteristics (velocity, hydraulic regime, residence time).

Figure 2.2 presents an example of the relative importance of the different chlorine decay components – bulk water, material, biofilm and sediments. These results were obtained by Kiéné et al. (1998), in laboratory experiments on metallic and plastic pipe samples and using water from a real distribution system. As can be seen, in this case for plastic materials the chlorine consumption due to material is negligible and the biofilm consumption is lower than bulk decay, which shows that wall decay is not always the main component. Decay due to reaction with accumulated sediments can assume a relatively high importance, being the major component in the case of plastics. On the other hand, for metallic pipes, the main component is the reaction with the material itself, due to corrosion phenomena.

![Figure 2.2 – Contribution of chlorine decay components for plastic and metallic pipe materials (adapted from Kiéné et al., 1998)](image)

### 2.6.2 Disinfection by-products

When chemical disinfection is used in water treatment, different disinfection by-products (DBP) are formed. Natural organic matter (NOM) like humic substances is the primary precursor for DBPs, but also bromide (Br) is precursor to some of the by-products.

Many DBPs are suspected carcinogens and drinking water standards have maximum allowed concentrations for some of them. In the Norwegian drinking water standards, only trihalomethanes are listed from the halogenated by-products. When ozone is used as disinfectant, the maximum
concentration of bromate is given because bromate is suspected to be a potent carcinogen.

DBPs are analysed using chromatographic methods, which are expensive. Therefore, models can be a good tool to assess whether there is a danger for formation of high concentrations of DBPs. Models could also be used to estimate how different water treatment processes affect the DBP formation. There exists a large number of publications where modelling of DBP formation has been attempted.

For chlorinated water, the structure of natural organic matter, and therefore reactions between disinfectants and NOM is very complex, making it difficult to develop mechanistic models for DBP formation. Therefore, most of the models for DBP formation are empirical. In addition, most of the modelling work has been done for THMs. Some model concepts have been based on respectively

- Linear correlation between THM formation and chlorine dose, total or dissolved organic carbon (TOC or DOC), or UV absorbance. In some cases, good correlation can be found between these parameters and THM formation.
- When there is a high concentration of chlorine in water, the rate of THM formation decreases with time until all the precursors are transformed into DBPs. There are several kinetic models proposed for this.
- DBP formation can be limited by chlorine dose or by organic matter (precursors). If chlorine dose is relatively high, all organics matter can be transformed into DBPs. In this situation, it is often easy to find correlations between water quality parameters and DBP formation.
- Where relatively low chlorine doses are used in the water works, chlorine may be used up before all the precursors are formed into DBPs. Ideally, the model should therefore include the concentration of chlorine and relate this to DBP formation.
- Several studies have shown that bromate concentration can be modelled by power functions similar to those for THM.

Developing accurate DBP models which can be used for a variety of water qualities is a difficult task. Power function types on empirical relationships including a variety of water quality parameters are promising tools. However, although they predict general trends in THM formation, they require more development to increase their accuracy. The most accurate models include chlorine decay and interaction between chlorine and precursors. However, these models have been case specific and more work is required to develop them for a general use.
References:

3 CURRENT PRACTICE IN O&M TO REDUCE WATER QUALITY RELATED PROBLEMS

To support the analysis of Best practise on water network management, interviews have been carried out for selected cities. A questionnaire was developed to support the interviews, which were performed in Berlin, Bristol, Leipzig, Lisbon, Oslo, Trondheim and Zürich.

Information was requested on utility profile, water supply system profile, actual water quality problems and water quality related operation and maintenance practise. A summary of the interview results is presented in the following chapters. The full answers are given in Annex I.

Figures 3.1 to 3.7 are showing some key numbers like number of customers, billed water volume and network length for all participating end-user in comparison. They also show the cost percentage for operational and capital maintenance of the total income. The deviations origin partly in the difference of the accounting system and are difficult to compare without further background knowledge.

Figure 3.5 shows the number of main failures in 2005. There is a huge difference between Berlin (0.1 failures per km) at the lower end and Leipzig (0.93 failures per km) at the higher end. This number depends much on the registration system and the maintenance programmes like leakage control that are currently applied.

Figure 3.6 shows the percentage of mains cleaning and renovation or replacement in 2005. Leipzig had an extensive mains cleaning programme in 2005 and this was obviously accompanied with pipe inspection since this figure is also very high in figure 3.5. Cleaning varies also very much from utility to utility and the policies on that measure are different since the problems of sedimentation and coloration are of varying magnitude. Lisbon and Oslo have a noticable high percentage of renovation and replacement compared to the level of 1-2 % that meets the natural degradation of pipes. There are many factors that can play a role in that number, like an overhanging rehabilitation need or parallel measures at other infrastructures.

An overview of major pipe materials is given in figure 3.7. Grey cast iron is still the predominant material in many utilities. The remaining lengths of asbestos cementous pipes depends on the utility strategy to replace this material. PE and PVC pipelines do still not play a major role for water mains and some utilities are reluctant to use them due to bad experience of bad qualities during the 70’s and 80’s.
The end-user interviews opened also for addressing research needs. The major issues that were addressed are:

- Improvement in failure prediction and life-time assessment
- Modelling pipeline deterioration by combining failure statistics, condition measurement and asset data
- Advancement in hydraulic modelling, including quality parameters
- Advanced maintenance software considering pipe age, hydraulic situation, leakage and bursts

![Number of customers](image1)

**Figure 3.1:** Number of customers

![Billed water](image2)

**Figure 3.2:** Total billed water volume per year
Figure 3.3: Network length of mains

Figure 3.4: Cost percentage for O&M and rehabilitation of total income

Figure 3.5: Main failures per km in 2005
Figure 3.6: Mains cleaning and renovation or replacement in 2005

Figure 3.7: Network materials in %
3.1 Berlin

The Berliner Wasserbetriebe are a water supply utility with about 1000 employees and provides water to 3,4 million customers. In total 195 million m³ of water is billed every year. The total sales revenues are 404 million Euro. The unbilled input volume is below 5 %.

The water source is groundwater which is treated conventionally in 9 treatment plants. The network size is about 7800 km of mains with 250 000 service connections. The network is not organised in district meter areas. Over the half of pipes consist of grey cast iron, 22 % are ductile iron, 12 % asbestos cement and 10 % steel pipes. Plastic pipes are almost not used in Berlin. Network pressure varies between 280 and 500 kPa.

Main failure and repairs are below 900 each year which corresponds to only 0,1 failures per km and year. 7 km (0,1 %) of the mains are cleaned yearly, 64 km (0,8 %) replaced and 7,3 km (0,1 %) renovated. 3200 service connections (0,01 %) are replaced each year.

Customer complaints are registered and considered in the O&M strategy. Berliner Wasserbetriebe have not yet any reports on contamination from infiltrated water. Hygienic guidelines for repairs exist, but there are no disinfection routines.

A SCADA system is used to measure pressure, flow, pH, oxygen, conductivity, turbidity and redox-potential at the outlet of each treatment plant. The network is modelled with InfoWorks, which is actively used for operation routines. The asset data is stored in a user GIS.

A computer model (OptNet) is used for rehabilitation planning. The relevant data for the strategy are pipe bursts, material, age and complaint records. Cement mortar lining comes into practise as the main renovation technique. After repairs or rehabilitation, pipes are flushed and sometimes disinfected. Service reservoirs are inspected, cleaned and disinfected once a year.

The leakage level is considered to be very low (< 5 %) and thus, Berliner Wasserbetriebe have not implemented a leakage reduction strategy for their network.

3.2 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 m³ of
water are billed each year. Bristol Water has a total of 380 employees, with a 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.

### 3.3 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. 1243 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 H₂O₂. 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.

3.4 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 m³ 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.

3.5 Oslo

Oslo municipality provides drinking water to about 535,000 customers. In total 91 million m$^3$ of water are billed each year.

Only lowland surface water is used as water source, which is treated conventionally. There is no demand for residual disinfectant concentration at the consumers tap.

The distribution network has a length of 1550 km, including 18 service reservoirs and about 49,000 service connections. The network is divided into 53 district meter areas, which correspond to pressure zones. 57 % of the pipes consist of grey cast iron, 35 % are ductile iron, 4 % steel and 3 % PE. 70 % of the ferrous pipes are without adequate corrosion protection. Minimum demand for network pressure is 200 kPa, maximum is 1400 kPa (sometimes exceeding to 2100 kPa).

21 % of the input volume is not billed, but domestic water consumption is mainly based on the size of living area and meters are not yet widely installed. Main failures and repairs have been 180 in 2005 which corresponds to 0,12 failures per km and year. 11,7 km (0,75 %) of the mains have been replaced in 2005 and 52,5 km (3,4 %) renovated.

The main water quality problem that Oslo is facing is an increase of colour, presumably due to climate change (extension of growth periods). A low pH level is also increasing the iron concentration in the network due to corrosion. A new treatment plant will tackle these problems.

Electronic complaint records exist, but are not representative as quality standard, because they are only partially recorded for action purposes. Customers will receive a supply service guarantee which guarantees water loss in maximal 12 hours per year, with a 200 NOK fine if this is exceeded. Improvements on complaint registration are planned.
Hygienic routines exist for main repair and replacement, which decide if it is necessary to disinfect. Direct intrusion of pollution into the network is not known, but intrusion into service reservoirs has been observed.

All water supply assets are completely electronically registered in a GIS. SCADA data is collected for flow, pressure, errors, pumping time and electricity consumption. The SCADA system will be connected to the GIS in the near future. The SCADA system is also used for operating valves. An older hydraulic model exists, but it is limited in detail.

On-line sensors in the network do not yet exist, but turbidity meters are planned to install.

Rehabilitation is not water quality driven. For renovation, epoxy, concrete and PU lining and Cured In Pipe method is applied. Structural pipe condition is the main driver for rehabilitation with failure frequency and vulnerability as inputs.

Flushing and pigging of pipes is applied regularly, for some pipelines yearly, based on experience of the O&M staff.

3.6 Trondheim

Trondheim municipality provides water supply to a population of 156 000. In total 15 million m$^3$ of water is billed each year, i.e. 100 m$^3$/customer pr year included industry. The total sales revenues are 25 million Euro, while running costs (operation, maintenance and capital) are 12 million Euro/year and investments for asset replacement and renovation is also 12 million Euro/year.

The water company is a municipal organisation. To serve water and wastewater to the population, in total 90 persons are employed, among them 65 for operation and maintenance.

The water source is upland surface water with very good raw water quality, and 100% water is disinfected (Chlorine) and alkalized. The network consists of 750 km of mains supporting 45000 service connections and holding 30 district metering areas. Diameters vary from 25 to 1200 mm. 29 % of the pipes consist of grey cast iron, 54 % are ductile iron, 5 % AC and 11 % PE or PVC.

Network pressure varies from 200 to 1000 kPa.

The number of failures is about 300 per year (320 repairs pr year), mainly caused by external corrosion. This corresponds to 0,4 failures per km and year. 40 km (5,3 %) of pipes are cleaned (flushing or pigging) yearly, 4,5 km/year (0,6 %) are replaced and 15 km/year (2 %) renovated.

Trondheim has not experienced major water quality problems. Thresholds have exceeded one of two times for total bacterial number (KIM) and some
practical problems (turbidity/colours) have been seen connected to flushing and repair. Contaminated water has been reported a couple of times. This is solved with disinfections, and procedures for this have been evaluated.

The municipality uses computer based systems for records included failures, complaints and inspection results. SCADA is used to collect information about pressure, reservoir level, pump, operation status, pressure control and water meters. No water quality sensors are used. A hydraulic model exists for the entire network and is used actively to analyse consequences of valve and pump operation.

Until now, no pipe has been renovated due to water quality problems. PE-lining including pipe cracking is main renovation method. Tube-in has been applied a couple of times as a temporary solution. Rehab planning is based on Decision support system CARE-W.

As for research needs, the city requests systemising of experiences, statistics and models for condition development based on failure statistics, condition measurements and knowledge about physical properties.

Regarding Operation and maintenance practises, the municipality has written practises for disinfection at mains repair, replacement and flushing and cleaning. Service reservoirs are inspected 4 times yearly. There is no pressure management.

The general impression is that Trondheim has a good control on water supply quality and reliability. There are no significant signs of increasing deterioration rates. The staff competence is adequate and economical situation is sufficient to keep the current level of service.

3.7 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 m³ 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.

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.
4 O&M SOLUTIONS TO WATER QUALITY RELATED PROBLEMS

4.1 Operation

According to the IWA definition (chapter 1), operation includes amongst others documentation, data collection and record keeping, water quality monitoring, sampling and analysing as well as risk management.

4.1.1 Documentation, data collection and record keeping

During the last 10-20 years an increase of understanding of the importance to collect and store pipe relevant information has taken place. During the same period the implementation of electronic systems in water system management has also opened up great opportunities to collect and store data in forms that can be efficiently utilised to keep an overview of location of network, repairs, inspection and condition.

4.1.2 Water quality monitoring, sampling and analysing

Sensors for water quality are sometimes used for online monitoring of water quality in order to obtain an early warning if quality parameters are beyond hazard limits (connected to automatic alarms), or as general water quality control. Sensors are available for several parameters, including turbidity, pH, oxygen, bacteria. The aim of this work task is to discuss the potential of this monitoring, how results should be used and which parameters should be included (wish-list and a possible technology list). This discussion should serve as an input into the Techneau work area 3, dealing in detail with sensor development.

The potential use of on-line continuous measurements:

- Documentation of water quality, considering customers complaints
- Warning customers if harmful substances infect drinking water
- Adjust network operation and maintenance programs, including location of flushing, valve operation and renovation
- Adjust treatment and source management
- Alert operators to acute problems
- For documentation in point-event investigation
4.2 Risk management

The strategy for managing operation and maintenance activities on a distribution system involves a forward looking risk-based approach to achieve consistent or improving water quality to customers in the most cost-effective manner. This strategy is encompassed in the Distribution and Operation Maintenance Strategies (DOMS) that is actively promoted within the UK regulatory framework by both water quality and economic regulators.

The DOMS strategy has been driven by the need to develop more adequate serviceability indicators which are focused to the particular incidents and hazards faced by individual water companies. A prime consideration is the desire for water companies to be able to detect and respond to failure events which occur infrequently and not to use judgements based solely on historical knowledge. Importantly, any framework must be set against sustainable limits for expenditure through application of cost-benefit analysis. However, it is important that DOMs are not seen in isolation from other activities taking place to improve water quality. They should be fully compatible within the Safe Water Framework promoted by WHO.

The purpose of DOMs therefore is to identify the operational and capital maintenance policies and interventions. Most importantly they must be supported by evidence-based justification both within the company and to the respective regulators. Whilst the focus is on improving water quality, the DOMs strategy should not ignore other service requirements of continuity of supply and maintaining adequate pressure.

The emphasis within DOMS is to have a strategy which is able to estimate the likelihood of future events and so move away from a reactive approach in which water companies respond to events after they occurred. An effective management strategy therefore requires the application of tools and techniques for predicting and assessing the risks associated with hazardous events in the distribution system. Rather than merely relying on potentially inaccurate historical and anecdotal judgements, this approach requires information and data of sufficient quality and quantity to make an objective assessment of the level of service being provided by the water company. The effectiveness of the risk management strategy is verified by a process of constant monitoring to determine whether the predicted and actual outcomes are similar.

4.2.1 Safe Water Framework

The guidelines for managing the quality of drinking water in supply, which are being developed and promoted by WHO, are moving towards a common approach for safeguarding human health (Fewtrell and Bartram 2001). The overall approach is encompassed within the Safe Water Framework which sets out to combine risk assessment and risk management into a single framework.
The first step in this process is to define the target for acceptable water quality supplied to consumers. These targets are normally based on the statutory monitoring requirements laid down in the EU Drinking Water Directive as transposed into national legislation in member states. In addition, health based targets are now being used in some EU countries as a benchmark for setting targets for water quality. Health based targets are based on the tolerable disease burden which is expressed as either a risk infection level or as disability adjusted life years (DALY). The Netherlands has introduced an acceptable level of risk infection for waterborne disease of one infection in a population size of 10,000. At present, health based targets are not widely accepted and further assessment is needed to determine whether such targets will be of practical value as part of the Safe Water Framework.

Whilst the primary focus is on targets aimed at protecting public health, it is also feasible to define targets for acceptable water quality which are based on other indices of quality. Targets can therefore be set for compliance with aesthetic conditions affecting water quality, such as discoloured water and undesirable tastes and odours.

