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R E P O R T

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CARE-W
WP6 - Testing and validation of CARE-W Rehab Manager

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SINTEF

COMPUTER AIDED REHABILITATION OF WATER NETWORKS
RESEARCH AND TECHNOLOGICAL DEVELOPMENT PROJECT OF EUROPEAN COMMUNITY

CARE – W

Computer Aided REhabilitation of Water networks

Decision Support Tools for Sustainable Water Network Management

WP6 - Testing and validation of CARE-W Rehab Manager

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Trondheim, January 2004

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1 Introduction

The *CARE-W* project is funded by the European Union, and aims to develop methods and software that will enable engineers of the water undertakings to establish and maintain an effective management of their water supply networks, rehabilitating the right pipes at the right time. The results shall be disseminated as a manual on Best Management Practice (BMP) for water network rehabilitation.

This project is organised in the following Working Packages (WP):

WP1: Construction of a control panel of performance indicators for rehabilitation;
WP2: Description and validation of technical tools;
WP3: Elaboration of a decision support system for annual rehabilitation programmes;
WP4: Elaboration of long-term strategic planning and investment;
WP5: Elaboration of *CARE-W Rehab Manager*;
WP6: Testing and validation of *CARE-W Rehab Manager*;
WP7: Dissemination;
WP8: Project management.

SINTEF is responsible for WP6, but the actual testing has been carried out by all of the partners and for different end-users spread all over Europe.

The testing of the *CARE-W Rehab Manager* (in the proposal the term *Prototype* was used) and all the tools contained within it is the final part of the *CARE-W* project, but one of the most important. It allows each software component to be thoroughly evaluated using data from many end-users – data that are diverse in terms of quantity and quality, as well as in geographic origin. It also permits the whole rehabilitation procedure to be tried, and facilitates the establishment of a recommended best practice, based on data availability and the utility's objectives. This report outlines the testing procedure and presents the results from the testing.

The aim of this WP in the *CARE-W* project is to test the various tools in the *CARE-W* toolkit within the main framework of the *CARE-W* software (*CARE-W Rehab Manager*). In addition to the testing of the integrated *CARE-W Rehab Manager*, the individual tools have also been tested separately. The testing phase addresses both the ease of use of the *CARE-W* software and tools as well as the relevance of the analysis that has been undertaken.

Besides aiding removal of software bugs, such broad testing provides many benefits:

- The opportunity to examine data availability in different regions and countries with a view to determining the "most appropriate use of *CARE-W*" for each;
- A chance to determine how "*CARE-W* - the *Rehab Manager*" can fit into and improve the existing rehabilitation management of end-users;
- Identification of extra functionality requirements and needs for further research.

The testing phase for the *CARE-W* project officially began at the end of June 2003, when version 1.5.0 of the *CARE-W* software was issued. Since then, several versions of the software have been released, being 1.5.4 the current one.

2 Overview of the testing

This Working Package has been broken down in two tasks as follows:

<u>*Task 6.1. System for testing*</u>: the toolkit was tested for 13 real cases (see Figure 1) reflecting different European conditions, including geographical location, size and water management organisation.

This testing has been carried out in three steps, according to the *CARE-W Description of Work* document:

1. Identification of the current state-of-art
2. Comparative studies of programmes for pipe failure forecasting and water supply service reliability
3. Testing , including evaluation, of the *Rehab Manager*.

<u>*Task 6.2. Analysis*</u>: A synthesis of the case studies is extracted from the testing to support further business development and implementation of the *CARE-W Rehab Manager*. This synthesis comprises a critical view of the tools and methods and will also include sensitivity and feasibility analyses.

Figure 1. Map showing CARE-W partners and end-users (testing sites)

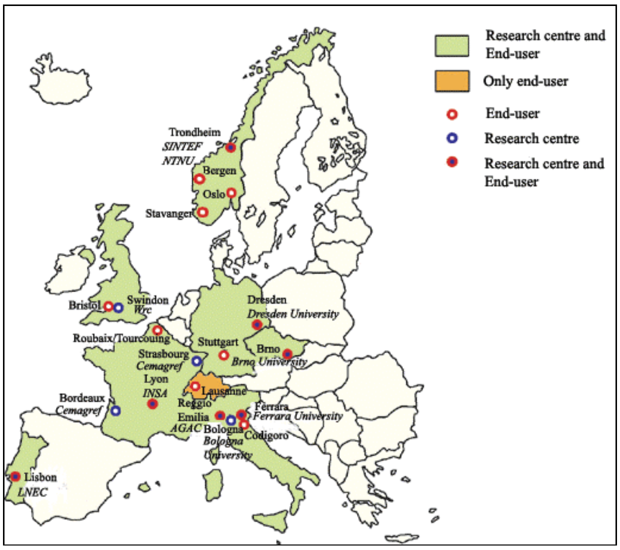


Table 1 gives an overview of the test cities, including some properties of water network and management.

The testing phase carried out in this penultimate work package involves all partners and end-users involved with the project The focus is on testing tools within the *CARE-W Rehab Manager* environment rather than as stand alone software.

For most of the test cases there is a end-user report providing feedback and suggestions for further improvement of the software. The individual test reports from the end-users are given as appendices of this document.

Table 1. Properties of the cities

City	Bristol	Brno	Codigoro	Dresden	Ferrara	Lausanne	Lyon	Oeiras/ Amadora	Oslo	Reggio Emilia	Roubaix/ Tourcouing	Stuttgart	Trondheim
Nationality	UK	CZ	I	D	I	CH	F	P	N	I	F	D	N
Location in Europe	W	CE	S	CE	S	C	C	SW	N	S	W	C	N
Population	L	M	S	M	S	S	L	S	M	S	S	M	S
Type of entity	P	P	M	P	M	M	P	M	M	P	P	P	M
Tourist area	N	N	P	Y	N	N	N	Y		N	N	N	N
Data records length (years)		5	6	5	6	50	5-18	30	25	22	90		10
Electronic records	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
GIS	Y	Y	N	(Y)	(Y)	Y	Y	Y	Y	Y	Y	Y	Y
Network length (km)	6400	1100		1600	400	750	3000	750	2000	633	490	1500	700
Inefficiency of use of water resources (%)		20		20		20	10	32	30	22	23	8	20
Water shortage	N	N	N	N	N	N	N	N	N	N	N	N	N
Average pipe age (years)		40		55		28	40	40	30	30	40	35	30
Annual renewal rate (%)		0,5		3		1,3	1	5		1,4	0,6	1	3

Explanation:
1. Location: S,E,N,W,C= south, east, north, west, central
2. Population: L (large, over 1,0 million), M (medium, 0,3 to 1,3 million), S (small under 0,3 million)
3. Type of entity: P=private, M=municipal
4. Tourist area: Y=yes, N=no, P=partly
5. Electronic records: Y=yes, N=no
6. GIS: Y=yes, N=no
7. Water shortage: Y=yes, N=no

The size of networks (or test zones within the network) varied considerably (Table 2). In some cases it was possible to use the whole network for one or more of the tools, whilst in other regions, small zones within the network, already identified as problematic, were tested. This variety was important in assessing the suitability of each tool given the number of pipes present. For example, failure prediction tools require as many pipes as possible (i.e. a suitably large sample) to ensure statistical significance, whilst large networks will lead to long computational times for hydraulic reliability models.

Table 2. Summary of main testing sites including tools tested

Test Network	*Size of network / main test zone (km)*	*CARE-W PI*	*CARE-W FAIL*	*CARE-W REL*	*CARE-W ARP*	*CARE-W LTP*
Bristol, UK	150		✓			
Brno, Czech Republic	1200	✓		✓	✓	✓
Codigoro, Italy	85		✓	✓		✓
Dresden, Germany	11				✓	✓
Ferrara, Italy	33		✓	✓		✓
Lyon, France	1100	✓	✓		✓	
Oslo, Norway	8	✓	✓	✓	✓	✓
Reggio Emilia, Italy	652	✓		✓	✓	✓
Stuttgart, Germany	1420	✓	✓	✓	✓	✓

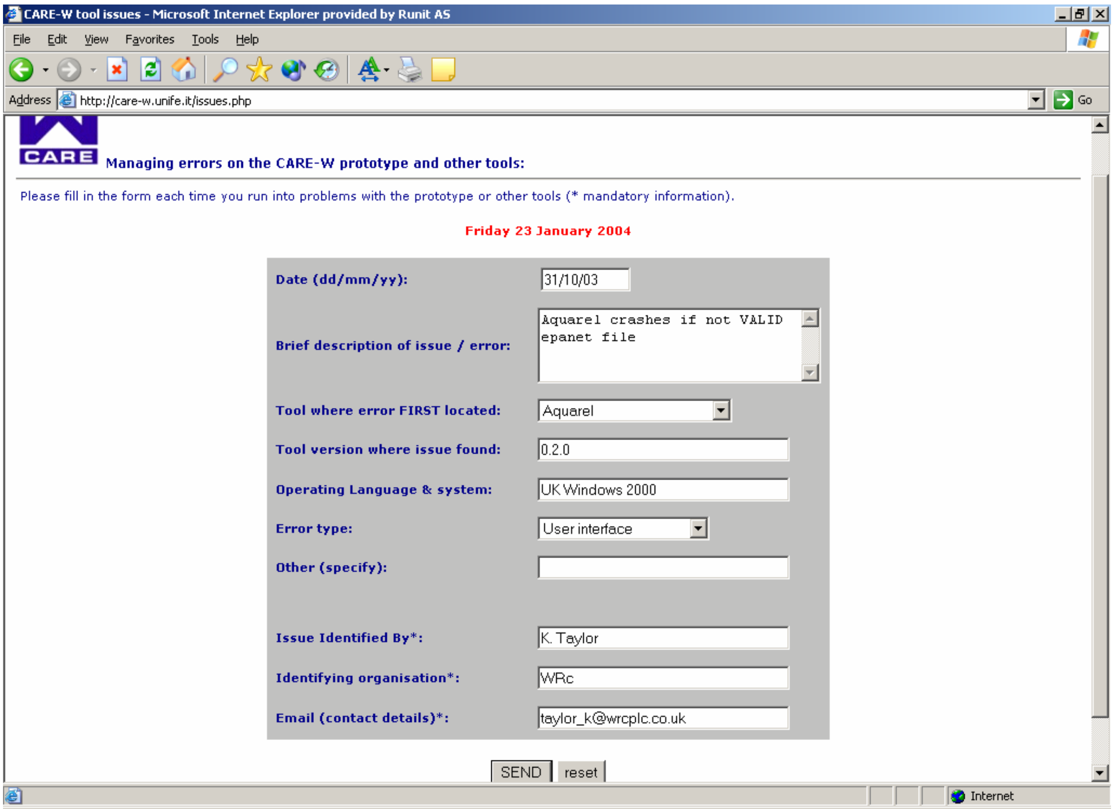
2.1 Testing approach

The testing was carried out by using error/issue log reports. As long as program errors where identified during the testing, partners and end-users were able to report about them. For this purpose, a server was set up with Basic Support for Cooperative Work (*BSCW*) software in order to provide an internal shared workspace for the project for *CARE-W* partners. A standard web form was designed and uploaded to the *BSCW* server intended for that purpose. The users could fill it with all details concerning each error found (Figure 2).

The information required to report any error is:

- Date
- Brief description of issue/error
- Tool where the error first located
- Tool where issue found
- Operating language and system
- Error type
- Contact details

Figure 2. The CARE-W issues reporting webform



All errors reported were stored in a workbook for further investigation (Figure 3). Once verified and tested the existence of each error, this was reported to the corresponding tool owner with as much details as possible to make possible to reproduce the error and fix it.

Three possible status of each error were defined following a code of colours:

- Errors still active (red);
- Errors already fixed by the tool owner (orange);
- Errors fixed and validated (green).

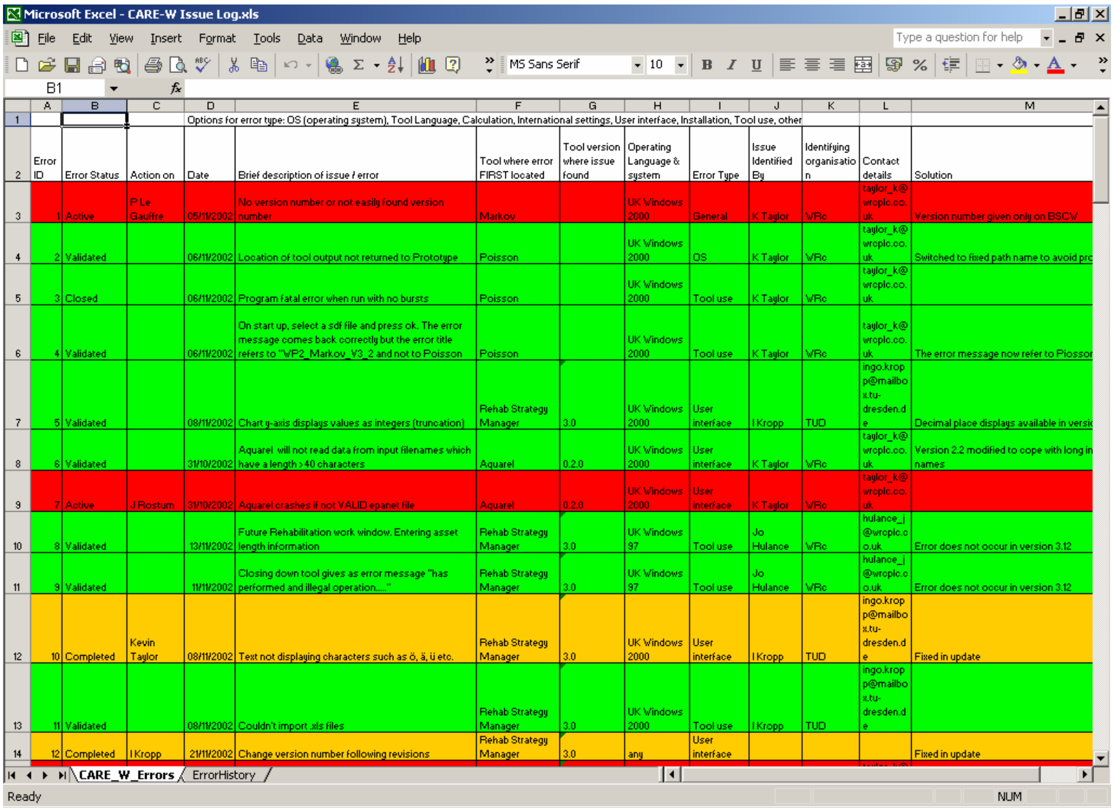
The current status of each error was tracked by direct email communication between the chief software developer and the tool owners, updating the issue log as errors were being fixed.