The risk management plan forms the second step in the Safe Water Framework. This second step comprises the Water Safety Plan (WHO 2004), and sets out the policies and operating procedures which are to be used by a water company to deliver water of the desired quality. The principal components of the Water Safety Plan are:

- System assessment to determine whether the entire water supply system from catchment to tap is capable of delivering water of an acceptable quality,
- Operational monitoring of the measures which are being used to control processes, and
- Management plans which document the system assessment and operational monitoring and describe implementation of the plan and the course of action needed in the event of an incident.

The third step in the Safe Water Framework assesses the performance of the Water Safety Plan. The actual quality of the water being delivered by implementing the Water Safety Plan is compared against the required targets defined in the first step.

Where targets are not being met, the fourth step in the process applies risk assessment procedures to identify the most suitable control measures. The Water Safety Plan is then revised to take account of these changes. The outcome of this revision is assessed to make sure that the improvements to the Water Safety Plan are effective.

Even in those circumstances where targets are being met, risk assessment can be a useful tool to determine the margin of safety in any particular water supply system. This will allow water companies to establish situations whether any particular section of the whole water supply system is vulnerable to changing operating and environmental conditions.
The Safe Water Framework is designed to operate in a loop so that the process is one of continual improvement. This approach has the advantage of being able to predict and put in place appropriate control measures to prevent incidents from occurring or to minimise their impact.

References:

4.2.2 Risk management approach
The approach being taken is to develop and apply risk management strategies to support the decision making process for identifying and prioritising cost-effective operational and maintenance activities that achieve consistent and improving water quality to customers. Typically this approach involves a series of well defined steps which aim to:
- identify the incidents by undertaking a systematic review of the current situation and prioritise those of being most important,
- develop models to predict their temporal and spatial occurrence,
- assess the impact of these hazards, and
- develop suitable control measures to managing future risks effectively.

This approach is compatible with the overall Safe Water Framework being developed by WHO and which is being implemented through Water Safety Plans (WSP) produced by water companies.

Problem formulation:
The first step in the risk assessment approach is to establish the baseline level of service currently being provided by the water company. The level of service can be maintenance of water quality as determined by the statutory monitoring requirements laid down by legislation, as well as aesthetic impacts caused by, for example, the appearance of discoloured water. This acts as the framework against which the effectiveness of subsequent interventions to improve the level of service can be benchmarked.

The risk based approach allows hazardous events associated with the distribution system to be identified and their frequency of occurrence and consequence for customers to be determined. When assessing the nature of the risks, it is important to distinguish between the type of hazardous event and its associated mode of failure. Consequently, it is necessary to establish the cause of failure for each discretely identified event. For example a hazardous event maybe discoloured water arising from re-suspension of sediment, but the actual cause may be failure occurring as a result of a mains burst.
The incidents may vary in their duration. Incidents of limited duration may occur as a result of a failure in the asset, for example discolouration arising from re-suspension of sediment following a mains break. Other incidents may be more persistent, and may include, for example corrosion of iron mains or release of poly-aromatic hydrocarbons from coal-tar lined pipes.

An assessment of the current condition can be obtained by direct monitoring of the water in supply as delivered to the consumers. Water quality is required to meet the statutory requirements for parameters in the EU Drinking Water Directive as transposed into national legislation within EU member countries. The parameters prescribed in the regulations are primarily concerned with protecting public health and govern primarily the chemical and microbiological quality. In addition, water companies may seek to obtain further information by conducting specific monitoring exercises or by carrying out customer surveys.

**Predicting the frequency of occurrence:**
Understanding the nature of the incident is not sufficient for improving the level of service being provided to consumers. It is important for a water company is able to predict the likelihood of the occurrence an incident. This assists the development of a management strategy which is able to intervene and prevent either the incident from occurring, or minimise its impact, rather than just responding to an event once it has occurred.

The model encompasses all the means used to derive an estimate of the likelihood of an event and so may comprise expert assessment and simple deterministic models through to more complex mechanistic models which take account of the varying degrees of uncertainty.

Statistical models seek to determine whether simple relationships exist between the incident and various sets of data. These relationships may be examined using a variety of techniques which range from graphical analysis, empirically derived formula to compare the relationships between the incident and different variables, and by using some form of regression analysis. Alternatively, mechanistic models can be applied to test the relationship between the cause of the incident and its corresponding outcome.

In the absence of sufficient data, the models are based on expert judgement relating to the best available knowledge of the system. Whilst such models tend to be the least robust, they can offer a simple means of screening many systems to identify where further and more detailed investigations would be required. The score-card system has been successfully developed and applied in an attempt to make such assessments more objective.

The model requires calibration and verification to check that the outcomes predicted by it are consistent with actual observations encountered in practice. Ideally data sets should be split in two, allowing one half of the data to be used for calibrating the model whilst the other half is used for validation.
of the model. Often data sets have insufficient data to enable this practice to be performed and reliance has to be placed on a secondary and less reliable source of data. Under certain circumstances, the accuracy of the models could be improved by undertaking specific monitoring programmes to gather more data. This has the effect of reducing the uncertainties and making the predictions from the model more accurate.

Assessing the impact:
The risk assessment aims to establish the consequence of each incident by determining both its likelihood and probability of occurrence, and its severity or impact on the consumer. Both these factors require suitable criteria for establishing their magnitude.

The probability of an event occurring could be described by its frequency of occurrence using a scale ranging from daily, weekly, and monthly through to yearly. These timescales could then represent high frequency through to low frequency of occurrence respectively.

The criteria for determining the consequences of an incident may be based on an assessment of its impact on consumers. The effects caused by an incident may include one or more of the following: health effects, aesthetic impacts and economic consequences. Accordingly, different thresholds are required for each of these effects as their severities are not the same. For example, for the same population size, a higher consequence would be attributed to a health impact compared to an aesthetic impact.

Some difficulties will be encountered when trying to determine the consequences of a health effect attributed to the presence of bacteria of sanitary significance which are the parameters routinely monitored under the regulations. These bacteria have no direct consequences to public health and so some arbitrary assessment has to be made to estimate their impact on customers. However, Microrisk, the recently completed EU study, has developed tools and techniques to assess the risks from a variety of waterborne pathogens in drinking water. The approach developed in this study will enable better risk estimates to be obtained which will improve an assessment of the public health impact. Indeed, some countries have adopted health based targets based on the tolerable level of risk infection permitted through drinking water. Such targets may prove useful in the future for setting appropriate health based criteria for assessing the consequences of an incident attributed to poor bacteriological water quality.

On this basis of this classification, the risk associated with each incident can be expressed as a function of its score on the probability scale and its corresponding score on the consequence scale. Thus the highest ranking would be given to an incident with a very high probability of occurring and where the consequences are severe. In contrast the lowest ranking would be given to an incident with a low probability of occurring and where the consequence has little impact. This enables each of the incidents to be
prioritized and action can be taken to deal with those deemed to be most important.

Applying control measures:
Once the incidents requiring action have been established, highest priority should be given to addressing those incidents deemed by the risk assessment to be the most serious. A strategy is developed which sets out the policies and procedures which have been developed to implement the appropriate control measures. Ideally, the control measures are aimed at preventing the incident from occurring in the first place. Alternatively, and less effectively, the control measure can either reduce the likelihood of an incident from occurring or lessen its impact.

A series of well defined steps are required to set up and monitor the control strategy, and are as follows:

- define the objective of the operational strategy,
- apply suitable performance measures to assess the effectiveness of the improvement strategy, and
- have a suitable monitoring and decision framework in place to determine the success of the strategy.

Defining the objective of the operational strategy takes into account an assessment of the control measures that can be applied and identify whether current practice is sufficiently adequate to respond to potential incidents. The feasibility of introducing new control measures can be considered along with revision of those already being used by the water company.

The effectiveness of the control measure has to be demonstrated to ensure that it is being properly implemented. Consequently, some form of operational monitoring is required to check that the desired level of service is being consistently achieved. Operational monitoring may take the form of monitoring water quality to ensure compliance with the statutory monitoring parameters, inspection of the assets to make sure that the integrity of the infrastructure is secure and that equipment is properly functioning as well as audits to check that the procedures are actually being implemented. The type and frequency of monitoring that is required will depend on the nature of the control measure being applied and the particular incident being managed with regard to its seriousness and potential impact.

Each of these categories of operational monitoring requires thresholds which are used to determine whether the control measure is having the desired effect. Routine inspection of the outcome from the monitoring programme is carried out to determine whether it provides the data that is needed to test the effectiveness of the control measure and that the required targets are being met.
4.2.3 Risk management implementation

The effectiveness of the risk assessment management strategy for distribution system operation and maintenance requires an operating system for implementation. This is periodically examined and modifications made to operating procedures where necessary. The performance of the strategy can be assessed to determine whether the level of service now being provided has improved compared to that being provided before the risk management strategy was put in place. On this basis, revisions may be required to the programme of operational monitoring and subsequently the control measure to ensure that both continue to function effectively.

Generally water companies have effective procedures for storage and retrieval of data and operating procedures. However, the information that is required for a distribution system operation and maintenance strategy is likely to be dispersed. As a consequence it doesn’t lend itself to being part of an effective set of policies and procedures for implementing a successful risk management approach.

Ideally, the overall operational and management strategy is contained in a common framework, setting out the overall objectives and containing details of the individual policies and procedures that support the risk management process. All relevant information should be capable of being archived and retrieved effectively. Linked to this strategy, is information relating to the status of the infrastructure, including:

- Classification and geographical referencing of the network,
- Maintaining asset data and modifications carried out on the system
- Recording performance of operational activities and associated costs.

The implementation of this strategy requires an appropriate administrative system to support its operation. Ideally, there is need for a nominated person in control of distribution system operational activities.

4.2.4 Discussion

Risk management is now an established practice within the water industry as a formalised process for continual improvements in water quality and the level of service provided. Very much the aim of this strategy is to have an approach which allows water companies to develop and implement policies and procedures which are most appropriate for their particular circumstances. The success of this approach however depends on continuous assessment to ensure that the management plan remains effective and is able to respond to changing environmental and operating conditions.

The development of practical tools and techniques for managing operation and maintenance activities on distribution systems being developed in WP5.6 could be incorporated within a risk management framework. This will allow water companies to select and implement the most appropriate control measures supported by an evidence based decision making process rather
than relying on historical or anecdotal assessments which may not be accurate. Therefore, one of the aims of the future work within WP5.6 is to develop a strategy which presents the model for optimising network activities into a single uniform approach, which is compatible with water safety planning.

This approach will also address the need to have defined procedures for risk assessment to support the risk management strategy. Within the water safety planning process it is important for water companies to develop a more forward looking approach to managing water quality by predicting when and where events are likely to occur rather than responding to events after they occurred. Therefore, the work in WP5.5 will contribute suitable tools and models for predicting deterioration in water quality which can be integrated into the overall risk management strategy.

The current operating regime within the water industry requires that the improvement measures are also assessed within an economic framework. This helps with decision on prioritising what event is most in need of being dealt with and what is the most cost effective control measure. The work being carried out within WP5.1 will prove useful by providing a solid basis on which to make those decisions.

In a wider context, the operational and maintenance strategy needs to be assessed on a much broader basis to ensure the plan delivers the desired improvements in the most cost-effective manner. In this way the outcomes from the risk assessment can be used to make evidence based decisions which can be justified within the company as well as to the relevant regulatory authorities.

References:

4.3 Maintenance

According to the IWA definition (alegre et al., 2006), maintenance includes system inspection, regular maintenance checks or service activities, repairs of failures and other defects, cleaning and refurbishment and regular meter replacement and maintenance.

4.3.1 Inspection and regular maintenance checks

Two major groups of assets should be considered with regard to inspection, according to the ease of access: above ground and buried assets. Above ground devices can be more easily inspected, as they allow for direct observation. Depending on the type of asset, specific inspection procedures
are adopted in complement to the visual observation, such as vibration and noise measurements, energy auditing, condition of fittings assessment, etc. For buried infra-structures, particularly pressurised pipes, indirect inspection procedures tend to be adopted, such as leak detection, location and repair, or condition assessment based on samples collected. CCTV inspection is used in some cases, but much less frequently than, e.g. in sewer networks.

Water quality related inspection of drinking water pipelines includes methods that describe condition at surface.

- CCTV/Photo. Electronic surface scanning with high temporal and resolution can now be obtained. Security aspects must be considered if such equipments are brought into contact with drinking water.
- Integrated systems for pipe surface inspection, leak detection and remaining wall thickness are emerging. These methods can detect points at the network where leakages have been developed or are developing. As such they are important to detect spots where water can infiltrate during periods without pressure, and thus cause harm to the water supply (Thameswater, Breivoll Inspection Technology).

Valve inspection is sometimes neglected due to high number of existing devices. Valve density (per km of mains or per number of service connections) depends very much from network to network. Some utility adopt a high valve density to minimise the consumers affected by any network intervention, other argue that they prefer to keep a lower valve density, but assure valves are adequately maintained. This is one of the issues TECHNEAU should analyse in more detail and identify best practices.

Regular maintenance of electro-mechanic devices requires interventions, such as cleaning, painting, fittings replacement and lubrication. Typically, many of the products used for these functions are not, by their nature, safe to be in direct contact with drinking water. Utilities and manufacturers implement different measures to mitigate the corresponding risk, but this is also an issue that deserves a particular attention in the framework of TECHNEAU.

Storage tank inspected includes external visual observation, in the case of above ground tanks, water balance audits and internal inspections. Internal inspections require that the tank cells are emptied. Internal inspection is generally periodic and associated with cleaning. Frequency adopted very much from case to case, and from country to country. In Portugal, for instance, it is considered that a good practice is that service reservoirs are cleaned every year, or every two years at the most. In other countries frequency is much lower (e.g. once in every 5 years). The hygienic requirements, the quality of the raw and the water temperature are factors to be taken into account, but apparently there is a need for a more detailed comparison of existing practices and definition of general guidance for the utilities. Cleaning is generally carried out using high pressure water jets. Sometimes cleaning products are used. In this case a careful selection of these products and a good control of its removal are crucial from the water quality...
viewpoint. Routine maintenance may involve leak repairs, and surface treatment (e.g. painting), which greatly depend on the type of surface.

4.3.2 Repair procedures

Repairs of burst and leaks in the drinking water network leave the pipe exposed to soil and dirt in the ditch, in some cases even wastewater. Additionally, pressure is removed for network close to repair spot. Most cities are concerned with this and have developed careful procedures to maintain hygienic issues, and normally the pipelines exposed by the repair are disinfected prior to further operation. However, normally, a larger zone downstream repair spot are left without pressure when repair is conducted.

Pipe repair procedures directly related to hygienic aspects may include requirements such as:

- The area of the intervention should be minimised, and adjacent areas with significant pressure drops monitored;
- Small and medium size fittings or other devices to be installed which will be in contact with the water should be cleaned and disinfected beforehand and taken to the worksite duly packed to prevent contamination;
- Bigger size devices should be disinfected locally;
- Pipes to install should be kept as clean as feasible during the work;
- All the area isolated for the intervention should be flushed;
- Whenever feasible, the area isolated for the intervention should be disinfected; however, this is frequently not the case, as referred in Error! Reference source not found.; improved practices with this regard are necessary;
- Flushing of adjacent areas may be advisable if the get depressurised as well.

4.3.3 Flushing and cleaning

Building up of sediments and corrosion products in distribution systems can impart taste, odour, colour and turbidity to water and, additionally, creates conditions to the enhanced growth of micro-organisms as they are protected from residual disinfectants. Besides increased customer complaints, overall water quality degrades over some located areas of the network. In some cases (e.g. tuberculation of the pipes), hydraulic conditions also deteriorate. Flushing and cleaning the water mains are maintenance operations that provide temporary benefits for some water quality problems as they are able to remove accumulated sediments and tuberculation. To obtain a more permanent solution, routine flushing and cleaning should be included in a combined program of flushing, mechanical cleaning and rehabilitation. Furthermore, the need to modify the characteristics of the water supplying the system, by changing the treatment scheme, has also to be evaluated.
Distribution system flushing consists of opening, in a planned pattern, adequate hydrants or washouts in order to remove deposits from well-defined zones of the system. Unidirectional flushing (UDF) is a refinement of standard flushing that consists of closing valves to restrict the direction that water can flow to open hydrants and, therefore, maximise velocity in pipes to be flushed (Mays, 2000; Antoun et al., 1999). It has the advantage of creating higher velocities while spending less water.