2.2 Updating tools

The testing process within the water utilities has been performed by the end-user in close collaboration with partners of the *CARE-W* consortium. End-users could take advantage of the expertise and know-how of technical staff directly involved in the development of the different working packages of *CARE-W*. This made it possible for the users to validate the usefulness of the software within their utilities. Some utilities were concerned about the feasibility of their own data record-keeping systems to work with *CARE-W*. This issue also raised awareness of the lack of data (i.e. short periods of records for failure data) that may be needed to start gathering.

On the other hand, partners got feedback from end-users on the usage of the tools and existing bugs which showed up during the testing. In the mean time, the tools were updated accordingly and uploaded to the *BSCW* server. Descriptions on the bug fixes and any new features added were reported in updated versions of the *Whatsnew.txt* or *Readme.txt* files.

Figure 3. CARE-W issue log workbook


Microsoft Excel - CARE-W Issue Log.xls

Options for error type: OS (operating system), Tool Language, Calculation, International settings, User interface, Installation, Tool use, other

Error ID	Error Status	Action on	Date	Brief description of issue / error	Tool where error FIRST located	Tool version where issue found	Operating Language & system	Error Type	Issue Identified By	Identifying organisation	Contact details	Solution
1	Active	P Le Gauffre	05/11/2002	No version number or not easily found version number	Markov		UK Windows 2000	General	K Taylor	WRc	taylor_k@wrcplc.co.uk	Version number given only on BSCW
2	Validated		06/11/2002	Location of tool output not returned to Prototype	Poisson		UK Windows 2000	OS	K Taylor	WRc	taylor_k@wrcplc.co.uk	Switched to fixed path name to avoid pro
3	Closed		06/11/2002	Program fatal error when run with no bursts	Poisson		UK Windows 2000	Tool use	K Taylor	WRc	taylor_k@wrcplc.co.uk	
4	Validated		06/11/2002	On start up, select a sdf file and press ok. The error message comes back correctly but the error title refers to "WP2_Markov_V3_2 and not to Poisson	Poisson		UK Windows 2000	Tool use	K Taylor	WRc	taylor_k@wrcplc.co.uk	The error message now refer to Piossor
5	Validated		08/11/2002	Chart y-axis displays values as integers (truncation)	Rehab Strategy Manager	3.0	UK Windows 2000	User interface	I Kropp	TUD	ingo.kropp@mailbox.tu-dresden.de	Decimal place displays available in versi
6	Validated		31/10/2002	Aquarel will not read data from input filenames which have a length >40 characters	Aquarel	0.2.0	UK Windows 2000	User interface	K Taylor	WRc	taylor_k@wrcplc.co.uk	Version 2.2 modified to cope with long in names
7	Active	J Rostum	31/10/2002	Aquarel crashes if not VALID epanet file	Aquarel	0.2.0	UK Windows 2000	User interface	K Taylor	WRc	taylor_k@wrcplc.co.uk	
8	Validated		13/11/2002	Future Rehabilitation work window. Entering asset length information	Rehab Strategy Manager	3.0	UK Windows 97	Tool use	Jo Hulance	WRc	hulance_j@wrcplc.co.uk	Error does not occur in version 3.12
9	Validated		11/11/2002	Closing down tool gives as error message "has performed and illegal operation....."	Rehab Strategy Manager	3.0	UK Windows 97	Tool use	Jo Hulance	WRc	hulance_j@wrcplc.co.uk	Error does not occur in version 3.12
10	Completed	Kevin Taylor	08/11/2002	Text not displaying characters such as ö, ä, ü etc.	Rehab Strategy Manager	3.0	UK Windows 2000	User interface	I Kropp	TUD	ingo.kropp@mailbox.tu-dresden.de	Fixed in update
11	Validated		08/11/2002	Couldn't import .xls files	Rehab Strategy Manager	3.0	UK Windows 2000	Tool use	I Kropp	TUD	ingo.kropp@mailbox.tu-dresden.de	
12	Completed	I Kropp	21/11/2002	Change version number following revisions	Rehab Strategy Manager	3.0	any	User interface				Fixed in update

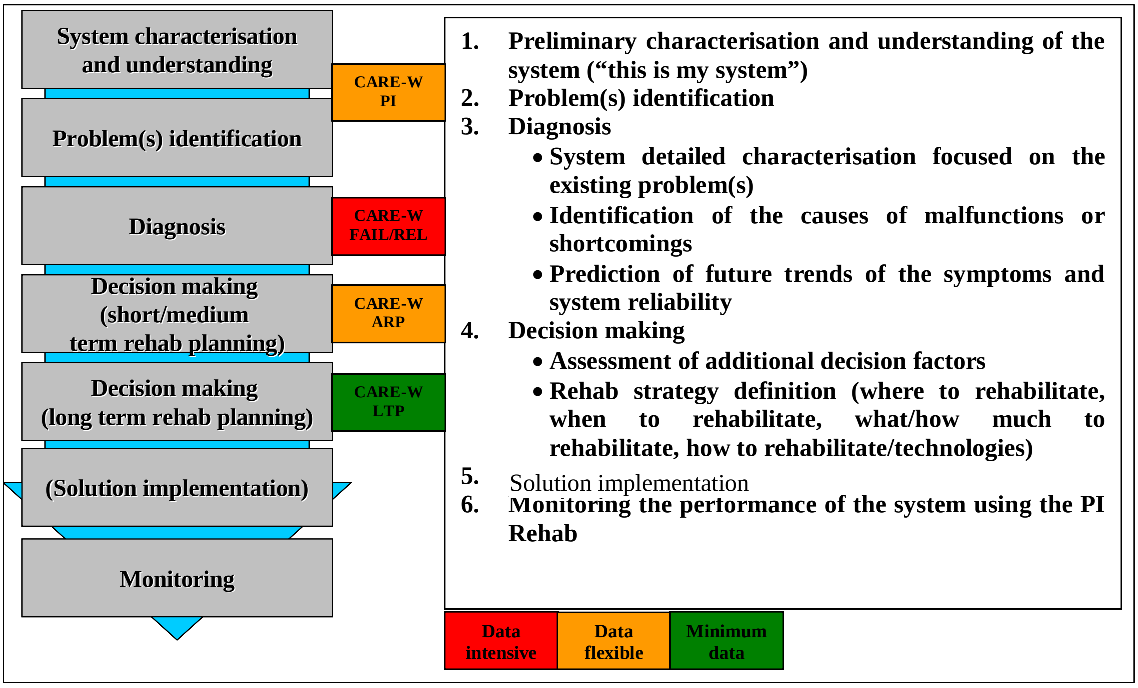
CARE_W_Errors / ErrorHistory

3 Output of the testing

3.1 Data availability and preparation

One of the objectives of *CARE-W* is for the software to be applicable to both data-rich and data-lean networks. Data availability influences the way the *CARE-W Rehab Manager* can be used. Some of the *CARE-W* modules are more data-consuming than others. The advanced user with updated GIS, digital maintenance records, calibrated hydraulic network simulation models, etc. can use all the functionality *CARE-W* provides. However, users with fewer data can also benefit, but will more than likely adopt a different path through the software (Figure 4). Exactly which tools to use should be decided case-by-case, based on an evaluation of availability and quality of data.