Air scouring is an alternative to these techniques, which has proven to be effective in areas where flushing is unsuitable, like in low-pressure areas where potential velocities are low. The air scouring technique involves the injection of filtered compressed air into an isolated section of water main to generate increased velocity, which is greater than the minimum velocity required to remove suspended sediments. Air scouring involves a mix of air and water called a slug flow. Given a constant supply of air and water the slug flow strips any loose deposits and some biofilm from the pipes. Industry experience indicates that air scouring uses approximately 40% less water than normal flushing techniques.

Besides routine maintenance, flushing is also used to clean new installed or repaired mains before and after disinfection. It can also provide an effective means of routine inspection and testing of the condition of hydrants, valves and other fittings of the system. Mechanical cleaning consists of introducing abrasive devices, with adequate diameter, into selected pipes of the network and forcing them to move along the pipe while they scrape the inner walls. The devices, together with dirty water, sediments and other solids, are then recovered at the end of the pipe being cleaned (for example, in a fire hydrant). While flushing is only able to remove sediments and soft scales, cleaning provides a more effective pipe scrape, therefore also removing more attached incrustations and hard tuberculation. As the pipe roughness decreases during cleaning, this operation can also result in the improvement of systems hydraulics.

Cleaning can be the first phase of a rehabilitation program and precede pipe lining.

Criteria to flush and clean:
Widely used criteria for mains flushing/cleaning are still very general and can be summarised as follows:

- flush and/or clean dead-ends of the network;
- flush and/or clean mains subject to sediments deposition, taking into account that heavier sediments accumulate in larger mains and form small mounds that can be re-suspended causing quality problems in smaller mains downflow (AWWA, 1986);
- clean mains suspected to have tuberculation and incrustation;
• locate mains to be flushed considering customer complaints of “dirty-water”, “sand in the water”, “organic material in the water”, turbidity, discoloured water, poor taste and odour;

• flush areas of the network suspected to have a specific contaminant originating from a well defined source of contamination (e.g. cross connections, infiltration from leakage or pipe bursts, insufficiently protected tanks);

Table 4.1 lists problems and parameters associated with increased travel time and, consequently, with water quality degradation problems that can be, eventually, solved with flushing/cleaning programs. These parameters can, therefore, be used as indicators of the necessity to flush/clean a network, in addition to the general criteria presented in the preceding paragraph.

Table 4.1 – Problems and parameters associated with increased travel time in distribution systems (adapted from EPA, 2002)

<table>
<thead>
<tr>
<th>CHEMICAL ISSUES</th>
<th>Disinfection by-products increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Disinfectant decay</td>
</tr>
<tr>
<td></td>
<td>Corrosion control effectiveness</td>
</tr>
<tr>
<td></td>
<td>Taste and odour</td>
</tr>
<tr>
<td>BIOLOGICAL ISSUES</td>
<td>Disinfection by-product degradation</td>
</tr>
<tr>
<td></td>
<td>Nitrification</td>
</tr>
<tr>
<td></td>
<td>Microbial regrowth (high bacterial counts)</td>
</tr>
<tr>
<td></td>
<td>Taste and odour</td>
</tr>
<tr>
<td></td>
<td>Biological corrosion</td>
</tr>
<tr>
<td>PHYSICAL ISSUES</td>
<td>Temperature increases</td>
</tr>
<tr>
<td></td>
<td>Sediment deposition</td>
</tr>
<tr>
<td></td>
<td>Colour</td>
</tr>
<tr>
<td></td>
<td>Turbidity</td>
</tr>
</tbody>
</table>

Several water supply systems modelling software (e.g. Infoworks WS from Wallingford Software and WaterCAD from Haestad Methods) include routines for sedimentation analysis, which enables the assessment of areas to flush/clean. For this evaluation, pipe materials information and spatial data such as customer complaints are needed.

KIWA (2002) describes a set of techniques, under the general designation of Resuspension Potential Method, for the assessment of discoloured water and that will point out problematic zones that need to be flushed/cleaned. The method is based on the principle that by introducing a disturbance in the water flow the sediment present will be resuspended and will cause an increase in the turbidity of the water (Figure 1). The increase in turbidity is a measure of the degree of sediments accumulated in the mains under analysis. Pipes with high sediment contents will be the candidates for flushing.
Nowadays, the RPM is already used by a large number of water suppliers to monitor the condition of the network in terms of particle deposition.

Operational practices for flushing:

At present, most water suppliers still refer to AWWA standards and guidelines, first described in AWWA (1986).

Procedures for flushing:
A general rule for designing a flushing program is that hydrants should be operated following a planned pattern that allows to pull the clean water into the area to be flushed (“flush with clean water behind you”). Therefore, flushing programs usually begin at the source and move out through the system. Additionally, in order to have adequate capacity, large mains should never be flushed from smaller mains.

Table 4.2 summarises main operational requirements during flushing programs. Detailed procedures can be found, for example, in AWWA (1986).

In order to have a sufficient amount of water to accomplish flushing objectives, minimum velocity should be 0,75 m/s, while the optimal value is 1,5 m/s. Higher values (3,6 m/s) may sometimes be required to remove sand from river undercrossings (AWWA, 1986). According to Mays (2000) minimum velocity to suspend solids is 0,61 m/s and maximum velocity that minimises waterhammer is 3,1 m/s. The corresponding rate of flow depends on pipe diameter and can be determined from pressure measures (taken with Pitot gauges), with the following equations (AWWA, 1986):

\[
Q = 26,8d^2 \sqrt{P}
\]

\[
V = \frac{0,409Q}{D^2}
\]
where: $Q$ – flushing rate (gpm)  
$d$ – diameter of nozzle or opening (in)  
$P$ – Pitot gauge pressure at nozzle or opening (psi)  
$V$ – flushing velocity (fps)  
$D$ – diameter of main being flushed (in)

Flushing in response to customer complaints of odour and taste should be done at low velocities, in order not to suspend settled solids and cause “dirty water” cases.

During flushing periods, the pressure of the system should be controlled (by varying hydrants flow) in order that values do not drop below 140 kPa (20 psi). Pressure checks should also be made in higher areas of the network. As water demands are lower, night flushing has the advantage of not lowering pressures as much as day flushing.

Other advantages of night flushing are the ease of operation due to reduced car traffic and the lower inconvenience caused by the water discharged from the system.

Finally, attention should be given to flushed water discharges: where to discharge, necessity to prevent floodings and need for dechlorination if these discharges are to be made in sensitive aquatic environments.

*Table 4.2 - Operational parameters during flushing programs (AWWA, 1986; Mays, 2000)*

<table>
<thead>
<tr>
<th>OPERATIONAL PARAMETER</th>
<th>REQUIREMENTS</th>
</tr>
</thead>
</table>
| Velocity              | minimum required: 0,75 m/s (AWWA, 1986); 0,61 m/s (Mays, 2000)  
desirable: 1,5 m/s (AWWA, 1986)  
maximum: 0,61 m/s (Mays, 2000)  
required for removal of sand from river undercrossings: 3,6 m/s |
| Pressure               | above 140 kPa |
| Duration of flushing  | long enough to clear the water and obtain normal disinfectant concentrations |
| Frequency of flushing  | determined by regular quality monitoring and customer complaints  
suggested initial frequency: 1/month  
adjust according to time that water takes to clear during flushing; if time is less than 6 seconds, then lower frequency to semi-annual schedule |

Procedures for cleaning:  
*Error! Reference source not found.* describes the characteristics of most commonly used cleaning devices, including information on conditions of use and some operational parameters during cleaning programs. Detailed procedures can be found, for example, in AWWA (1986). The two main cleaning methods are the use of water propelled polyurethane foam rubber devices called pigs and the use of scrapers. Pigs are bullet-shaped devices available with different exterior coatings and foam densities.
Lower densities, usually called “soft sponges”, are used for light cleaning (removing loose sediments, soft scales and slimes without disturbing hardened incrustations) and higher densities are needed to completely remove harder deposits. Scrapers are mechanical devices equipped with spring-loaded metal blades that move through the pipes in several ways: water propelled, physically pushed or pulled. Scrapers are suited for removing the hardest incrustations.

Like in flushing programs, attention should be given to the disposal of water discharged during cleaning: where to discharge, necessity to prevent flooding and need for dechlorination if these discharges are to be made in sensitive aquatic environments.

Post-cleaning procedures are also important and consist of flushing the mains that has been cleaned, followed by chlorinating at high concentration (400 mg/l for 1 hour) and a final flushing.

Monitoring flushing and cleaning:
AWWA (1986) recommends that, during the flushing/cleaning period, samples should be taken for analysis of residual disinfectant, odour, colour and turbidity. The presence of visible particles or organisms should also be evaluated.

Of course, if flushing is implemented in emergency situations, to remove specific contaminants that entered the system (for example, chemicals originating from cross-connection contamination), monitoring of the relevant substance should be carried out until its concentration can no longer be detected.

If the purpose of a cleaning program is to improve the hydraulic capacity of a main, effectiveness of cleaning is usually evaluated by calculating the Hazen-Williams C-factor, before and after the operation.

Modelling flushing and cleaning:
Hydraulic and water quality models can assist in designing, implementing and evaluating the effectiveness of flushing/cleaning programs. Models are useful in:

- determining direction of flow in systems with multiple sources or looping paths;
- determining velocities in pipes expected during flushing, in order to evaluate if adequate flushing values are obtained;
- determining system pressures during flushing, in order to evaluate if pressure does not drop below minimum recommended values, thus affecting consumers in the network being flushed;
- determine the duration of flushing that allows the water disturbed by flushing to be expelled from the system;
- locate and minimise areas that will not be successfully cleaned after a flushing operation, due to only slight increases in velocity over normal
conditions and to insufficient duration that prevents suspended sediments from exiting at the flushed hydrants.

Hydraulic modelling will be sufficient to deal with the first 3 items. Hydrants being flushed can easily be modelled by changing the demand in a node corresponding to the location of the hydrant in the network (Walski, 2001). A water quality model, performing EPS (Extended Period Simulation) runs, will be needed for the determination of flushing times. For this purpose, the modeller can use the water quality tracing feature in the model and track chlorine as an indicator of effectiveness of the flushing. As an alternative, the user can tag the water initially in the system with a concentration of 0,0mg/l and the water at the source with a concentration of 100mg/l and monitor the time needed for the fresh water to move trough the system during flushing (Walski, 2001).
Models cannot simulate turbidity during flushing because this parameter does not conform to the law of conservation of mass (Walski, 2001).

References:


Table 4.3 – Cleaning devices and some associated operational procedures (adapted from CSIRO, 2003)
<table>
<thead>
<tr>
<th>Type of cleaning device</th>
<th>Subtype of cleaning device</th>
<th>Device characteristics</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pig</td>
<td>Bare pig</td>
<td>- no coating</td>
<td>- suited for light cleaning (removing loose sediments, soft scales and slimes)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- low material densities (32-96kg/m³)</td>
<td>- used in pipes 50mm to more than 1800mm in diameter and lengths up to 1200m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- sized 2% over the pipe inner diameter</td>
<td>- used to make final sweep after other types of pigs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- length is twice the pipe diameter</td>
<td>- is the first pig to be sent through a pipe to probe the flow direction and real pipe diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- device is propelled by water pressure</td>
<td>- used to make final sweep after other types of pigs</td>
</tr>
<tr>
<td></td>
<td>Coated pig</td>
<td>- same density of high density bare pig</td>
<td>- suited for cleaning most type of tuberculation except very hard incrustations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- differs from bare pigs because it has outer coating of tough polyurethane syntetic rubber strips arranged in a criss cross pattern (when pressure is applied at the back, the bands expand and act as a wedge against the pipe wall)</td>
<td>- used in pipes 50mm to more than 1800mm in diameter and lengths up to 1200m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- sized 2% over the pipe inner diameter</td>
<td>- 10-20 swabs required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- length is twice the pipe diameter</td>
<td>- device is propelled by water pressure</td>
</tr>
<tr>
<td></td>
<td>Scraper pig</td>
<td>- smaller than coated pigs, but the rubber strips contain heavy silicon carbide grit or flame-hardened wire bristles</td>
<td>- suited for cleaning the harder incrustations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- length is twice the pipe diameter</td>
<td>- used to scrap pipes in preparation for lining</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- device is propelled by water pressure</td>
<td>- used in pipes 50mm to more than 1800mm in diameter and lengths up to 1200m</td>
</tr>
<tr>
<td></td>
<td>Power boring</td>
<td>- involves pushing and rotating a tool against a counterflow of water</td>
<td>- 10-20 swabs required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- the tool consists of a steel body holding bent steel rods that spring against the pipe wall</td>
<td>- suited for cleaning very heavily turbeculated mains</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- removal of tuberculation is made by the rotating action of the tool, which is provided by a series of connecting steel rods driven by a boring machine</td>
<td>that prevent the passage of a cable for drag scraping or that do not generate adequate pressure for pressure scraping</td>
</tr>
<tr>
<td></td>
<td>Drag scraping</td>
<td>- the scraper is repeatedly pulled back and forth inside the pipe, with the aid of two cables connected to the cleaning tool</td>
<td>- used in pipes of 75-300mm in diameter and lengths up to 150m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- the cleaning tool consists of a series of spring steel blades set into a main body</td>
<td>- only one pass through the pipe is required</td>
</tr>
<tr>
<td></td>
<td>Pressure scraping</td>
<td>- scraper is propelled by water pressure (same operation principle as pigging)</td>
<td>- suited for cleaning very heavily turbeculated mains</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- the cleaning tool consists of a series of spring steel blades set into a main body</td>
<td>- used in pipes of 75-1000mm in diameter (usually 75-450mm) and lengths of 100-250m</td>
</tr>
</tbody>
</table>
|                         |                           | - minimum water pressure needed: 200kPa | - only in pipes with no valves
4.4 Models

4.4.1 Hydraulic simulation models
A hydraulic simulation model is composed of:

- System data (topologic and asset physic data, consumption data, operational controls);
- Set of mathematical equations describing the hydraulic behaviour of a water network;
- Numerical algorithms to solve these equations.

Model outputs are expressed in terms of state values, such as pipe flows, velocities and head losses, nodal head, etc. If calibrated, models produce results - with an accuracy that can be estimated - the behaviour of the entire real system, aiming at analysing typical scenarios, existing or hypothetical.

Among the most common applications are (Coelho et al., 2005):

- Support to network design;
- Support to the elaboration of master plans;
- Simulation of problems and scenarios of routine operation, without or with the consideration of system failures of emergency situations (e.g. fire fighting);
- Staff training;
- Support to the diagnosis of deficient systems and the definition of rehabilitation measures;
- Control and optimization of rechlorination points, based on travel times;
- Support to optimum pump scheduling;
- Support to DMA planning, allowing for the comparison of the hydraulic behaviour of different candidate alternatives and for the minimization of the negative impacts;
- Support to pressure control strategies.

Almost all these uses are relevant from the water quality viewpoint as well.

4.4.2 Water quality models
Water quality models could be useful to support sampling of tests, plan for operation, maintenance and rehabilitation and to optimise treatment models.

The principle idea of a hydraulic model is to analyse if a network has sufficient supply capacity at all nodes. As a second purpose, it can potentially be used for analysis of water quality. Water quality modelling will increase the understanding of water quality affecting processes in the network, and may partly substitute sensor measurements. Water quality modelling may thus be a good tool for operation and maintenance planning, optimization of treatment processes etc.

Roughly, there are three groups of water quality models:

- Models that can track water quality changes in network, without any modelled reaction.
• Models that can track water quality changes in network, and simulating a reaction.
• Microbiological models that simulates a process on microbiological parameters.

There are three main processes for water quality changes through the network, additional to the mass transport due to moving water body:
• One-dimensional advection
• Mixing of water with different concentration in nodes or basins
• Chemical or biological reactions

Existing hydraulic models like EpaNet, MIKENet, Water Cad, Aquis, Piccolo, Infoworks, H20Net facilitates 0.order and 1.order equations for reactions in water body or with pipe wall. This is mostly used to model chlorine decay, but can in principle model whatever 0.order and 1.order reaction.

Travel time is modelled with hydraulic models with relatively high accuracy, though there are some difficulties of definition of travel time including:
• Because of the blending of different source waters and the existence of parallel paths to the customer, age of water is almost always an average in such sense
• Because of the individual variation of demand, travel time is not a constant value or pattern for a given site in the system. Moreover, travel time of a plug of water is dynamic over its path to the customer.

The mentioned models have some differences regarding the applied mixing processes. This is of significant importance in for example water storage basins. The models can also track the water through the network, from which node it comes to which node it flows. This may be useful information of flush plans.

Chlorine decay and formation disinfection bi-products (DBP) plus sedimentation and dis-colourisation of water are the most common water quality problems to be modelled. The models WatSed (Wallingford) and Piccolo have been developed for sediment transport, and to define areas vulnerable to sedimentation (Vieira 2003).

From a hygienic point of view it would have been even more important to model microbiological processes. Models on biological growth and bio stability have been developed (Vieira 2003). Until now this deterministic model approach has been too complicated for commercial implementation.

References:


• Hardy-Cross, L. (1936). Analysis of flow in networks of conduits or conductors, Bulletin no.286, University of Illinois Experimental Station, Urbana, IL, EUA.


4.5 Monitoring systems

Sensors for water quality are used for online monitoring of water quality to obtain an early warning if water quality are beyond hazard limits (connected to automatic alarms), or a general water quality control. The aim of this work task is to discuss the potential of this monitoring, how results should be used and which parameters should be included (wish-list and a possible technology list). This discussion should serve as inputs into the Techneau WPs dealing in detail with sensor development.

The potential use of on-line continuous measurements:

- Documentation of water quality, considering customers complaints
- Warning customers if harmful substances infect drinking water
- Adjust network operation and maintenance programs, including location of flushing, valve operation and renovation
- Adjust treatment and source management

Table 5.1 below gives an overview of existing and emerging sensor technologies (Hafskjold et al. 2005, in Norwegian). By correlation analysis, these techniques may be used for a wider range of water quality parameters.

### Table 5.1: Existing and emerging sensor technologies

<table>
<thead>
<tr>
<th>Existing on-line sensor technologies</th>
<th>Existing at-line technologies (multi-analysis instruments)</th>
<th>Emerging technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>Nutrients (phosphorous, nitrogen, ammonium)</td>
<td>UV-spectrometri</td>
</tr>
<tr>
<td>pH</td>
<td>TOC, COD, BOD</td>
<td>Design of proteins (DNA)</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Hydrocarbons</td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>Heavy metals</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Coliform bacteria</td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particles</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Additional to sensors for water quality analysis, inspection of pipe condition can give important information for water quality based maintenance. CCTV and camera inspection have existed for many years. Those methods are primarily applied for wastewater systems, but some also for drinking water. Leak detection methods are also commercial, while integrated systems for pipe surface inspection, leak detection and remaining wall thickness are emerging. These methods can detect points at the network where leakages have been developed or are developing. As such they are important to detect spots where water can infiltrate during periods without pressure, and thus cause harm to the water supply.

4.6 Integrated method for water quality driven rehabilitation

Up to now, water quality modelling has only to a very limited degree been used for maintenance and rehabilitation planning. In a previous EU project, the system Computer Aided REhabilitation of Water networks (CARE-W) was developed. This is mainly based on physical parameters (bursts, leaks, water supply regularity. A stronger inclusion of water quality issues for rehabilitation planning and project ranking has been requested.

As a part of WP 5.6.2, CARE-W will therefore be extended with a water quality model that tentatively will be designed as

1. Running water quality model on travel time, velocities (risk sedimentation) and adequate water quality parameters, define on vulnerable parts of network (pipes, sites)
2. Check records on ground water level, pipe condition, define rules for finding pipes with a risk for infiltration of contaminated water
3. Analyse adequate sensor measurements, select problem spots.
4. Include defined pipes with increased water quality risk to CARE-W ARP model (reprogram ARP)
5. A framework for a new combined deterministic/probabilistic model for pipe failure will be designed. This will rely on mechanisms for corrosion formation (sediments, external water/humidity level, materials, construction year). The model will be tested on existing network if data is available.
I Interview answers from end-users

Berlin

Utility profile

<table>
<thead>
<tr>
<th>Utility ID:</th>
<th>Berliner Wasserbetriebe [Full official designation of the utility]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of activity</td>
<td>☑ Water only</td>
</tr>
<tr>
<td>☑ Multiservices</td>
<td></td>
</tr>
<tr>
<td>Utility size:</td>
<td>404 10^6 € of sales revenues from the water supply services /year</td>
</tr>
<tr>
<td></td>
<td>195 10^6 m³ of billed water /year</td>
</tr>
<tr>
<td>Employees:</td>
<td>1000 employees [utility total]</td>
</tr>
<tr>
<td></td>
<td>O&amp;M employees [water supply services]</td>
</tr>
<tr>
<td>Total running costs:</td>
<td>10^6 € /year [total running costs of the water supply services]</td>
</tr>
<tr>
<td>Total capital costs:</td>
<td>10^6 € /year [total capital costs of the water supply services]</td>
</tr>
<tr>
<td>Running costs of O&amp;M functions:</td>
<td>% of total running costs</td>
</tr>
<tr>
<td>If feasible, split into:</td>
<td>Operation running costs: % of total running costs</td>
</tr>
<tr>
<td></td>
<td>Maintenance running costs: % of total running costs</td>
</tr>
<tr>
<td>O&amp;M outsourcing:</td>
<td>% [approximate % of O&amp;M opex related to outsourcing]</td>
</tr>
<tr>
<td>Investments for asset replacement and renovation</td>
<td>% of the total capital costs</td>
</tr>
</tbody>
</table>

Comments [optional field]

Water supply system profile

Type of system:

| ☑ Bulk supply and |
| ☑ Bulk supply only |
| ☑ Distribution only |

Water sources
<table>
<thead>
<tr>
<th>Water Source</th>
<th>% of Total Abstraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland surface water</td>
<td>0%</td>
</tr>
<tr>
<td>Lowland surface water</td>
<td>0%</td>
</tr>
<tr>
<td>Natural springs and wetlands</td>
<td>0%</td>
</tr>
<tr>
<td>Well water</td>
<td>0%</td>
</tr>
<tr>
<td>Borehole water</td>
<td>100%</td>
</tr>
<tr>
<td>Saline and brackish water</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Comments** [optional field]

**Treatment**

- No treatment: 0% of water delivered to users without any treatment
- Disinfection only: 0% of total abstraction
  - 14 (for emergency cases) [Number of] disinfection facilities
- Carbonizing/pH increase: 0% of total abstraction
- Conventional treatment: 100% of total abstraction
  - 9 [Number of] treatment plants
- Advanced treatment: 0% of total abstraction
  - 0 [Number of] treatment plants
- Water volume produced: 206,106 m³/year

**Transmission and distribution**

- Target residual disinfectant: to mg/l at the consumer's tap
- Network size: ca. 7800 km of mains
  - 0 [Number of] service reservoirs customers
  - 0 [Aprox. number of] domestic tanks
  - 3.4 Mio [Number of] customers
  - 250000 [Aprox. number of] service connections
  - 0 [Aprox. number of] district metering areas

- Diameters:
  - Minimum diameter: 80 mm
  - Maximum diameter: 1400 mm
  - Dominant range:
Less or equal 200 mm
Greater than 200 mm but not greater than 400
Greater than 400 mm

Mains materials:
- 56 % of grey cast iron
- 22 % of ductile iron
- 9.8 % of steel
- 0 % of ferrous mains without adequate corrosion protection
- 11.8 % of asbestos cement
- 0.16 % of polyethylene
- 0.17 % of polyvinyl chloride

Mains failures: <900 [Number of] failures
Mains repairs: <900 [Number of] repairs [planned and unplanned]
Non-revenue water: <5 % of input volume that is not billed
Cleaned mains: 7 km of mains
Replaced mains: 64 km of mains
Renovated mains: 7.3 km of mains
Replaced service connections: 3200 [Number of] service connections
Network pressure
- 280 kPa of minimum network pressure any node
- 500 kPa of maximum network pressure at any node

Comments [optional field]

Water quality problems in the network

<table>
<thead>
<tr>
<th>Type of problems and frequency of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting standardized thresholds for microbiologic, chemical, physical parameters</td>
</tr>
<tr>
<td>Health hazard (e.g. bacteria)</td>
</tr>
<tr>
<td>Practical requirements (turbidity/colour)</td>
</tr>
<tr>
<td>Practical requirements (taste/odour)</td>
</tr>
</tbody>
</table>
## Water quality-related Operation & Maintenance practices in the network

### O&M organisation

<table>
<thead>
<tr>
<th>Organisation of operation and maintenance (structure, crew, equipment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew training.</td>
</tr>
<tr>
<td>Do complaint records exist? Are they a reason for operation and maintenance actions?</td>
</tr>
<tr>
<td>- There is a crew training</td>
</tr>
<tr>
<td>- Complaint records exist and this are of course one of the reasons for O&amp; M [expand as needed]</td>
</tr>
</tbody>
</table>

### Hygienic protection

<table>
<thead>
<tr>
<th>Routines and rules to protect network from infiltration. Has infiltration of contaminated water been reported?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are disinfection routines sufficient to protect all customers?</td>
</tr>
<tr>
<td>Do guidelines exist for hygiene on repair and management actions (disinfection rules, crew equipment, control)?</td>
</tr>
<tr>
<td>- No contamination of water has been reported yet</td>
</tr>
<tr>
<td>- There is no desinfection routines</td>
</tr>
<tr>
<td>- A guideline for Hygiene on actions exist [expand as needed]</td>
</tr>
</tbody>
</table>

### Computer records and model

<table>
<thead>
<tr>
<th>Do computer based utility systems for the network exist? If so, what do they include?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the entire network covered by the record system?</td>
</tr>
<tr>
<td>- GIS, rehabilitation strategy, network modelling [expand as needed]</td>
</tr>
<tr>
<td>Is SCADA used? If so, what information is collected?</td>
</tr>
<tr>
<td>Are automatic mapping (GIS) applied to water network management?</td>
</tr>
<tr>
<td>- SCADA is used</td>
</tr>
<tr>
<td>- Pressure, flow, at the outlet of each water work and booster are online measured and stored</td>
</tr>
<tr>
<td>- pH, oxygen, conductivity, turbidity and redox-reaction( potential)are also measured and stored</td>
</tr>
<tr>
<td>- They are used to control the water supply [expand as needed]</td>
</tr>
<tr>
<td>Does a hydraulic model of network exist? Is it used for analysis of pressure, velocity, flow tracks, travel times, water quality parameters (which)?</td>
</tr>
<tr>
<td>Is a computer model used for operation and maintenance purposes? If yes, what type of model and how?</td>
</tr>
<tr>
<td>- A hydraulic model is used for all mentioned parameters</td>
</tr>
<tr>
<td>- A dynamic model (InfoWork) is also used for operation. [expand as needed]</td>
</tr>
<tr>
<td>Are valves operated to regulate water age and flow velocity?</td>
</tr>
<tr>
<td>- No [expand as needed]</td>
</tr>
<tr>
<td>Are valves operated to regulate water age and flow velocity?</td>
</tr>
<tr>
<td>[expand as needed]</td>
</tr>
</tbody>
</table>

### Sensors and automatic control devices
Are on-line water quality sensors used? If yes, what parameters are monitored and where are they used?
How are the measurements processed, stored and how are they used?

- Yes

pH, oxygen, conductivity, turbidity and redox-reaction (potential) are also measured at the outlet of water works [expand as needed]

Rehabilitation due to water quality problems
Have pipes been renovated (relined) to improve water quality?
Have other rehab projects been completed with the aim of improving water quality?

- Relining methods are used to rehabilitate the pipes
- Cement mortar grouting are also used [expand as needed]

Rehabilitation
Practice for renovation (methods)

- Relining and cement mortar grouting [expand as needed]
Input/information applied

- Burst data, material and age of pipes, complaint records [expand as needed]
Applied strategies for rehab planning

- A computer model for rehabilitation strategy [expand as needed]
Applied software tools

- OptNet [expand as needed]
Applied guidelines, manuals, publications

[expand as needed]

Research needs
What information are you missing for operation and maintenance decisions?
Do hydraulic model, utility data system, GIS and other IT tools meet your needs?
How would you imagine operation and maintenance in an ideal world?

[expand as needed]

O&M practices

Mains repair Are written procedures:
Are there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?

- Cleaning
- Desinfection is used, if it’s needed. [expand as needed]

Mains replacement Are written procedures:
Are there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?

- Cleaning
- Desinfection is used, if it’s needed. [expand as needed]

| Service connection repair & replacement | Are written procedures:
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there any procedure adopted aiming for water quality protection? Which? Is the work carried out with the connection main pressurized? Are service connections systematically disinfected after intervention? If not, why? If yes, how?</td>
<td></td>
</tr>
</tbody>
</table>

- Cleaning
- Desinfection is used, if it’s needed. [expand as needed]

| Mains cleaning (including flushing) | Are written procedures:
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the objective of flushing or other cleaning methods (improve water quality, protect against sediment storage formation?)</td>
<td></td>
</tr>
<tr>
<td>How are pipes selected for cleaning (records, experiences, models?)</td>
<td></td>
</tr>
<tr>
<td>How often is cleaning repeated, and how is the frequency defined?</td>
<td></td>
</tr>
<tr>
<td>What kind of cleaning technology is used?</td>
<td></td>
</tr>
<tr>
<td>Crew and equipment for cleaning?</td>
<td></td>
</tr>
<tr>
<td>Are other cleaning methods applied rather than flushing?</td>
<td></td>
</tr>
</tbody>
</table>

[expand as needed]

| Service reservoirs inspection and cleaning | Are written procedures:
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures</td>
<td></td>
</tr>
<tr>
<td>Service reservoirs are inspected and cleaned once a year</td>
<td></td>
</tr>
<tr>
<td>- The reservoirs are cleaned by squirting with drinking water</td>
<td></td>
</tr>
<tr>
<td>- After squirting the bottom is disinfected with H2O2</td>
<td></td>
</tr>
<tr>
<td>...... [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

| Domestic tanks inspection and cleaning | Are written procedures:
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures, utility’s responsibility and participation</td>
<td></td>
</tr>
<tr>
<td>[expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

| Active leakage control | Are written procedures:
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Are water quality issues expressly taken into account when developing leakage control schemes or rehabilitation plans (due to changes in network configuration)? If yes, how?</td>
<td></td>
</tr>
<tr>
<td>- We don’t have any leakage control, because there is no remarkable leakage [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

| Pressure management | Are written procedures:
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Is pressure management adopted to reduce leakage? What is the general procedure? What is the acceptable minimum pressure? Is there any evidence that pressure management may increase the risk of external contamination in the system?</td>
<td></td>
</tr>
<tr>
<td>- There is no pressure management in order to reduce leakages, because of no remarkable leakage [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>
Bristol

Utility profile

Utility ID: BRISTOL WATER [Full official designation of the utility]

Type of activity: Water only

Utility size:
- 110 10^6 € of sales revenues from the water supply services /year
- 288.26 10^6 m^3 of billed water /year
- 380 employees [utility total]
- 230 O&M employees [water supply services]

Total running costs: 90 10^6 € /year [total running costs of the water supply services]

Total capital costs: 42 10^6 € /year [total capital costs of the water supply services]

Running costs of O&M functions: 21 % of total running costs

If feasible, split into:
- Operation running costs: 15 % of total running costs
- Maintenance running costs: 6 % of total running costs

O&M outsourcing: 33 % [approximate % of O&M opex related to outsourcing]

Investments for asset replacement and renovation: 60 % of the total capital costs

Comments [optional field]

Total running costs are taken to be operating costs. No allowance made for financing costs, tax and dividends.

Water supply system profile

Type of system:
- Bulk supply and
- Bulk supply only
- Distribution only

Water sources

- Upland surface water
- Lowland surface water 84 % of total abstraction
<table>
<thead>
<tr>
<th>Type</th>
<th>% of total abstraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural springs and wetlands</td>
<td>% of total abstraction</td>
</tr>
<tr>
<td>Well water</td>
<td>% of total abstraction</td>
</tr>
<tr>
<td>Borehole water</td>
<td>16%</td>
</tr>
<tr>
<td>Saline and brackish water</td>
<td>% of total abstraction</td>
</tr>
</tbody>
</table>

**Comments** [optional field]

**Treatment**

- **No treatment**: % of water delivered to users without any treatment
- **Disinfection only**: 0.6% of total abstraction
  - 2 [Number of] disinfection facilities
- **Carbonizing/pH increase**: % of total abstraction
  - [Number of] facilities
- **Conventional treatment**: 99.4% of total abstraction
  - 18 [Number of] treatment plants
- **Advanced treatment**: % of total abstraction
  - [Number of] treatment plants
- **Water volume produced**: 290 Ml/year 10^6 m^3/year

**Short description of the existing treatment facilities**

A range of treatment facilities which are matched are to the quality of the source water. Disinfection only is applied to good quality ground water. The surface water sources which are of more variable quality are treated by more than one process including combined DAF and ozone, slow sand filtration and super and de-chlorination and coagulation, filtration and disinfection.