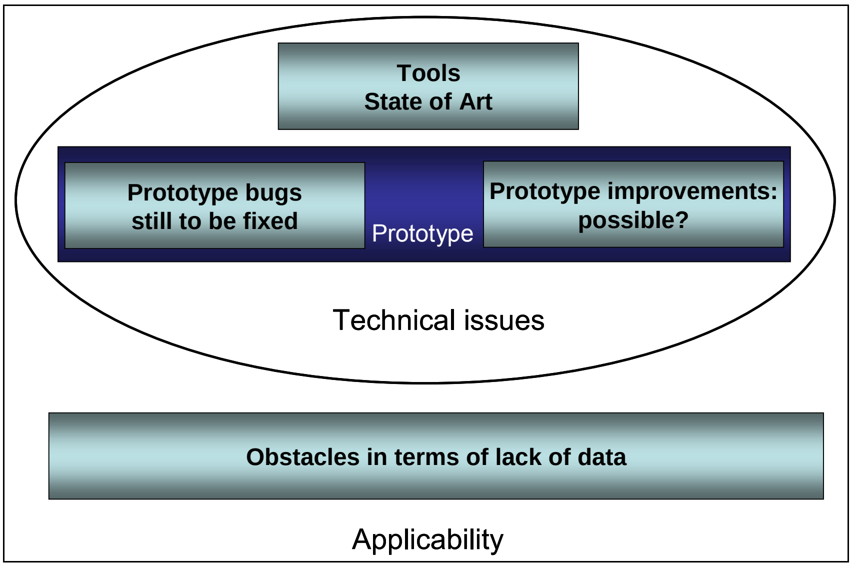
Figure 4. Rehabilitation planning procedure



CARE-W can also have the role as a catalyst to start or improve the process of recording data and act as an incentive to store as much data as possible of the highest quality. Tools such as failure prediction models require historical failure records and the variation in record lengths (number of years of data) amongst the test sites, helps determine a minimum recommended value.

In this chapter it is presented the current state of art for the different tools of *CARE-W* resulting from the analysis of the testing (Figure 5). Testing of the toolkit made possible bugs to come out and provided many hints for possible improvements of the *CARE-W Rehab Manager* and the tools for a better integration and a more friendly use of the software. And, vice versa, the applicability of *CARE-W* to real cases in water utilities unmasked obstacles existing on corporate databases to implement the software: lack of data, quality, etc.

Figure 5. Overview of the testing



Although this testing was mainly focused on the integration of the tools with the *CARE-W Rehab Manager*, individual testing of the tools as stand-alone software could also be performed. In certain situations, the issues shown up on their use through the *CARE-W Rehab Manager*, prevented results from being obtained, so stand-alone use was necessary while bugs were identified, reported and fixed. The state of art for the tools is outlined in Table 3.

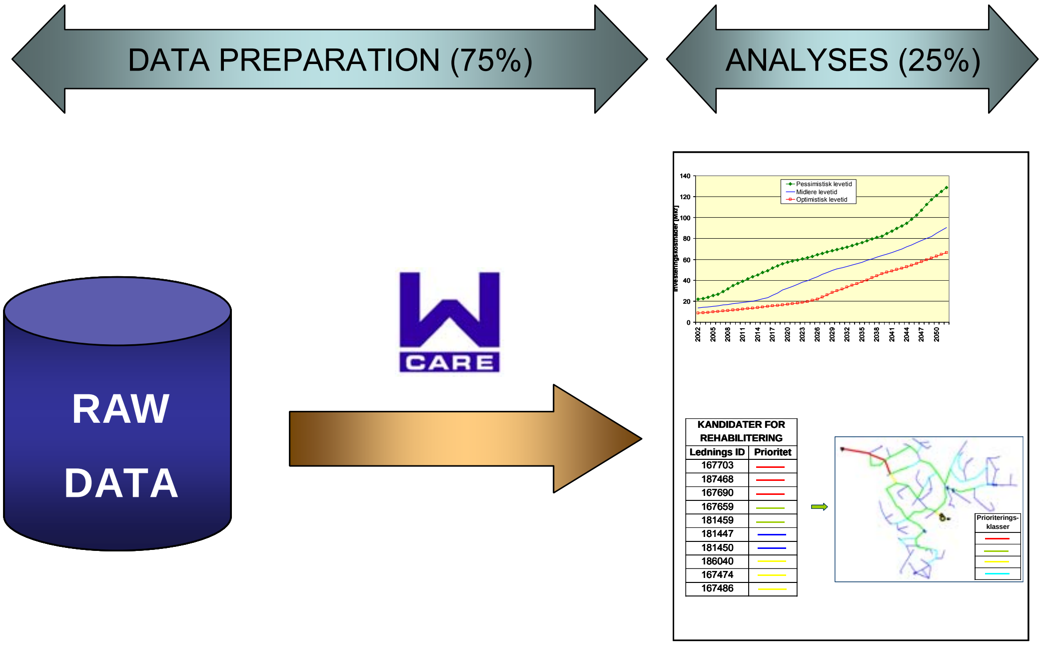
Table 3. State-of-art of the CARE-W tools

Tool	Still bugs	OK as stand-alone	OK in the prototype
CARE-W_PI Tool	-	Yes	Yes
CARE-W_REL AquaRel	Yes	-	-
CARE-W_REL RelNet	-	Yes	Yes
CARE-W_REL Failnet-Reliab	Yes	-	Yes
CARE-W_FAIL PHM	Yes	-	Yes
CARE-W_FAIL Poisson	-	Yes	Yes
CARE-W_ARP	-	-	Yes
CARE-W_LTP	-	-	Yes

In general, the preparation of raw data to supply the software in order to be able to run is still an important aspect of the *CARE-W* and represents the major workload of *CARE-W* projects(Figure 6). On the other hand, this is maybe the most critical part of the project. In fact, results from *CARE-W* will depend on the quality of the input data: any analysis undertaken using the *CARE-W Rehab Manager* will only be as good as the data used. Therefore, in order to produce reliable results the input data has to be checked.

The *Rehab Manager* in its present version does not supply features for automatic quality control of input data. It is the user's responsibility to ensure that valid data are available for import into the *Rehab Manager*, i.e. the data are arranged in a consistent and definable manner, data types are correct, and data values are meaningful. This should be done before loading the data into the *CARE-W* database. Everyday use and database familiarity is the best way to quality control existing data.

Figure 6. Workload in CARE-W



A common data problem is a mismatch between the links in a hydraulic model and the pipes digitized in the GIS. For the reliability tools, values are only calculated for links which have a corresponding ID in the *CARE-W* database. Thus, it is recommended that the hydraulic model is identical to the GIS network, which is not always the case (e.g. simplified hydraulic models). Additionally, before the analysis starts, failures/breaks must be linked to the pipes where they actually occur. If they are not, the failure tools are not able to run.

The most common known data issues are as follows:

- Breaks not linked to pipes (in some databases the breaks are linked to properties).
- Illogical combinations of pipe material, diameter and installation year (e.g. 150 mm PVC laid in 1930). Normally the diameter is more certain than material and installation year.
- Illogical failure types (e.g. corrosion/rust on plastic pipes).
- Missing pipe data (e.g. material, year, length or diameter are missing). The local database should if possible be updated and corrected. As an alternative, default values might be used, but it is probably best not to include these pipes in the *CARE-W* database and in subsequent analysis, until anomalies have been resolved.
- Failure date pre-dates year of installation.
- Multiple breaks at the same pipe in the same day.
- Rehabilitation date pre-dates year of installation.

In order to cleanse the database and update several values at the same time the *Expression Builder* function in the *CARE-W Rehab Manager* can be used. Here, it is possible to update values for a set of pipes, e.g. all pipes with diameter, 133.3 mm could be changed to 130 mm.

To implement automatic validation checks in the *CARE-W Rehab Manager* is an extensive work and is not included in the present version. However, in the future when *CARE-W* is commercial software such features should be implemented.

Other issue regarding data preparation was the suitability of using rehabilitation entities or clusters rather than single pipes, i.e. groups of pipes with similar attributes, allowing a better planning of rehabilitation activities, based on a zone-wise criterion (topography, system of streets, etc.) that would have not been suitable to undertake if the plan had been developed at single pipe-level. CARE-W does not include a clustering feature therefore extra preparation of data was necessary before running the software.