**Transmission and distribution**

- **Target residual disinfectant**: set at treatment works to give free chlorine of 0.1 mg/l at the consumer’s tap
- **Network size**: 6576.28 km of mains
- **reservoirs customers**: 133 SRs and 10 towers [Number of] service reservoirs customers
- **n/a [Aprox. number of] domestic tanks**
- **497403 [Number of] customers**
- **457600 [Aprox. number of] service connections**
- **386 [Aprox. number of] district metering areas**
Diameters:              Minimum diameter: 50 mm  
                          Maximum diameter: 1500 mm  
Dominant range:   
       ☑ Less or equal 200 mm  
       ☑ Greater than 200 mm but not greater than 400  
       ☑ Greater than 400 mm  

Mains materials:  58 % of grey cast iron  
                      5 % of ductile iron  
                      1 % of steel  
                      N/A % of ferrous mains without adequate corrosion protection  
                      19 % of asbestos cement  
                      14 % of polyethylene  
                      2 % of polyvinyl chloride  

Mains failures:  166 (per 1000 km) [Number of failures]  
Mains repairs:  1150 [Number of repairs] [planned and unplanned]  
Non-revenue water:  16.31 % of input volume that is not billed  
Cleaned mains:  150.01 km of mains  
Replaced mains:  17.49 km of mains  
Renovated mains:  3.6 km of mains  
Replaced service connections:  821 [Number of service connections]  
Network pressure  10 kPa of minimum network pressure any node  
                  60 kPa of maximum network pressure at any node  

**Comments [optional field]**

Remaining mains are concrete.

Data on unlined ferrous mains not reliable.

Network pressure given in metres head. Note that only 0.1% of properties would receive pressures at around 10 m and approx 5% would receive pressures around 60m.

**Water quality problems in the network**

<table>
<thead>
<tr>
<th>Type of problems and frequency of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting standardized thresholds for microbiologic, chemical, physical parameters</td>
</tr>
<tr>
<td>Only problem is iron failures at approx 15 per year [expand as needed]</td>
</tr>
<tr>
<td>Health hazard (e.g. bacteria)</td>
</tr>
</tbody>
</table>
No longer a problem [expand as needed]
Practical requirements (turbidity/colour)

No longer a problem [expand as needed]
Practical requirements (taste/odour)

No longer a problem [expand as needed]

### Water quality-related Operation & Maintenance practices in the network

#### O&M organisation

| Organisation of operation and maintenance (structure, crew, equipment) |
| Crew training. |
| Do complaint records exist? Are they a reason for operation and maintenance actions? |

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 are 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. [expand as needed]

#### Hygienic protection

| Routines and rules to protect network from infiltration. Has infiltration of contaminated water been reported? |
| Are disinfection routines sufficient to protect all customers? |
| Do guidelines exist for hygiene on repair and management actions (disinfection rules, crew equipment, control)? |

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. [expand as needed]

#### Computer records and model

| Do computer based utility systems for the network exist? If so, what do they include? |
| Is the entire network covered by the record system? |

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. [expand as needed]

Is SCADA used? If so, what information is collected? Are automatic mapping (GIS) applied to water network management?

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, schematics

**GIS extensively used.** [expand as needed]

Does a hydraulic model of network exist? Is it used for analysis of pressure, velocity, flow tracks, travel times, water quality parameters (which)?

Is a computer model used for operation and maintenance purposes? If yes, what type of model and how?

All mains models exist for the whole of the distribution network. These 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. [expand as needed]

Are valves operated to regulate water age and flow velocity?

Valving operations performed to keep water flowing and avoid creating stagnant conditions.

[expand as needed]

Are valves operated to regulate water age and flow velocity?

Repeated question. [expand as needed]

**Sensors and automatic control devices**

Are on-line water quality sensors used? If yes, what parameters are monitored and where are they used?

How are the measurements processed, stored and how are they used?

On line water quality monitors are used. Data is recorded, monitored and stored via SCADA and telemetry. It provides real time monitoring and allows you 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 [expand as needed]

### Rehabilitation due to water quality problems

| Have pipes been renovated (relined) to improve water quality? |
| Have other rehab projects been completed with the aim of improving water quality? |

Yes. Other rehab projects have included upgrading treatment to improve water quality, 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. [expand as needed]

### Rehabilitation

#### Practice for renovation (methods)

Historically mains were re-lined with epoxy resin but now replaced by PU lining. Apply structural slip-lining and replacement by pipebursting or conventional trenching. [expand as needed]

#### Input/information applied

Historically used downstream series sampling for iron failures but currently using bursts data over the past 10 or 3 years. Being developed to look at both bursts and iron failures. [expand as needed]

#### Applied strategies for rehab planning

A GIS tool has been developed to prioritise individual mains based on burst frequency but policy is now moving towards including iron failures in the assessment. [expand as needed]

#### Applied software tools

Tool developed within GE Smallworld GIS software. [expand as needed]

#### Applied guidelines, manuals, publications

Use of industry developed standards. [expand as needed]

### Research needs

What information are you missing for operation and maintenance decisions?
Do hydraulic model, utility data system, GIS and other IT tools meet your needs?
How would you imagine operation and maintenance in an ideal world?

A range of missing data includes event data not linked precisely to its location, material data for the distribution system, age of certain assets.

All models under constant development and so are becoming more refined and better able to meet the needs of Bristol Water.

Knowledge to predict failure, i.e. knowing when and where it is going to happen. [expand as needed]

### O&M practices
### Mains repair

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there any procedure adopted aiming for water quality protection?</td>
<td>Are written procedure</td>
</tr>
<tr>
<td>Which? Are mains systematically disinfected after repair?</td>
<td>If not, why? If yes, how?</td>
</tr>
<tr>
<td>Standard procedures are used based on risk assessment and applying suitable disinfection before the mains is brought into service.</td>
<td>[expand as needed]</td>
</tr>
</tbody>
</table>

### Mains replacement

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there any procedure adopted aiming for water quality protection?</td>
<td>Are written procedure</td>
</tr>
<tr>
<td>Which? Are mains systematically disinfected after repair?</td>
<td>If not, why? If yes, how?</td>
</tr>
<tr>
<td>As above [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

### Service connection repair & replacement

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there any procedure adopted aiming for water quality protection?</td>
<td>Are written procedure</td>
</tr>
<tr>
<td>Which? Is the work carried out with the connection main pressurized?</td>
<td>Are service connections systematically disinfected after intervention? If not, why? If yes, how?</td>
</tr>
<tr>
<td>As above [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

### Mains cleaning (including flushing)

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the objective of flushing or other cleaning methods (improve water quality, protect against sediment storage formation?)</td>
<td></td>
</tr>
<tr>
<td>How are pipes selected for cleaning (records, experiences, models?)</td>
<td></td>
</tr>
<tr>
<td>How often is cleaning repeated, and how is the frequency defined?</td>
<td></td>
</tr>
<tr>
<td>What kind of cleaning technology is used?</td>
<td></td>
</tr>
<tr>
<td>Crew and equipment for cleaning?</td>
<td></td>
</tr>
<tr>
<td>Are other cleaning methods applied rather than flushing?</td>
<td></td>
</tr>
<tr>
<td>Flushing is carried out to remove sediment and debris from the distribution system, avoid future discolouration problems and in response to bacteriological problems.</td>
<td></td>
</tr>
<tr>
<td>Immediate response to unplanned failures otherwise improvement based on a 5 year year cycle constantly re-assessed on prevailing water quality.</td>
<td></td>
</tr>
<tr>
<td>Practice is mostly based on flushing and carried out in-house by Bristol Water. Pigging is occasionally performed but has limited benefit because of potential damage to the integrity of the mains. [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

### Service reservoirs inspection and cleaning

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures</td>
<td></td>
</tr>
<tr>
<td>Cleaning operated on a four-year cycle in accordance with written procedures.. Involves draining, hosing down walls, disinfecting and re-instating into service. Flood tests used to assess integrity of the roof. Drop tests used to assess integrity of structure. [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

### Domestic tanks inspection and cleaning

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures, utility’s responsibility and participation</td>
<td>n/a [expand as needed]</td>
</tr>
<tr>
<td>Active leakage control</td>
<td>Are written procedure</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Are water quality issues expressly taken into account when developing leakage control schemes or rehabilitation plans (due to changes in network configuration)? If yes, how?</td>
<td></td>
</tr>
<tr>
<td>Yes - to avoid risk of discolouration during operations and to maintain adequate circulation in the network. [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure management</th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is pressure management adopted to reduce leakage? What is the general procedure? What is the acceptable minimum pressure? Is there any evidence that pressure management may increase the risk of external contamination in the system?</td>
<td></td>
</tr>
<tr>
<td>Maintain positive pressure on the main. Pressure reducing valves (PRVs) and or flow compensating PRVs with set-point pressure installed where appropriate. Generally 15m standard.</td>
<td></td>
</tr>
<tr>
<td>No evidence of contamination caused by pressure management practice. [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>
EPAL

Utility profile

Utility ID: Empresa Portuguesa das Águas Livres, S.A. -EPAL (replies refer only to the Lisbon distribution system, not to the whole company) [Full official designation of the utility]

Type of activity

- Water only
- Multiservices

Utility size:

- 77.7 10^6 € of sales revenues from the water supply services / year
- 60.8 10^6 m³ of billed water / year
- 402 employees [utility total]
- 193 O&M employees [water supply services]

Total running costs:

- 71.0 10^6 € / year [total running costs of the water supply services]

Total capital costs:

- 20.6 10^6 € / year [total capital costs of the water supply services]

Running costs of O&M functions:

- 85.8 % of total running costs

If feasible, split into:

- Operation running costs: 78% of total running costs
- Maintenance running costs: 7.8% of total running costs

O&M outsourcing:

- 11.6 % [approximate % of O&M opex related to outsourcing]

Investments for asset replacement and renovation:

- 89.5 % of the total capital costs

Comments [optional field]

Water supply system profile

Type of system:

- Bulk supply and
- Bulk supply only
- Distribution only

Water sources

- Upland surface water - % of total abstraction

[Full official designation of the utility]
Lowland surface water  86 % of total abstraction  
Natural springs and wetlands  2 % of total abstraction  
Well water  - % of total abstraction  
Borehole water  12 % of total abstraction  
Saline and brackish water  % of total abstraction

<table>
<thead>
<tr>
<th>Comments [optional field]</th>
</tr>
</thead>
</table>

**Treatment**

- No treatment  - % of water delivered to users without any treatment  
- Disinfection only  13,75 % of total abstraction  
  23 [Number of] disinfection facilities  
- Carbonizing/ pH increase  - % of total abstraction  
  1 [Number of] facilities  
- Conventional treatment  86,25 % of total abstraction  
  2 [Number of] treatment plants  
- Advanced treatment  - % of total abstraction  
  - [Number of] treatment plants  
- Water volume produced  255 10^6 m^3 /year

**Short description of the existing treatment facilities**

1. Surface catchements

The 2 surface water catchments are treated in 2 treatment facilities (WTP):

WTP of Asseiceira - 500 000 m3/day production capacity. Treatment scheme: pre-chlorination, remineralisation and agressivity correction, coagulation, filtration, pH correction and final desinfection with chlorine.

WTP of Vale da Pedra - 225 000 m3/day production capacity. Treatment scheme: pre-chlorination, pH correction, coagulation-floculations, decantation, filtration, pH correction and final desinfection with chlorine.

2. Borehole water

Treatment scheme: desinfection with chlorine or sodium hipoclorite and mixture with treated surface waters.
3. Spring Water

Treatment scheme: UV -desinfection followed by chlorination and mixture with treated surface waters.

Transmission and distribution

Target residual disinfectant: 0,2 to 0,4 mg/l at the consumer’s tap

Network size: 1427 km of mains

14 [Number of] service reservoirs customers
- [Aprox. number of] domestic tanks

341764 [Number of] customers

90000 [Aprox. number of] service connections

30(b) [Aprox. number of] district metering areas

Diameters:

Minimum diameter: 80 mm

Maximum diameter: 1500 mm

Dominant range:
- Less or equal 200 mm
- Greater than 200 mm but not greater than 400

- Greater than 400 mm

Mains materials:

19,32 % of grey cast iron

27,76 % of ductile iron

0,42 % of steel

- % of ferrous mains without adequate corrosion protection

29,06 % of asbestos cement

16,66 % of polyethylene

0,38 % of polyvinyl chloride

Mains failures: [Number of] failures

Mains repairs: 692 [Number of] repairs [planned and unplanned]

Non-revenue water: 23,54 % of input volume that is not billed

Cleaned mains: km of mains

Replaced mains: km of mains

Renovated mains: (a)85,3 km of mains

Replaced service connections: 6594 [Number of] service connections

Network pressure 300 kPa of minimum network pressure any node
600 kPa of maximum network pressure at any node

**Comments** [optional field]

(a) Total of mains rehabilitated. There is no available information about the kind of rehabilitation carried out.

(b) 30 DMA fully implemented, out of a total of 130 planned.

---

**Water quality problems in the network**

<table>
<thead>
<tr>
<th>Type of problems and frequency of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting standardized thresholds for microbiologic, chemical, physical parameters</td>
</tr>
</tbody>
</table>

Consumer's tap in the city of Lisbon (Year 2005):

- Microbiological parameters - compliance in 99.88% samples
- Physical parameters - compliance in 99.99%
- Chemical parameters - compliance in 99.88% samples [expand as needed]

Health hazard (e.g. bacteria)

- [expand as needed]

Practical requirements (turbidity/colour)

- Turbidity - compliance in 99.88% samples
- Colour - compliance in 100% samples [expand as needed]

Practical requirements (taste/odour)

- Taste and odour - compliance in 100% samples [expand as needed]

---

**Water quality-related Operation & Maintenance practices in the network**

<table>
<thead>
<tr>
<th>O&amp;M organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisation of operation and maintenance (structure, crew, equipment)</td>
</tr>
<tr>
<td>Crew training.</td>
</tr>
<tr>
<td>Do complaint records exist? Are they a reason for operation and maintenance actions?</td>
</tr>
</tbody>
</table>

Structure - operation and maintenance are two different departments

Main information systems: Maintenance (Maximo), GIS (Ginteraqua), SCADA, Customers IS (SIGC).

Complaint records do exist and they are a reason for O&M actions (flushing, analysis, etc.). [expand as needed]

---

**Hygienic protection**

Routines and rules to protect network from infiltration. Has infiltration of contaminated water been reported?

Are disinfection routines sufficient to protect all customers?

Do guidelines exist for hygiene on repair and management actions (disinfection rules, crew equipment, control)?

Episodic suspects of water contamination, after service suspensions for reparation, have occurred. The mains have been washed and disinfected and they have been reactivated only after good laboratorial results.
Guidelines for hygiene on repair and management actions do exist, and the routines are considered to be sufficient to protect all customers.

<table>
<thead>
<tr>
<th>Computer records and model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do computer based utility systems for the network exist? If so, what do they include?</td>
</tr>
<tr>
<td>Is the entire network covered by the record system?</td>
</tr>
<tr>
<td>There are a number of utility systems covering the entire network: SCADA (see below); GIS (used for the network characterization; maintenance work-orders management; network renewal and enlargement records); Maximo (used for electromechanical equipment maintenance).</td>
</tr>
<tr>
<td>Is SCADA used? If so, what information is collected?</td>
</tr>
<tr>
<td>Are automatic mapping (GIS) applied to water network management?</td>
</tr>
<tr>
<td>SCADA is used for distribution planning and operation (network pressures, water flows, water quality parameters, reservoir’s water levels, pump conditions, equipment malfunctions, energy failures, chlorine leak detections, conditions (i.e. leaks) of the chlorine neutralization system, etc.)</td>
</tr>
<tr>
<td>Does a hydraulic model of network exist? Is it used for analysis of pressure, velocity, flow tracks, travel times, water quality parameters (which)?</td>
</tr>
<tr>
<td>Is a computer model used for operation and maintenance purposes? If yes, what type of model and how?</td>
</tr>
<tr>
<td>There is a simplified mathematical network model for diameters 200 mm and higher. It is used for pressure analysis, water speeds and flows in network enlargement situations and modifications due to programmed suspensions, in order to evaluate its impact on water delivery.</td>
</tr>
<tr>
<td>Are valves operated to regulate water age and flow velocity?</td>
</tr>
<tr>
<td>We operate on reservoirs levels in order to induce a water flow, by means of stopping and starting pumping groups and sometimes by valve regulations along network</td>
</tr>
<tr>
<td>Are valves operated to regulate water age and flow velocity?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensors and automatic control devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are on-line water quality sensors used? If yes, what parameters are monitored and where are they used?</td>
</tr>
<tr>
<td>How are the measurements processed, stored and how are they used?</td>
</tr>
<tr>
<td>On-line water quality sensors are used to monitor the following parameters: free residual chlorine, pH, turbidity, water temperature and conductivity. The sensors are preferably installed in the distribution network entrances and exits to bulk water system, and also in some reservoirs and pumping facilities.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rehabilitation due to water quality problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have pipes been renovated (relined) to improve water quality?</td>
</tr>
<tr>
<td>Have other rehab projects been completed with the aim of improving water quality?</td>
</tr>
<tr>
<td>No. No.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rehabilitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice for renovation (methods)</td>
</tr>
</tbody>
</table>
Renovation is carried out by trench digging, in order to replace asbestos cement and cast iron by HDPE and ductile iron.

**Input/information applied**

- Number of failures, age, material, function and replacement vs refurbishment costs

**Applied strategies for rehab planning**

- Definition of priority areas

**Applied software tools**

- GIS

**Applied guidelines, manuals, publications**

- Strategic Plan, Panels of Experts and Multicriteria Matrix developed with GIS

**Research needs**

- What information are you missing for operation and maintenance decisions?
- Do hydraulic model, utility data system, GIS and other IT tools meet your needs?
- How would you imagine operation and maintenance in an ideal world?

- More available data (pressure, water flows and quality parameters) in strategic points along the network would be of great benefit. Additionally, it would be good to develop the mathematical model for water quality control, to model every network diameters, as well as to develop empirical models to predict whole life costing including estimation of performance and condition of the network.

**O&M practices**

<table>
<thead>
<tr>
<th>Mains repair</th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?</td>
<td></td>
</tr>
<tr>
<td>There are written procedures in order to ensure the free residual chlorine existence in all networks. The mains are always washed when they are put in service, they are also disinfected whenever possible, and samples are collected for laboratorial analysis whenever the main can wait to be put in service after the results.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mains replacement</th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?</td>
<td></td>
</tr>
<tr>
<td>There are written procedures in order to ensure the free residual chlorine existence in all networks. The mains are always washed when they are put in service, they are also disinfected and samples are collected for laboratorial analysis whenever the main can wait to be put in service after the results.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Service connection repair &amp; replacement</th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there any procedure adopted aiming for water quality protection? Which? Is the work carried out with the connection main pressurized? Are service connections systematically disinfected after intervention? If not, why? If yes, how?</td>
<td></td>
</tr>
<tr>
<td>Not applicable.</td>
<td></td>
</tr>
<tr>
<td><strong>Mains cleaning (including flushing)</strong></td>
<td>Are written procedure</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>What is the objective of flushing or other cleaning methods (improve water quality, protect against sediment storage formation?)</td>
<td></td>
</tr>
<tr>
<td>How are pipes selected for cleaning (records, experiences, models?)</td>
<td></td>
</tr>
<tr>
<td>How often is cleaning repeated, and how is the frequency defined?</td>
<td></td>
</tr>
<tr>
<td>What kind of cleaning technology is used?</td>
<td></td>
</tr>
<tr>
<td>Crew and equipment for cleaning?</td>
<td></td>
</tr>
<tr>
<td>Are other cleaning methods applied rather than flushing?</td>
<td></td>
</tr>
<tr>
<td>Programmed flushing is carried out by DMA. Flushing are also made with discharge valves, network extreme valves and fire hydrants. The flush sequence is made according to the current water flow, from upstream to downstream. Records on the flushes are made and critical points are identified for a new flush after a certain period proposes.</td>
<td>[expand as needed]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Service reservoirs inspection and cleaning</strong></th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures</td>
<td></td>
</tr>
<tr>
<td>There is a written procedure. The frequency adopted is 1 year</td>
<td>[expand as needed]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Domestic tanks inspection and cleaning</strong></th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures, utility’s responsibility and participation</td>
<td></td>
</tr>
<tr>
<td>Not applicable.</td>
<td>[expand as needed]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Active leakage control</strong></th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are water quality issues expressly taken into account when developing leakage control schemes or rehabilitation plans (due to changes in network configuration)? If yes, how?</td>
<td></td>
</tr>
<tr>
<td>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. Analysis of water quality before and after the DMA &quot;lock-in&quot; is undertaken along with monitoring of at least one sample point within each DMA (at the entry point and / or potential critical points)</td>
<td>[expand as needed]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Pressure management</strong></th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is pressure management adopted to reduce leakage? What is the general procedure? What is the acceptable minimum pressure? Is there any evidence that pressure management may increase the risk of external contamination in the system?</td>
<td></td>
</tr>
<tr>
<td>There are written procedures for pressure management. The general procedure consists of setting pressure reduction devices to 300 kPa.</td>
<td>[expand as needed]</td>
</tr>
</tbody>
</table>
Leipzig

Utility profile

Utility ID: Kommunale Wasserwerke Leipzig (Germany)

Type of activity: Water only

Utility size:
- € 64,181,060 of sales revenues from the water supply services / year
- € 26,161,060 of billed water / year
- 260 employees [utility total]
- 142 O&M employees [water supply services]

Total running costs: € 42,681,060 / year [total running costs of the water supply services]
Total capital costs: € 18,771,060 / year [total capital costs of the water supply services]

Running costs of O&M functions: 61.34 % of total running costs

If feasible, split into:
- Operation running costs: % of total running costs
- Maintenance running costs: % of total running costs

O&M outsourcing: ca. 80 % [approximate % of O&M opex related to outsourcing]

Investments for asset replacement and renovation: 90.5 % of the total capital costs

Water supply system profile

Type of system:
- Bulk supply and
- Bulk supply only
- Distribution only

Water sources:
- Upland surface water: % of total abstraction
- Lowland surface water: % of total abstraction
Natural springs and wetlands  % of total abstraction
Well water  % of total abstraction
Borehole water  100 % of total abstraction
Saline and brackish water  % of total abstraction

Comments [optional field]

Treatment
No treatment  0 % of water delivered to users without any treatment
Disinfection only  0 % of total abstraction
[Number of] disinfection facilities
Carbonizing/ pH increase  100 % of total abstraction
[Number of] facilities
Conventional treatment  100 % of total abstraction
5 [Number of] treatment plants
Advanced treatment  % of total abstraction
[Number of] treatment plants
Water volume produced  24,2 $10^6$ m$^3$/year

Short description of the existing treatment facilities

Transmission and distribution
Target residual disinfectant:  no residual to  mg/l at the consumer's tap
Network size:  2294 km of mains
19 [Number of] service reservoirs customers
0 [Aprox. number of] domestic tanks
598,000 [Number of] customers
77643 [Aprox. number of] service connections
30 [Aprox. number of] district metering areas
Diameters: Minimum diameter: 50 mm
Maximum diameter: 1200 mm
Dominant range:
Less or equal 200 mm
Greater than 200 mm but not greater than 400 mm
Greater than 400 mm

Mains materials:
- 43.6% of grey cast iron
- 24.4% of ductile iron
- 8.5% of steel
- 50% of ferrous mains without adequate corrosion protection
- 11.7% of asbestos cement
- 8.8% of polyethylene
- 1.3% of polyvinyl chloride

Mains failures: 2135 failures
Mains repairs: 2135 repairs [planned and unplanned]
Non-revenue water: 21.1% of input volume that is not billed
Cleaned mains: 500 km of mains
Replaced mains: 19.8 km of mains
Renovated mains: 1.7 km of mains
Replaced service connections: 1243 service connections

Network pressure
- 250 kPa of minimum network pressure any node
- 650 kPa of maximum network pressure at any node

Comments [optional field]
failures without service connections

Water quality problems in the network

Type of problems and frequency of occurrence

<table>
<thead>
<tr>
<th>Description</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting standardized thresholds for microbiologic, chemical, physical parameters</td>
<td>159 x meeting standardized thresholds [expand as needed]</td>
</tr>
<tr>
<td>Health hazard (e.g. bacteria)</td>
<td>20 x meeting standardized thresholds for microbiology (mostly colony counts and coliforms) [expand as needed]</td>
</tr>
<tr>
<td>Practical requirements (turbidity/colour)</td>
<td>2 x meeting standardized thresholds for turbidity and colour [expand as needed]</td>
</tr>
<tr>
<td>Practical requirements (taste/odour)</td>
<td>No problems with taste or odour [expand as needed]</td>
</tr>
</tbody>
</table>
**Water quality-related Operation & Maintenance practices in the network**

<table>
<thead>
<tr>
<th>O&amp;M organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisation of operation and maintenance (structure, crew, equipment)</td>
</tr>
<tr>
<td>Crew training.</td>
</tr>
<tr>
<td>Do complaint records exist? Are they a reason for operation and maintenance actions?</td>
</tr>
<tr>
<td>- Organisation: 1 department, 5 teams, 49 members of staff, 35 vehicles</td>
</tr>
<tr>
<td>- Regular crew training is conducted</td>
</tr>
<tr>
<td>- Complaint record exist and is a reason for operation and maintenance actions [expand as needed]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hygienic protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routines and rules to protect network from infiltration. Has infiltration of contaminated water been reported?</td>
</tr>
<tr>
<td>Are disinfection routines sufficient to protect all customers?</td>
</tr>
<tr>
<td>Do guidelines exist for hygiene on repair and management actions (disinfection rules, crew equipment, control)?</td>
</tr>
<tr>
<td>- No infiltration of contaminated water has been reported</td>
</tr>
<tr>
<td>- To protect network from infiltration an minimum pressure of 250 kPa in any point of the network is ensured, the reservoirs are closed, using of diffusion dense plastic pipes in polluted areas</td>
</tr>
<tr>
<td>- Guidelines for hygiene on repair and management actions exist [expand as needed]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Computer records and model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do computer based utility systems for the network exist? If so, what do they include?</td>
</tr>
<tr>
<td>Is the entire network covered by the record system?</td>
</tr>
<tr>
<td>- A computer based utility system of the network exist</td>
</tr>
<tr>
<td>- It includes the water works, the reservoirs and the pressure stations</td>
</tr>
<tr>
<td>- The entire network is covered [expand as needed]</td>
</tr>
<tr>
<td>Is SCADA used? If so, what information is collected?</td>
</tr>
<tr>
<td>Are automatic mapping (GIS) applied to water network management?</td>
</tr>
<tr>
<td>- SCADA is used</td>
</tr>
<tr>
<td>- Measured parameters: flow, pressure, water level in reservoirs, operating hours, pH [expand as needed]</td>
</tr>
<tr>
<td>Does a hydraulic model of network exist? Is it used for analysis of pressure, velocity, flow tracks, travel times, water quality parameters (which)?</td>
</tr>
<tr>
<td>Is a computer model used for operation and maintenance purposes? If yes, what type of model and how?</td>
</tr>
<tr>
<td>- A hydraulic model of the network exists, it is used for analysis of pressure, velocity, travel time</td>
</tr>
<tr>
<td>- The model is used for define pressure zones, optimizing flow conditions, optimizing pipe diameter, check flow conditions for decommissioning within rehabilitation actions, optimization of operating and investment costs</td>
</tr>
</tbody>
</table>
For operation and maintenance purposes the software SAP R/3 is used, functions: financial management, assets accounting, cost accounting, materials management. Are valves operated to regulate water age and flow velocity? Yes

<table>
<thead>
<tr>
<th>Sensors and automatic control devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are on-line water quality sensors used? If yes, what parameters are monitored and where are they used?</td>
</tr>
<tr>
<td>How are the measurements processed, stored and how are they used?</td>
</tr>
<tr>
<td>Pressure measurement at every input point into a metering area and at 6 representative points in the network</td>
</tr>
<tr>
<td>pH measurement at every input points into the metering areas and in the water works</td>
</tr>
<tr>
<td>The measurements are stored and used for the the evaluation of failures</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rehabilitation due to water quality problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have pipes been renovated (relined) to improve water quality?</td>
</tr>
<tr>
<td>Have other rehab projects been completed with the aim of improving water quality?</td>
</tr>
<tr>
<td>Pipes are renovated to improve water quality</td>
</tr>
<tr>
<td>Reduction of pipe diameter, reduction of volume of reservoirs, decommissioning of water towers</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rehabilitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice for renovation (methods)</td>
</tr>
<tr>
<td>Relining, berstlining</td>
</tr>
<tr>
<td>Input/information applied</td>
</tr>
<tr>
<td>Hydraulic situation and statics situation</td>
</tr>
<tr>
<td>Applied strategies for rehab planning</td>
</tr>
<tr>
<td>Evaluation of the conditions of the pipes</td>
</tr>
<tr>
<td>Applied software tools</td>
</tr>
<tr>
<td>OPTNET</td>
</tr>
<tr>
<td>Applied guidelines, manuals, publications</td>
</tr>
<tr>
<td>Technical standards of the German Technical and Scientific Association for Gas and Water (DVGW): W 401, GW 320, GW 323, GW 325, GW 321</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>What information are you missing for operation and maintenance decisions?</td>
</tr>
<tr>
<td>Do hydraulic model, utility data system, GIS and other IT tools meet your needs?</td>
</tr>
<tr>
<td>How would you imagine operation and maintenance in an ideal world?</td>
</tr>
</tbody>
</table>
- Linking of operation and maintenance decisions with the forecast development of other infrastructure parameters (streets, gas, telecommunication, industrial parks …)
- Linking of SAP and GIS
- Concerted and coordinated maintenance program of municipal enterprises

### O&M practices

#### Mains repair

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
</table>
- Procedure described in the DVGW Technical Standards W291 completed by own instructions  
- Repaired Mains are not systematically disinfected  
- Flushing of the pipe, disinfection of fittings and couplings, selective using of disinfection spray, sampling immediately after flushing and after one day (expand as needed) |

#### Mains replacement

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
</table>
- Procedure described in the DVGW Technical Standards W291 completed by own instructions  
- New mains are systematically disinfected  
- Flushing of the pipe, disinfection with H2O2 (Herlisil / Sanosil) sampling immediately and after one day (expand as needed) |

#### Service connection repair & replacement

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
</table>
| Is there any procedure adopted aiming for water quality protection? Which? Is the work carried out with the connection main pressurized? Are service connections systematically disinfected after intervention? If not, why? If yes, how? | - A procedure exists  
- Flushing, sampling  
- No disinfection because of there is no technical solution to bring the disinfectant into the service connection without influencing the water quality in the main (expand as needed) |

#### Mains cleaning (including flushing)

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are written procedure</td>
<td></td>
</tr>
</tbody>
</table>
What is the objective of flushing or other cleaning methods (improve water quality, protect against sediment storage formation?)
How are pipes selected for cleaning (records, experiences, models?)
How often is cleaning repeated, and how is the frequency defined?
What kind of cleaning technology is used?
Crew and equipment for cleaning?
Are other cleaning methods applied rather than flushing?