3.2 Main findings

In general, no problems were encountered during the installation of the individual tools. The installation procedure of the *CARE-W Rehab Manager* was not found however particularly straightforward, in part due to the need to set up folders and ensure that files are correctly located within them. However, installing subsequent upgrades is much easier and there is no need to remove and reinstall the software longer.

There is a wide variety of database structures being currently used by utilities. Moreover, structural and maintenance data use to be stored in separate databases. In the *CARE-W Rehab Manager*, GIS asset and failure data are imported as shape files (*.*shp*). Some end-users use GIS software which does not produce shape files (e.g. *SmallWorld* by Bristol Water plc), being therefore necessary to extract data with other external tools in order to produce shape files importable by the *CARE-W Rehab Manager*. Nonetheless, several features like selection of elements in the GIS interface, expression builder and help file have proved usefulness.

Since not every tool could be tested completely by all end-users, a procedure was performed in order to evaluate the applicability of each tool to their particular situation. Firstly each tool was rated regarding data availability and benefit for the utility, and thereafter any tool was applied where there was room for profit.

CARE-W_PI

Regarding the individual tools, the *CARE-W_PI Tool* allowed to retrieve a complete outline of the network performance and conditions, disclosing needs for rehabilitation activities.
PI availability on water utilities highly depends on recording habits. End-user have their own data recording system which may allow for the calculation of some indicators in the *CARE-W_PI Tool*, It proved to be useful for finding network zones with potential for rehabilitation and to monitor its effects. The *CARE-W_PI Tool*, together with the *CARE-W_FAIL* tools and the built-in GIS system on the *CARE-W Rehab Manager* have provided end-user with suggestion on the methodology to collect data.

CARE-W_FAIL

PHM and *Poisson* could be tested in several networks, although results could not be properly validated, since data were too few to produce reliable results. Consistency on input data for the program (maintenance and structural data files) is crucial when running this program. Missing input data is an important issue on this program, being necessary to establish a procedure to “fill the gaps” in order to make the program work.

CARE-W_REL

Setup and run of *CARE-W_REL RelNet* encountered no problems and was found to be easy and straightforward. The user-friendly interface made possible an intuitive usage of the tool. However, remarks on the long processing time needed to get results has been pointed out in several cases.

CARE-W_ARP

Data on failures and reliability provide sound criteria for the *CARE-W_ARP* module. These data could be used for the annual planning whenever available, which was not always the case (i.e. network hydraulic model in another file format than *EPAnet*). It was found that in most cases, slight alterations on the criteria used weights chosen by the user did not have a significant effect on the overall results. However, although *CARE-W_ARP* could ease the planning of rehab activities, it is far form replacing staff expertise and knowledge on their networks. It should be used therefore as an aid tool for decision support, rather than decision-making.

CARE-W_LTP

Assessments on long term rehabilitation needs allowed to establish rehab priorities on specific areas of a network, resulting in up to 50% reduction of failure rates in some cases. However, special care had to be taken when planning annual rehabilitation policies: if socio-economical issues are taken into account as criteria for annual rehabilitation plans, results might significantly differ from those obtained if only hard facts such bursts and leakage are considered.

Uncertainty handling in decision making for long-term plans could be approached by *CARE-W_LTP Scenario Writer* defining upper an lower boundaries for the condition of the water utility as consistent scenarios. This tool proved also to be very usable and intuitive, despite the tough preparatory task of gathering all data needed for the definition of key factors.

Some difficulties arose with the use of the *CARE-W_LTP Rehab Strategy Manager* regarding the assessment on efficiencies on rehab methods. Some of the data needed to define rehabilitation strategies were not available and had to be estimated, thus reducing the confidence of results.

In general, *CARE-W* is seen by some end-users as a complement for existing tools being used already by the water utilities on their asset maintenance plans. For this reason it is critical that data can be imported from or exported to these tools in an easy way. For other end-users, it assist on the identification of goals, providing a standard methodology for rehabilitation planning.

CARE-W usage by the end-user might be a tough task to undertake if there is no additional consultation support form the partners. This is an important finding highlighted several times on this testing: proper training is therefore essential.

3.3 Updated help files

Each of the individual tools, and also the *CARE-W Rehab Manager* has its own help system. The testing proved the need of end-users for a suitable on-line help system that makes possible an easy usage of the software and a better understanding of the scientific fundamentals behind each individual tool. Windows Help files created during the first stages of development of the tools have been kept updated according to the suggestions made by end-users and when new features have been added to the software.

The quality on the Help system varies between the different tools. Some are more clear or user-friendly than others. browsing the different help topics is addressed in different ways depending on the tool: through navigation buttons or by means of index of contents, or searching facilities. The need of a common help system format for all the tools has been pointed out.

3.4 Bugs

The installation procedure of the *CARE-W* toolkit as a whole has been found to be rather difficult to carry out. Several adjustments on the operating system may be required to run properly, making it necessary to install the software on a separate computer.

Poisson could not successfully conduct an analysis. Further investigation determined that the intermediate text files were not being created when the *mdf* and *sdf* were read by *Poisson* (e.g. mat.txt; ld.txt; diam.txt). It is believed that this issue is concerned with the method used by *Windows XP* to read text files. *Windows XP* is a much higher specification than that agreed by the *CARE-W* consortium. Therefore *Poisson* would not have been designed or tested to be run on this platform.

Special care should be taken on the path for the files used by *CARE-W_ARP* and *CARE-W_FAIL Failnet-Reliab*. These tools do not run properly if input files are not located on the right folder. The help system of each of these tools must provide the user with information on this issue.

Although not a bug, it has been found that *CARE-W_REL RelNet* creates many temporary files during data processing before obtaining results on pipe reliabilities. Those temporary files remain on the hard drive even after closing the tool, requiring therefore manual deletion by the user. Furthermore, the three-step calculation process in *CARE-W_REL RelNet* is not automated, which might be interesting when analysing the reliability of large networks, which require long time data processing. These two latter are main issues specially in resource-limited computers. These issues have been recently addressed in the release 2.04, together with some improvements on stability and system resources consumption.

Some problems arose when producing the input file for *CARE-W_ARP* with the *CARE-W Rehab Manager*. Some data were missing and had to be added manually to the input file.

In some GIS systems, each pipe consists on multiple elements, depending on the digitisation method, having all elements the same user reference. However, the *Rehab Manager* would treat each GIS element as an individual main and therefore would not be able to import more than one element with the same user reference. This has been fixed after version 1.5.2.

Regarding the use of the *CARE-W_LTP* tools, data transfer from the *CARE-W_LTP Scenario Writer* to the *CARE-W_LTP Strategy Manager* and *Rehab Strategy Evaluator* has not been fully understood by some end-users, so testing was not possible.

A few bugs found when defining import specifications (*definitions for data transfer*) have been fixed in version 1.5.2 of the *CARE-W Rehab Manager*, improving and easing the use of the tool.

The *CARE-W_REL RelNet* input file (i.e. an **.inp* file) produced by the *CARE-W Rehab Manager* is not always fully compatible with *CARE-W_REL RelNet*. In certain cases, the original input file from the *EPAnet* model has been necessary to be used in order to make the calculations. Although some tolerance to input files supplied by the *Rehab Manager* has been implemented in *CARE-W_REL RelNet*, there might still be some room for improvement of the compatibility within *CARE-W Rehab Manager* and *CARE-W_REL RelNet*.

3.5 Proposals for enhancement

The maintenance and upgrading (i.e. compatibility with *Windows XP*) of the *CARE-W* software and toolkit is an issue that needs to be addressed in the commercial phase of *CARE-W*, particularly as Microsoft is continuously upgrading their systems.

Some tools use external software (e.g. *CARE-W_REL RelNet* and *CARE-W_REL AquaRel* use *EPAnet2* dynamic link library, and *CARE-W_LTP* tools use *FireBird*). As long as *CARE-W* results rely to certain extent on that software, compatibility should be maintained for future versions of this.

Extra functionalities on the *CARE-W_LTP Rehabilitation Strategy Manager* have been suggested by end-users, namely comparison between strategies within the same window or saving of settings when closing the program.

Further development of the *CARE-W_LTP Scenario Writer* and *CARE-W_LTP Strategy Evaluator* could be addressed towards its applicability in utilities providing other services, or even multi-services utilities, in which long-term planning becomes more relevant since some key factors may influence more than one service at once.

Some tools, e.g. *CARE-W_REL RelNet*, still require much computer resources to run. Code optimization towards resources consumption should be addressed in future releases. Capability to work with entities larger than pipe sections is also expected to be implemented in future versions of *CARE-W_REL RelNet*.

It would be beneficial if the *Tool Manager* of the *CARE-W Rehab Manager* had a browse facility to ease the selection of file locations. Furthermore, it might be interesting to have this selection automatically done by default after the installation *CARE-W Rehab Manager* has finished, so the user will not need to care about this issue.

It might be needed to agree on the requirement of the *CARE-W Rehab Manager* to be able to import at least, certain standard interchange GIS file format usable by most of the GIS software packages existing on the market. Furthermore, it may be able to import any other proprietary formats.

Other suggestions to improve the use of the *CARE-W Rehab Manager* have been made by the end-users, such as the use of the *Expression Builder* feature, sorting of table records and resizing of windows within the interface. On the other hand, the example project file supplied with the software (*Crissier.mdb*) lacks some structural data which should be amended, so end-users will be able to learn the use of *CARE-W* without trouble.

A better integration between the different tools and the *CARE-W Rehab Manager* involves that when any tool is launched from the latter, it could “remember” the files (name and path) to be processed. The same may apply when returning processed results to the *CARE-W Rehab Manager*.

Other minor improvements, although not critical, might be considered to be include within the software. Better integration with the Windows environment can be achieved by using controls from the Microsoft *Common Dialogs* dynamic link library in many of the forms within the tools. This is applicable to most of the tools so there is still some room for the improvement of the interface, reducing the opportunity for user error, providing all the tools of *CARE-W* with a similar appearance.

Some users appreciated also the possibility to have *CARE-W* translated to the local language. At the current stage, this is only possible in *CARE-W_LTP Rehabilitation Strategy Manager*.

4 Concluding remarks

Overall, the tools included in *CARE-W* can work successfully with the *CARE-W Rehab Manager*. All bugs identified during the testing have been fixed and validated. Compatibility between input and output data from *CARE-W Rehab Manager* and the individual tools has been found to be an important issue, and proved to be acceptable at the current stage. Compatibility with existing information systems used by utilities is still an issue to be addressed.

The testing carried out by end-users made it possible to evaluate data availability on corporate databases as well as their structure, thus enabling the way for future implementation of rehab programmes based on *CARE-W*. New ideas for data recording have been identified by the end-users. On the other hand, extra functionality needed in the software was identified.

Feedback provided by the testing and validation of *CARE-W* extends and enhances the current possibilities to approach rehabilitation of water networks. End-user participating in the testing of *CARE-W* generally validated the software as a useful tool which fits with those already being used in water utilities for asset maintenance management. It is expected that the *CARE-W* toolkit as a whole will allow for the definition of a recommended best practices for future rehabilitation plans, based on data availability and management goals.

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Appendices

Report on testing carried out in Bristol, UK

COMPUTER AIDED REHABILITATION OF WATER NETWORKS

RESEARCH AND TECHNOLOGICAL DEVELOPMENT PROJECT OF EUROPEAN COMMUNITY

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CARE – W

Computer Aided REhabilitation of Water networks.
Decision Support Tools for Sustainable Water Network Management

WP6 – Testing and Validation of the CARE-W Prototype

REPORT ON TESTING CARRIED OUT BY BRISTOL WATER PLC

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December 2003

1. INTRODUCTION

The aim of this phase of the CARE-W project is to test the various tools in the CARE-W toolkit within the main framework of the CARE-W software (CARE-W prototype). This testing phase should address both the ease of use of the CARE-W software and tools as well as the relevance of the analysis that has been undertaken.

This document describes the scope of the testing work that has been undertaken by Bristol Water plc, an End User of the CARE-W project.

This is the final report of the end user testing, and as such, presents the testing that has been carried out up to mid November 2003. The testing phase for the CARE-W project officially began at the end of June 2003, when version 1.5.0 of the CARE-W software was issued. However, due to the reporting requirements of the UK Asset Management Planning (AMP) cycle, Bristol Water were unable to devote any resources to the CARE-W project until early September.

2. SCOPE OF THE TESTING WORK

Bristol Water agreed to test the CARE-W Failure Forecasting tools which embody the following models:

- Poisson version 1.03, and;
- Proportional Hazard Model (PHM) version 2.0a.

This testing was carried out within the framework of the CARE-W software. Bristol Water conducted the testing, using their own data and PCs. WRc provided assistance by training Bristol Water staff in the installation and use of the CARE-W software and tools and in the preparation of the data. Additional support has been supplied by Cemagref in relation to the PHM tool.

The following tasks have been completed:

- Selection of testing site;
- Installation of CARE-W software and the failure forecasting tools;
- Initial preparation of data;
- Use of the CARE-W software to create projects, import data, create datasets and use the failure forecasting tools.

These tasks are described in more detail in this report.

3. TEST SITE DESCRIPTION

Bristol Water plc is a water-only supply company located in the south western part of England. The main area of supply is to the city of Bristol, but the boundaries of the water company include some smaller conurbations as well as rural areas.

Bristol Water have selected Water Supply Zone (WSZ) 230 as the site for this testing exercise.

WSZ 230 is a rural area on the northern edge of the Mendip Hills, approximately 10 km east of the centre of Weston-Super-Mare. The zone is approximately 41 square km in area, with population clustered in villages or small towns. The largest town is Banwell in the west. RAF Locking is located on the western boundary of the zone. The land is mainly used for agricultural and horticultural purposes. Dwellings are mainly domestic, or small agricultural / commercial units.

The housing type is varied, consisting of old farm houses and village dwellings, through to small recent estates, and infill / conversion developments. Commercial demand tends to be in the form of farms, public houses and restaurants. There are no unusually large water users.

The zone is sited on the edge of the Mendip Hills and the ground level varies between 7m and 270m AOD.

The WSZ contains 4077 properties and consists of approximately 150 km of mains of various diameters and materials. Figure 1 shows the break down of the mains material (greater than 50 mm diameter) as a percentage of length. The majority of the mains in this WSZ are cast iron (49%). 16% is asbestos cement and a further 19% unknown. Figure 2 shows the length of mains constructed in particular periods. As can be seen from Figure 2 the majority of the mains in this network (44%) were installed in the last 20 years.