- Water flushing to avoid stagnation and brown water events
- Experiences, complaints, water analysis
- The cleaning of the end pipes is repeated every 2 months
- Just water flushing is used
- Department networks carry out the flushing, equipment: vehicle, stand pipe, water meter, pipes
- Beside water flushing no other cleaning methods are used

<table>
<thead>
<tr>
<th>Service reservoirs inspection and cleaning</th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures</td>
<td></td>
</tr>
<tr>
<td>- Service reservoirs are inspected and cleaned once a year</td>
<td></td>
</tr>
<tr>
<td>- The reservoirs are cleaned by squirting with drinking water</td>
<td></td>
</tr>
<tr>
<td>- After squirting the bottom is disinfected with chlorine</td>
<td></td>
</tr>
<tr>
<td>..... [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Domestic tanks inspection and cleaning</th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures, utility’s responsibility and participation</td>
<td></td>
</tr>
<tr>
<td>- No domestic tanks [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Active leakage control</th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are water quality issues expressly taken into account when developing leakage control schemes or rehabilitation plans (due to changes in network configuration)? If yes, how?</td>
<td></td>
</tr>
<tr>
<td>- Active leakage control exists but is not taken into account for control schemes or rehabilitation plans [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure management</th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is pressure management adopted to reduce leakage? What is the general procedure? What is the acceptable minimum pressure? Is there any evidence that pressure management may increase the risk of external contamination in the system?</td>
<td></td>
</tr>
<tr>
<td>- Pressure management is adopted to reduce leakage.</td>
<td></td>
</tr>
<tr>
<td>- Pressure reducing valves are used for selected areas with sensitive pipes</td>
<td></td>
</tr>
<tr>
<td>- The acceptable minimum pressure is 200 kPa + 35 kPa per floor</td>
<td></td>
</tr>
<tr>
<td>- There is no evidence that pressure management increase external contaminations [expand as needed]</td>
<td></td>
</tr>
</tbody>
</table>
Oslo

Utility profile

Utility ID: Oslo Water and Wastewater Company [Full official designation of the utility]
Type of activity
- Water only
- Multiservices
Utility size: 106 € of sales revenues from the water supply services /year
Meters + areal calculation: 91 106 m³ of billed water /year
employees [utility total]
O&M employees [water supply services]
Total running costs: 106 € /year [total running costs of the water supply services]
Total capital costs: 106 € /year [total capital costs of the water supply services]
Running costs of O&M functions: % of total running costs
If feasible, split into:
- Operation running costs: % of total running costs
- Maintenance running costs: % of total running costs
O&M outsourcing: % [approximate % of O&M opex related to outsourcing]
Investments for asset replacement and renovation: % of the total capital costs

Comments [optional field]

Water supply system profile
Type of system:
- Bulk supply and
- Bulk supply only
- Distribution only
Water sources
- Upland surface water % of total abstraction
Lowland surface water 100 % of total abstraction
Natural springs and wetlands % of total abstraction
Well water over 1000 customers % of total abstraction
Borehole water % of total abstraction
Saline and brackish water % of total abstraction

Comments [optional field]

Treatment

No treatment % of water delivered to users without any treatment
Disinfection only 100 % of total abstraction
[Number of] disinfection facilities
Carbonizing/ pH increase 10 % of total abstraction
[Number of] facilities
Conventional treatment % of total abstraction
[Number of] treatment plants
Advanced treatment % of total abstraction
[Number of] treatment plants
Water volume produced 106 m³/year

Short description of the existing treatment facilities

Transmission and distribution

Target residual disinfectant: detectable from treatment plant to mg/l at the consumer’s tap
Network size: 1550 km of mains
535000 [Number of] service reservoirs customers
18 [Aprox. number of] domestic tanks
[Number of] customers
49000 [Aprox. number of] service connections
53 [Aprox. number of] district metering areas
Diameters: Minimum diameter: 100 mm
Maximum diameter: 1500 mm
Dominant range:
Less or equal 200 mm
Greater than 200 mm but not greater than 400
Greater than 400 mm

Mains materials:
- 60% of grey cast iron
- 30% of ductile iron
- 10% of steel
- 70% of ferrous mains without adequate corrosion protection
- 0% of asbestos cement
- 0% of polyethylene
- 0% of polyvinyl chloride

Mains failures: 179 [Number of] failures
Mains repairs: 180 [Number of] repairs [planned and unplanned]
Non-revenue water: 21% of input volume that is not billed
Cleaned mains: [km of mains]
Replaced mains: [km of mains]
Renovated mains: [km of mains]
Replaced service connections: [Number of] service connections

Network pressure: 2 bar kPa of minimum network pressure any node
14 bar (21 bar abs max) kPa of maximum network pressure at any node

Comments [optional field]

Water quality problems in the network

<table>
<thead>
<tr>
<th>Type of problems and frequency of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting standardized thresholds for microbiologic, chemical, physical parameters</td>
</tr>
<tr>
<td>pH, colour, (iron), colour increasing during last decades [expand as needed]</td>
</tr>
<tr>
<td>Health hazard (e.g. bacteria)</td>
</tr>
<tr>
<td>e-coli found in sources, in particula near thermocline [expand as needed]</td>
</tr>
<tr>
<td>Practical requirements (turbidity/colour)</td>
</tr>
<tr>
<td>new treatment plant will remove colour/urbidity [expand as needed]</td>
</tr>
<tr>
<td>Practical requirements (taste/odour)</td>
</tr>
<tr>
<td>None [expand as needed]</td>
</tr>
</tbody>
</table>
### Water quality-related Operation & Maintenance practices in the network

#### O&M organisation

| Organisatation of operation and maintenance (structure, crew, equipment) |
| Crew training. |
| Do complaint records exist? Are they a reason for operation and maintenance actions? |

#### Thematic courses for ex on leakage control, Nationla exam (ADK)

| Complaint records exist by Gemini tool, but is not representative as quality standard, only partially recorded for action purposes. Customers releasing service guarantee listed in yearly report (guarantee water loss in 12 hours, 200 NOK/customer to be funded). Improvement on complaint registration is planned. |

#### Hygienic protection

| Routines and rules to protect network from infiltration. Has infiltration of contaminated water been reported? |
| Are disinfection routines sufficient to protect all customers? |
| Do guidelines exist for hygiene on repair and management actions (disinfection rules, crew equipment, control)? |

#### Desinfection when intrusion of polluted water due to repair work (very seldom), a form is developed to assist the judgement. Necessary to measure effect. Repeated desinfection necessary

| Intrusion of polluted water into drinking water system only through roof of water basin, direct intrusion to network not known. |

#### Computer records and model

| Do computer based utility systems for the network exist? If so, what do they include? |
| Is the entire network covered by the record system? |

| 100% electronic records, . |
| [expand as needed] |

| Is SCADA used? If so, what information is collected? |
| Are automatic mapping (GIS) applied to water network management? |

#### SCADA used for flow, pressure, errors, pump time, electricity consumption. SCADA will be implemented into overall GIS-related hydraulic model 8n 2 years. Scada used for automatic valve operation. |

| Does a hydraulic model of network exist? Is it used for analysis of pressure, velocity, flow tracks, travel times, water quality parameters (which)? |
| Is a computer model used for operation and maintenance purposes? If yes, what type of model and how? |

#### Hydraulic model since 1980, made more detailed when needed

| Are valves operated to regulate water age and flow velocity? |
| No [expand as needed] |

| Are valves operated to regulate water age and flow velocity? |
| [expand as needed] |
**Sensors and automatic control devices**

Are on-line water quality sensors used? If yes, what parameters are monitored and where are they used?

How are the measurements processed, stored and how are they used?

Remaining chlorine from treatment plant, turbidity meter planned 4 places to track water source. Tried pH, but was not appropriate due to operation needs.

**Rehabilitation due to water quality problems**

Have pipes been renovated (relined) to improve water quality?

Have other rehab projects been completed with the aim of improving water quality?

No

**Rehabilitation**

Practice for renovation (methods)

Lining (concrete, epoxy, polyuretan), Cured in Pipe (CIP)

Input/information applied

Structural information

Applied strategies for rehab planning

Failure frequency, vulnerability

Applied software tools

Hydraulic model MIKE Net

Applied guidelines, manuals, publications

Own guidelines

**Research needs**

What information are you missing for operation and maintenance decisions?

Do hydraulic model, utility data system, GIS and other IT tools meet your needs?

How would you imagine operation and maintenance in an ideal world?

Structural condition, continuous along the line.

**O&M practices**

**Mains repair**

Are written procedure

Is there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?

Desinfection when needed. Procedure for decide disinfection

**Mains replacement**

Are written procedure

Is there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?
### When it is judged necessary

<table>
<thead>
<tr>
<th>Service connection repair &amp; replacement</th>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there any procedure adopted aiming for water quality protection? Which? Is the work carried out with the connection main pressurized? Are service connections systematically disinfected after intervention? If not, why? If yes, how?</td>
<td>No [expand as needed]</td>
</tr>
</tbody>
</table>

### Mains cleaning (including flushing)

<table>
<thead>
<tr>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the objective of flushing or other cleaning methods (improve water quality, protect against sediment storage formation?)</td>
</tr>
<tr>
<td>How are pipes selected for cleaning (records, experiences, models?)</td>
</tr>
<tr>
<td>How often is cleaning repeated, and how is the frequency defined?</td>
</tr>
<tr>
<td>What kind of cleaning technology is used?</td>
</tr>
<tr>
<td>Crew and equipment for cleaning?</td>
</tr>
<tr>
<td>Are other cleaning methods applied rather than flushing?</td>
</tr>
</tbody>
</table>

### Service reservoirs inspection and cleaning

<table>
<thead>
<tr>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures</td>
</tr>
</tbody>
</table>

### Domestic tanks inspection and cleaning

<table>
<thead>
<tr>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures, utility’s responsibility and participation</td>
</tr>
</tbody>
</table>

### Active leakage control

<table>
<thead>
<tr>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are water quality issues expressly taken into account when developing leakage control schemes or rehabilitation plans (due to changes in network configuration)? If yes, how?</td>
</tr>
</tbody>
</table>

### Pressure management

<table>
<thead>
<tr>
<th>Are written procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is pressure management adopted to reduce leakage? What is the general procedure? What is the acceptable minimum pressure? Is there any evidence that pressure management may increase the risk of external contamination in the system?</td>
</tr>
</tbody>
</table>
Trondheim

Utility profile

Utility ID: Trondheim municipality
Type of system: Water and wastewater
Type of activity: Planning, construction, operation, maintenance
Utility size: $11 \times 10^6$ € of sales revenues / year (water supply selling to external customers)
$15 \times 10^6$ m$^3$ of billed water / year
90 employees
65 O&M employees
Total running costs: $5.5 \times 10^6$ € / year (operation and maintenance for drinking water system)
Total capital costs: $5.5 \times 10^6$ € / year
Running costs of O&M functions: 40 % of total running costs rehabilitation
If feasible, split into:
Operation running costs: 12 % of total running costs (operation of water network)
Maintenance running costs: 22 % of total running costs (maintenance of network)
O&M Outsourcing: 0 % [approximate % of O&M opex related to outsourcing]
Investments for asset replacement and renovation: 50 % of the total capital costs

<table>
<thead>
<tr>
<th>Comments [optional field]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal definition of O&amp;M</td>
</tr>
<tr>
<td>Operation: Actions to maintain functionality of asset, including check of indicated failures, leakage, flushing, cleaning, valve operation, pumping stations</td>
</tr>
<tr>
<td>Maintenance: Actions to maintain network condition (repairs)</td>
</tr>
<tr>
<td>Rehabilitation: Actions to replace or renovate pipelines and attached manholes</td>
</tr>
</tbody>
</table>

Water supply system profile

Water sources
<table>
<thead>
<tr>
<th>Source type</th>
<th>% of total abstraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland surface water</td>
<td>100 %</td>
</tr>
<tr>
<td>Lowland surface water</td>
<td>0 %</td>
</tr>
<tr>
<td>Natural springs and wetlands</td>
<td>0 %</td>
</tr>
<tr>
<td>Well water</td>
<td>0 %</td>
</tr>
<tr>
<td>Borehole water</td>
<td>0 %</td>
</tr>
<tr>
<td>Saline and brackish water</td>
<td>0 %</td>
</tr>
</tbody>
</table>

Comments [optional field]

“Upland” is interpreted as “upstream”

Treatment

- No treatment: 0 % of water delivered to users without any treatment
- Disinfection only: 0 % of total abstraction
  1 [Number of] disinfection facilities
- Conventional treatment: 0 % of total abstraction
  0 [Number of] treatment plants
- Advanced treatment: 100 % of total abstraction
  1 [Number of] treatment plants

Water volume produced $22 \times 10^6$ m$^3$ /year

Comments [optional field]

Treatment consists of carbonizing plus disinfection by chlorine

Transmission and distribution

- Target residual disinfectant: 0 to 0 mg/l at the consumer’s tap
- Network size: 750 km of mains
  12 [Number of] service reservoirs customers
  0 [Aprox. number of] domestic tanks
  156000 [Number of] customers (persons)
  45000 [Aprox. number of] service connections
  30 [Aprox. number of] district metering areas
- Diameters:
  Minimum diameter: 25 mm
  Maximum diameter: 1200 mm
Dominant range:
greater than 200 mm but not greater than 400 mm

Mains materials: 28,5 % of grey cast iron
53,7 % of ductile iron
2,2 % of steel
% of ferrous mains without adequate corrosion protection
4,7 % of asbestos cement
2,3 % of polyethylene
8,6 % of polyvinyl chloride

Mains failures: 300 [Number of] failures
Mains repairs: 320 [Number of] repairs [planned and unplanned]
Non-revenue water: 30 % of input volume that is not billed
Cleaned mains: 40 km of mains (including 20 km pig and 20 km flushing)
Replaced mains: 4.5 km of mains
Renovated mains: 1.5 km of mains

Network pressure node
200 kPa of minimum network pressure any node
1000 kPa of maximum network pressure at any node

Comments [optional field]
Information on pipe materials will be added from Gemini register
Municipality has no responsibility for private service connections,
Consequently, no records exists
Total investment water network rehabilitation is 45 mill NOK (5.6 mill Euro)

Water quality problems

<table>
<thead>
<tr>
<th>Type of problems and frequency of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting standardized thresholds for microbiologic, chemical, physical parameters</td>
</tr>
<tr>
<td>Thresholds exceeded one or two times (KIM), very limited problem [expand as needed]</td>
</tr>
<tr>
<td>Health hazard (bacteria)</td>
</tr>
<tr>
<td>Minimal [expand as needed]</td>
</tr>
<tr>
<td>Practical requirements (turbidity/colour)</td>
</tr>
</tbody>
</table>
Can occur due to flushing and pipe repair [expand as needed]
Practical requirements (taste/odour)

Can occur due to poor circulation (“dead ends”) [expand as needed]

Water quality-related Operation & Maintenance practices in the network

General

**O&M organisation**

Organisation of operation and maintenance (structure, crew, equipment)
Crew training.
Do complaint records exist? Are they a reason for operation and maintenance actions?

Adequate training of crew by courses and “on-the-job” training. Focus on hygiene (pressure control, disinfection in field), flushing and plug operation.

Complaint records exist are used actively for failure detection and problem solving [expand as needed]

**Hygienic protection**

Routines and rules to protect network from infiltration. Has infiltration of contaminated water been reported?
Are disinfection routines sufficient to protect all customers?
Do guidelines exist for hygiene on repair and management actions (disinfection rules, crew equipment, control)?

Contaminated water has been reported a couple of times (E-coli), see later question

Procedures for disinfection exist. [expand as needed]

**Computer records and model**

Do computer based utility systems for the network exist? If so, what do they include?
Is the entire network covered by the record system?

Computer based utility system exists and include properties, reported failures and O&M reports.

The entire networks is covered by this system [expand as needed]

Is SCADA used? If so, what information is collected?
Are automatic mapping (GIS) applied to water network management?

SCADA is used to collect information about pressure, reservoir level, pump operation status, pressure and water meters
<table>
<thead>
<tr>
<th><strong>GIS</strong></th>
<th>Applied actively. Network maps can be produced in operators vehicle. Thematic maps on “dead ends” and pressure level are produced [expand as needed]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Does a hydraulic model of network exist? Is it used for analysis of pressure, velocity, flow tracks, travel times, water quality parameters (which)?</strong></td>
<td>Hydraulic model exists for entire network and is used actively to analyse consequences of valve and pump operation [expand as needed]</td>
</tr>
<tr>
<td><strong>Is a computer model used for operation and maintenance purposes? If yes, what type of model and how?</strong></td>
<td>No [expand as needed]</td>
</tr>
<tr>
<td><strong>Sensors and automatic control devices</strong></td>
<td>Are on-line sensors used? If yes, what parameters are monitored and where are they used? How are the measurements processed, stored and how are they used?</td>
</tr>
<tr>
<td><strong>Reservoir level, pumping status, valve status, pressure and water flow are monitored and stored in SCADA system. No water quality sensor is used.</strong> [expand as needed]</td>
<td></td>
</tr>
<tr>
<td><strong>Rehabilitation due to water quality problems</strong></td>
<td>Have pipes been renovated (relined) to improve water quality? Have other rehab projects been completed with the aim of improving water quality?</td>
</tr>
<tr>
<td><strong>No pipes have been renovated to improve water quality. Some but few rehab projects have been completed due to water quality problems</strong> [expand as needed]</td>
<td></td>
</tr>
<tr>
<td><strong>Rehabilitation</strong></td>
<td>Practice for renovation (methods) PE lining including pipe cracking. Tube-in has been applied a couple of times as a temporary solution [expand as needed] Input/information applied</td>
</tr>
<tr>
<td><strong>Failure statistics</strong> [expand as needed] Applied strategies for rehab planning</td>
<td></td>
</tr>
<tr>
<td><strong>Failure statistics (now/future CARE-W)</strong> [expand as needed] Applied software tools</td>
<td></td>
</tr>
<tr>
<td>(Now: None; Future: CARE-W) [expand as needed] Applied guidelines, manuals, publications</td>
<td></td>
</tr>
<tr>
<td>(Now: None; Future: CARE-W) [expand as needed]</td>
<td></td>
</tr>
<tr>
<td><strong>Research needs</strong></td>
<td>What information are you missing for operation and maintenance decisions? Do hydraulic model, utility data system, GIS and other IT tools meet your needs?</td>
</tr>
</tbody>
</table>
How would you imagine operation and maintenance in an ideal world?