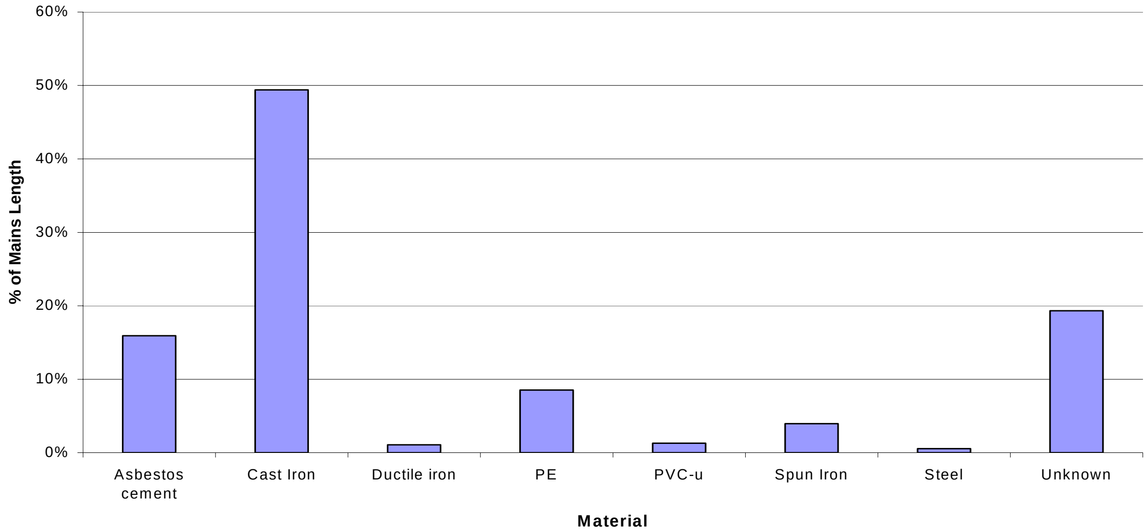

Figure 1 Percentage of mains material

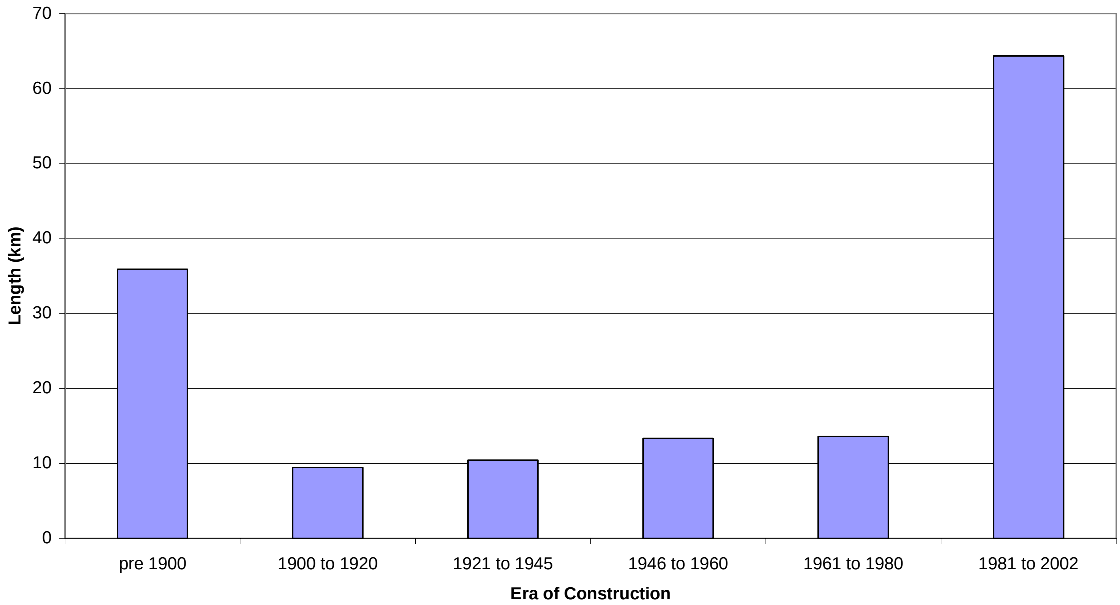

Figure 2 Age of mains

Mains failure data is available from January 1995 to July 2003. the data for a total of 70 mains failures were available for the failure forecast analysis. The number of failures on each mains material type is shown in Figure 3 below. As may be excepted the majority of failures are on the cast iron mains.

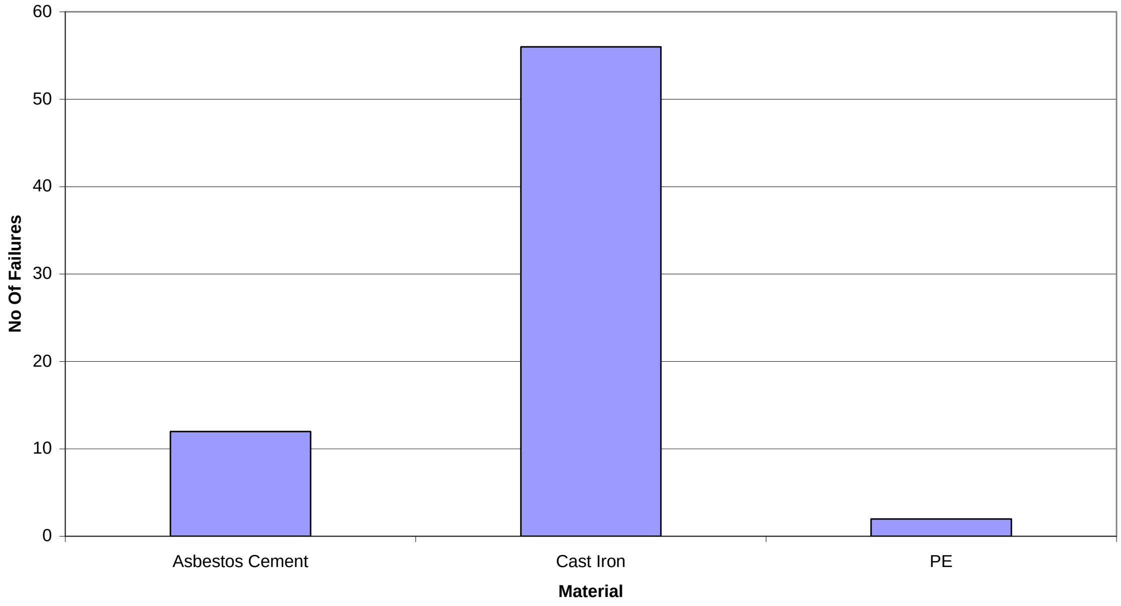

Figure 3 Number of Failures by Material Type

4. INSTALLATION OF CARE-W SOFTWARE AND TOOLS.

The recommended PC specification required to run the CARE-W software and failure forecasting tools effectively was as follows:

1 GHz Processor, 256 Mb RAM, Windows 2000 and Office 2000 Professional.

This is the minimum specification agreed by the CARE-W consortium.

Initially WRc installed the CARE-W software, the PI tools, Poisson and PHM onto a lap top using a Windows XP machine. Although this is higher than the recommended machine specification, no problems were encountered during the installation. However Poisson could not successfully conduct an analysis. Further investigation by WRc determined that the intermediate text files were not being created when the mdf and sdf were read by Poisson (e.g. mat.txt; ld.txt; diam.txt). It is believed that the issue is concerned with the method that Windows XP uses to read text files.

Windows XP is a much higher specification than that agreed by the Care-w consortium therefore Poisson would not have been designed or tested to be run on this platform. The maintenance and upgrading of the CARE-W software and tool-kit is an issue that needs to be addressed before the project finishes, particularly as Microsoft are continually upgrading their systems.

WRc implemented a temporary solution which does not require any programming changes to either the CARE-W software or Poisson at this stage. This solution was conveyed to Bristol Water and the Poisson tool owner for information.