Systematising of experiences, statistics, models for condition development based on failure statistics and condition measurements and physical properties [expand as needed]

### O&M practices

<table>
<thead>
<tr>
<th>O&amp;M practices</th>
<th>Are written procedures</th>
<th>Are written procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mains repair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?</td>
<td>Written procedures for water quality protection at repairs, else not [expand as needed]</td>
<td></td>
</tr>
<tr>
<td>Mains replacement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?</td>
<td>Written procedure for disinfection [expand as needed]</td>
<td></td>
</tr>
<tr>
<td>Service connection repair &amp; replacement</td>
<td>Are written procedures</td>
<td>Are written procedures</td>
</tr>
<tr>
<td>Is there any procedure adopted aiming for water quality protection? Which? Is the work carried out with the connection main pressurized? Are service connections systematically disinfected after intervention? If not, why? If yes, how?</td>
<td>No, not done by the municipality [expand as needed]</td>
<td></td>
</tr>
<tr>
<td>Mains flushing and cleaning</td>
<td>Are written procedures</td>
<td>Are written procedures</td>
</tr>
<tr>
<td>What is the objective of flushing/cleaning (improve water quality, protect against sediment storage formation?)</td>
<td>Written procedures adopted, based on complaints. Yearly frequency for dead ends else no frequency.</td>
<td></td>
</tr>
<tr>
<td>How are pipes selected for flushing/cleaning (records, experiences, models?)</td>
<td>Sediment removal is the objective of flushing and cleaning (plugs).</td>
<td></td>
</tr>
<tr>
<td>How often is flushing/cleaning repeated, and how is the frequency defined?</td>
<td>Will need a better policy for flushing and cleaning, may be based on hydraulic software.[expand as needed]</td>
<td></td>
</tr>
<tr>
<td>What kind of flushing/cleaning technology is used?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crew and equipment for flushing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are other cleaning methods applied?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service reservoirs inspection and cleaning</td>
<td>Are written procedures</td>
<td>Are written procedures</td>
</tr>
<tr>
<td>Frequency, procedures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. yearly frequency cleaning of service reservoirs [expand as needed]

<table>
<thead>
<tr>
<th>Domestic tanks inspection and cleaning</th>
<th>Are written procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency, procedures, utility’s responsibility and participation</td>
<td>Not relevant [expand as needed]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Active leakage control</th>
<th>Are written procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are water quality issues expressly taken into account when developing leakage control schemes or rehabilitation plans (due to changes in network configuration)? If yes, how?</td>
<td>No problem experience [expand as needed]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure management</th>
<th>Are written procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is pressure management adopted to reduce leakage? What is the general procedure? What is the acceptable minimum pressure? Is there any evidence that pressure management may increase the risk of external contamination in the system?</td>
<td>No [expand as needed]</td>
</tr>
</tbody>
</table>
Zürich

Utility profile

Utility ID: Water Supply Zurich [Full official designation of the utility]

Type of activity: Water only

Multiservices

Utility size: 82.5 10^6 € of sales revenues from the water supply services /year

56.8 10^6 m^3 of billed water /year

277 employees [utility total]

ca. 200 O&M employees [water supply services]

Total running costs: 41.7 10^6 € /year [total running costs of the water supply services]

Total capital costs: 40.0 10^6 € /year [total capital costs of the water supply services]

Running costs of O&M functions: ca.75 % of total running costs

If feasible, split into:

Operation running costs: -% of total running costs

Maintenance running costs: -% of total running costs

O&M outsourcing: 5 % [approximate % of O&M opex related to outsourcing]

Investments for asset replacement and renovation 72 % of the total capital costs

Comments [optional field]

further financial details on the web site: www.stadt-zuerich.ch/wasserversorgung

Water supply system profile

Type of system:

Bulk supply and

Bulk supply only

Distribution only

Water sources

Upland surface water 0 % of total abstraction
Lowland surface water 70% of total abstraction
Natural springs and wetlands 15% of total abstraction
Well water 0% of total abstraction
Borehole water 15% of total abstraction
Saline and brackish water 0% of total abstraction

Comments [optional field]
70%湖水, 15%地下水（补给系统与莱茵河的河岸过滤），15%为泉水

Treatment
No treatment 0% of water delivered to users without any treatment
Disinfection only 15% of total abstraction
1 [Number of] disinfection facilities
Carbonizing/ 0% of total abstraction
pH increase 2 [Number of] facilities
Conventional treatment 70% of total abstraction
4 [Number of] treatment plants
Advanced treatment 0% of total abstraction
0 [Number of] treatment plants

Water volume produced 56.9 106 m3/year

Short description of the existing treatment facilities
Lengg lake water plant: Capacity 250'000 m3/d. Treatment: preozonation, pH-adjustment to 8.2, rapid filtration, intermediate ozonation, activated carbon filtration, slow sand filtration.
Moos lake water plant: Capacity 80'000 m3/d. Treatment: preoxidation with Cl2/ClO2, flocculation with aluminiumsulfate, rapid filtration, ozonation, activated carbon filtration, slow sand filtration, pH adjustment 8.0.
Hardhof ground water plant: Capacity 150'000m3/d. Artificial ground water recharge system. Treatment: disinfection only (chlorine dioxide). Spring water: ca. 20'000 m3/d. Mixed with lake water in the Moos plant before ozonation.

Transmission and distribution
Target residual disinfectant: 0 to 0 mg/l at the consumer’s tap
Network size: 1545 km of mains
20 [Number of] service reservoirs customers
0 [Aprox. number of] domestic tanks
<table>
<thead>
<tr>
<th><strong>Number of customers</strong></th>
<th>350,000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aprox. number of service connections</strong></td>
<td>32,000</td>
</tr>
<tr>
<td><strong>Aprox. number of district metering areas</strong></td>
<td>20</td>
</tr>
</tbody>
</table>

**Diameters: mm**
- Minimum diameter: 100 (mains), 50 (house connections)
- Maximum diameter: 2300 mm
- Dominant range:
  - Less or equal 200 mm
  - Greater than 200 mm but not greater than 400
  - Greater than 400 mm

**Diameters: mm**
- Minimum diameter: 100 (mains), 50 (house connections)
- Maximum diameter: 2300 mm
- Dominant range:
  - Less or equal 200 mm
  - Greater than 200 mm but not greater than 400
  - Greater than 400 mm

**Mains materials:**
- 37.5% of grey cast iron
- 43.3% of ductile iron
- 3% of steel
- 1% of asbestos cement
- 14.5% of polyethylene
- 1% of polyvinyl chloride

**Mains failures:** 264 [Number of failures]

**Mains repairs:** 264 [Number of repairs] [planned and unplanned]

**Non-revenue water:** 10.3% of input volume that is not billed

**Cleaned mains:** 1.5 km of mains

**Replaced mains:** 21 km of mains

**Renovated mains:** 0 km of mains

**Replaced service connections:**
- ca. 500 [Number of service connections]

**Network pressure:**
- 350 kPa of minimum network pressure any node
- 1100 kPa of maximum network pressure at any node

**Comments** [optional field]

Network size: 1120 km of mains and 425 km of service connections.
Service connections repairs 2005: 314
Replacements of service connections: 11 km
Water quality problems in the network

<table>
<thead>
<tr>
<th>Type of problems and frequency of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting standardized thresholds for microbiologic, chemical, physical parameters</td>
</tr>
<tr>
<td>Rare microbiological problems in end pipes</td>
</tr>
<tr>
<td>Health hazard (e.g. bacteria)</td>
</tr>
<tr>
<td>None</td>
</tr>
<tr>
<td>Practical requirements (turbidity/colour)</td>
</tr>
<tr>
<td>&lt; 0.1 NTU / colourless</td>
</tr>
<tr>
<td>Practical requirements (taste/odour)</td>
</tr>
<tr>
<td>taste and odourless, most complaints are caused by problems in the house installations</td>
</tr>
</tbody>
</table>

Water quality-related Operation & Maintenance practices in the network

<table>
<thead>
<tr>
<th>O&amp;M organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisation of operation and maintenance (structure, crew, equipment)</td>
</tr>
<tr>
<td>Crew training.</td>
</tr>
<tr>
<td>Do complaint records exist? Are they a reason for operation and maintenance actions?</td>
</tr>
<tr>
<td>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 involved. (Part of the ISO 9001 management system) There is a complaint record. Practically all technical complaints are due to house installation problems and not to the network.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hygienic protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routines and rules to protect network from infiltration. Has infiltration of contaminated water been reported?</td>
</tr>
<tr>
<td>Are disinfection routines sufficient to protect all customers?</td>
</tr>
<tr>
<td>Do guidelines exist for hygiene on repair and management actions (disinfection rules, crew equipment, control)?</td>
</tr>
<tr>
<td>The network has at any location a minimal pressure of 3.5 bar. Hygienic precautions for pipes under construction (closed pipes). No infiltration of contaminated water detected in the last 10 years / No network protection (chlorination) applied in the lake water plants / guidelines for cleaning and disinfection of drinking water pipes after rehabilitation.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Computer records and model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do computer based utility systems for the network exist? If so, what do they include? Is the entire network covered by the record system?</td>
</tr>
<tr>
<td>SCADA for management of treatment plants, reservoirs and pressure zones. GIS for technical data of the network. &quot;EC-Netz&quot; for hydraulic modelling.</td>
</tr>
<tr>
<td>Is SCADA used? If so, what information is collected? Are automatic mapping (GIS) applied to water network management?</td>
</tr>
<tr>
<td>SCADA for water distribution, reservoir management. Parameters in SCADA:</td>
</tr>
</tbody>
</table>
Water consumption in m³/day for partners, customers, pressure zones, pressure reduction stations.

GIS for the entire network with all technical equipment (hydrants, valves, etc.) and all technical data (age of pipe, material type, etc.)

Does a hydraulic model of network exist? Is it used for analysis of pressure, velocity, flow tracks, travel times, water quality parameters (which)?

Is a computer model used for operation and maintenance purposes? If yes, what type of model and how?

The hydraulic model "EC-Netz" is applied to calculate flow velocities, flow time and pressure. The calculation of water age is not realized yet. The model is not used for quality parameters.

No computer model is used for maintenance

Are valves operated to regulate water age and flow velocity?

Mains from water works to reservoirs: Valves are operated to ensure a mean water age of about 24 h. Mains after reservoir: No regulation of water age/flow velocity.

Are valves operated to regulate water age and flow velocity?

- [expand as needed]

**Sensors and automatic control devices**

Are on-line water quality sensors used? If yes, what parameters are monitored and where are they used?

How are the measurements processed, stored and how are they used?

No, only in the treatment plants

**Rehabilitation due to water quality problems**

Have pipes been renovated (relined) to improve water quality?

Have other rehab projects been completed with the aim of improving water quality?

Yes, pipes have been replaced (not relined) to solve bacterial problems. (The bacterial problems were caused by a relined pipe (textile tube))

**Rehabilitation**

Practice for renovation (methods)

Replacement of defective pipes or "relining" with PE pipe (pipe in pipe), no relining with textile tubes because of quality problems with relined pipes in a network without chlorine residual. Active corrosion protection for selected mains (stray current)

Input/information applied

[expand as needed]

Applied strategies for rehab planning

Goal: Yearly rehabilitation of about 1.5 to 2% of the network.

Applied software tools

SAP: PM-Modul and PS-Modul

Applied guidelines, manuals, publications

SVGW guidelines (Swiss Association of Gas and Water Works), legal requirements,
### Research needs

What information are you missing for operation and maintenance decisions?
Do hydraulic model, utility data system, GIS and other IT tools meet your needs?
How would you imagine operation and maintenance in an ideal world?

Hydraulic modelling of a complex network "ring-system" to reliably calculate the age of the water, the flow direction and velocity and the temperature. Modelling of interaction between maintenance, age of pipe, hydraulic situation, and leakages and bursts. Modelling of bacterial growth as a function of temperature, assimilable organic carbon (AOC) and water age.

### O&M practices

#### Mains repair

<table>
<thead>
<tr>
<th>Are written procedures</th>
<th>Is there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOP for cleaning and disinfection of pipes after repair. No regular disinfection, just when rinsing with water is not successful to meet the microbiological limits. Disinfect with sodium hypochlorite 40 mg/L (as chlorine) for 78 h.</td>
<td></td>
</tr>
</tbody>
</table>

#### Mains replacement

<table>
<thead>
<tr>
<th>Are written procedures</th>
<th>Is there any procedure adopted aiming for water quality protection? Which? Are mains systematically disinfected after repair? If not, why? If yes, how?</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOP for Cleaning and disinfection of pipes after replacement. Procedure for microbiological testing before the main is released by the quality department for use. No regular disinfection, just when rinsing with water is not succesful to meet the microbiological limits. Disinfect with sodium hypochlorite 40 mg/L (as chlorine) for 78 h.</td>
<td></td>
</tr>
</tbody>
</table>

#### Service connection repair & replacement

<table>
<thead>
<tr>
<th>Are written procedures</th>
<th>Is there any procedure adopted aiming for water quality protection? Which? Is the work carried out with the connection main pressurized? Are service connections systematically disinfected after intervention? If not, why? If yes, how?</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOP for cleaning and disinfection of pipes after repair/replacement. No regular microbial testing, just in case of problems/complaints. No regular disinfection, just when rinsing with water is not successful. Disinfect with sodium hypochlorite 40 mg/L (as chlorine) for 78 h.</td>
<td></td>
</tr>
</tbody>
</table>

#### Mains cleaning (including flushing)

<table>
<thead>
<tr>
<th>Are written procedures</th>
<th>What is the objective of flushing or other cleaning methods (improve water quality, protect against sediment storage formation)? How are pipes selected for cleaning (records, experiences, models?) How often is cleaning repeated, and how is the frequency defined? What kind of cleaning technology is used? Crew and equipment for cleaning? Are other cleaning methods applied rather than flushing?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cleaning by flushing with water to remove sediments, organic materials, biofilms to meet the water quality limits after starting up. Cleaning after rehabilitation of pipes (only) (SOP). Cleaning (flushing and if necessary disinfection) is repeated until the water meets the microbiological limits. Cleaning is made by flushing with water, when not successful then mains are disinfected with sodium hypochlorite, 40mg/L (as chlorine) for 72h. Disinfection is made by the network staff together with the quality control department. Except sodium hypochlorite, no cleaning agents are used. [expand as needed]

### Service reservoirs inspection and cleaning

<table>
<thead>
<tr>
<th>Are written procedures</th>
<th>Frequency, procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Once per year according a SOP. Cleaning with water. In case of constructions in the reservoir, also disinfection is made by spraying floor and the walls with diluted sodium hypochlorite solution.</strong> [expand as needed]</td>
</tr>
</tbody>
</table>

### Domestic tanks inspection and cleaning

<table>
<thead>
<tr>
<th>Are written procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency, procedures, utility’s responsibility and participation</strong></td>
</tr>
<tr>
<td>- [expand as needed]</td>
</tr>
</tbody>
</table>

### Active leakage control

<table>
<thead>
<tr>
<th>Are written procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Are water quality issues expressly taken into account when developing leakage control schemes or rehabilitation plans (due to changes in network configuration)? If yes, how?</strong></td>
</tr>
<tr>
<td><strong>Preventive leakage control once per year of about 50% of the network. 3 methods applied: water metering and 2 acoustic systems. Water quality issues are discussed in the weekly coordination meeting with the network staff.</strong> [expand as needed]</td>
</tr>
</tbody>
</table>

### Pressure management

<table>
<thead>
<tr>
<th>Are written procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Is pressure management adopted to reduce leakage? What is the general procedure? What is the acceptable minimum pressure? Is there any evidence that pressure management may increase the risk of external contamination in the system?</strong></td>
</tr>
<tr>
<td><strong>No pressure management applied. Water distribution is divided in four pressure zones. Water from the plant is pumped to the reservoirs and other pumping stations. Distribution on the base of hydrostatic pressure (difference in altitude; there are a few exceptions to this principle).</strong> [expand as needed]</td>
</tr>
</tbody>
</table>