Bristol Water subsequently installed the CARE-W software and tools on a different PC running on Windows 2000. Bristol Water reported that they did not find the installation procedure particularly straightforward, in part due to the need to set up directories and ensure that files are correctly located within them. However, WRc have designed the CARE-W software so that installing subsequent upgrades is much easier, and avoids the need to remove and re-install all the software.

Bristol Water commented that it would be beneficial if the Tool Manager within CARE-W had a browse facility to ease the selection of file locations.

5. DATA PREPARATION AND IMPORTING TO CARE-W

Background

Bristol Water's asset and failure data is held on a GIS (Smallworld GIS). Bristol Water have done a great deal of work assigning the failure data to specific mains, as this information was required for the preparation of the AMP business plans. The CARE-W software imports GIS asset and failure data as shape files (*.shp). Smallworld GIS does not produce shape files, therefore it was necessary to extract the data into MapInfo, another GIS package which does produce shape files. There were a number of issues that had to be addressed, as follows:

1. Deal successfully with pipes digitised using multiple GIS elements.
2. Define a procedure for the conversion of Smallworld data into shape files;
3. Process the raw data into the correct format for use by the failure forecasting tools;
4. Define the specifications to allow the GIS data to be imported into the CARE-W software.

Item 1

This was highlighted as an issue by Bristol Water during this initial testing phase. The existence of multiple elements for one pipe is a result of the method by which the pipe records were digitised by Bristol Water. Essentially an element is created each time the mouse is clicked during the process of digitisation. As the data is still displayed geographically this does not cause a problem for Bristol Water. A main could potentially consist of a number of GIS elements, all of which would have the same user reference. The CARE-W database is structured such that the details for each main are only stored once, therefore each main must have a unique user reference. The CARE-W software would treat each GIS element as an individual main and would therefore would not be able to import more than one element with the same user reference.

WRc have now amended the CARE-W software to read multiple element GIS data. When importing the data, the CARE-W software starts with the first element that was digitised. Any other elements will only be added if they are contiguous with the first element. This may result in a few non-contiguous elements being missed but WRc believe this is a minor issue.

Version 1.5.2 of the software contains this upgrade. Bristol Water were supplied with version 1.5.2 on 26th September 2003 and have reported the particular issue of multiple elements for one pipe have been resolved.

Item 2 and 3

These two items specifically relate to how the data held on Bristol Water's data management systems needs to be processed such that it can be read by the CARE-W software, and ultimately the failure forecasting tools. WRC worked in conjunction with Bristol Water in order to develop a procedure for processing their data. This procedure was tested by Bristol Water who were able to successfully import company data to the CARE-W software.

Item 4

Item 4 is concerned with the process of importing the GIS shape files (processed using the guidance mentioned under items 2 & 3) into a project created in the CARE-W software. Bristol Water were able to test the "Definition of data transfer" facility during this initial testing phase and made the following observations:

- When setting up a definition for transfer, unable to set up name for the definition - get a runtime error (subscript out of range);

- Unable to select several fields at once to delete.

Improvements have been made to the Definition of Data Transfer facility (also known as the management of import specifications) in version 1.5.2 of the CARE-W software. WRc has also provided Bristol Water with additional guidance to help in the design of these data import specifications. As with the previous items, these improvements and guidance notes have been tested by Bristol Water and the ease of use of the software has been greatly improved as a direct result.

6. USING THE CARE-W SOFTWARE

Initially, due to the problems encountered with the data preparation Bristol Water were restricted to testing the software with the demo project supplied with version 1.5.0 of the CARE-W software (Crissier network). Certain observations were made based on this initial testing:

- The selection of elements in the GIS viewer is very straightforward;

- The expression builder is very useful, although Bristol Water have made a suggestion to speed up the use of this facility (see item 1 below), and;

- The help file has been useful.

A number of issues or suggestions for improvement have also been made, as follows:

1. Could previous expressions be used to create new selections / datasets;

2. It would be useful to be able to sort within the tabular views (e.g. selection lists);

3. Cannot resize the schematic window itself within CARE-W.

Item 1

WRc has developed the syntax for two expressions that were thought to be of use. One expression allows the selection of all the pipes in two datasets, and the other allows the selection of all the pipes in one dataset but not another. The syntax is contained in a word document called “Whereclauses.doc” located in the top level of the directory where the carew.exe has been installed. The text from the expressions can simply be copied and pasted into the expression builder in the CARE-W software. This document can be easily updated with further expressions as they are developed and new versions can be made available. The comment made in item 1 has arisen for two reasons. First of all WRc neglected to tell Bristol Water that this document existed. The help file (which was used by Bristol Water) does not contain a reference to it.

Item 2

This item is concerned with the Selection tab and Active dataset tab. These two tabs provide an alternative method to viewing data. This tabular view does have very limited functionality as it was felt that the GIS view was a more robust way to view and assess data. This may need to be reviewed.

Item 3

The final item is concerned with the facility to move the bar dividing the legend from the map in the GIS view. This functionality has been added to version 1.5.2, and has now been used effectively by Bristol Water on a regular basis.

Following the delivery of the data transfer improvements, and the associated documentation, Bristol Water were able to import the mains and failure data for WSZ 230 (described in section 3) and to use the CARE-W package on a “real” network.

7. USING THE FAILURE FORECASTING TOOLS

Bristol Water were initially not able to fully test the failure forecasting tools using their own system data. Some initial testing was carried out using the demo project (Crissier). Again, Bristol Water made a number of observations.

1. The failure forecasting tools occasionally “hang” when trying to run, and;

2. Could the SDF and MDF (names and locations) to be used in the Poisson / PHM run be "remembered" from setting up the files from within CARE-W.

Item 1 will require further investigation.

All of the tools in the CARE-W tool kit (with the exception of the PI tool) will automatically look for input files in the directory and folder that has been specified by the user in the Tool

Manager. These folders will contain a number of files from which the user can select. The tools therefore can automatically select the location of the files, but not the name, as suggested in item 2. This is a feature of the tools themselves and would need to be addressed by the individual tool owners.

Bristol Water were able to test the failure forecasting tools upon the WSZ 230 and made further observations about the ease of use of the tools:

1. When creating a new project in PHM could the software select both the .sdf and .mdf when one is selected from the browser.
2. When creating a new project within PHM it is currently necessary to edit the Date of ending observation to the format 01/01/yyyy to ensure the failure forecasting runs. It is recognised that this is already being looked at.
3. When selecting the number of PHM models it is necessary to select from the drop down menu otherwise the option to set the lower levels of failures for each model. It is also not obvious that the user needs to select OK to proceed.
4. To set the PHM forecast time horizon it is necessary to deselect using advices on the analysis configuration menu.
5. Working with the Poisson failure forecasting tool also requires the user to select both the .mdf and .sdf files using the browser.
6. When setting the variables and modalities it would be useful if the list of materials, for example, reduced as options were allocated.

Returning the results to the CARE-W environment is a smooth procedure if the process of failure forecasting has been followed step by step resulting in properly named and dated files. Viewing the results using the expression builder to make selections is straightforward. The only specific issue which testing has raised about this stage of the analysis is whether progress bars could appear when the results are being taken back into the CARE-W software.

8. RESULTS

WSZ 230 had been analysed as part of the AMP3 process during 1999. The historical nature of the analysis undertaken identified two lengths of main for replacement by 2005. Both these mains were identified on the basis of high wall loss and a clustering of bursts (the highly corrosive nature of the soil was also noted). These replacements are shown in Figure 4 below:

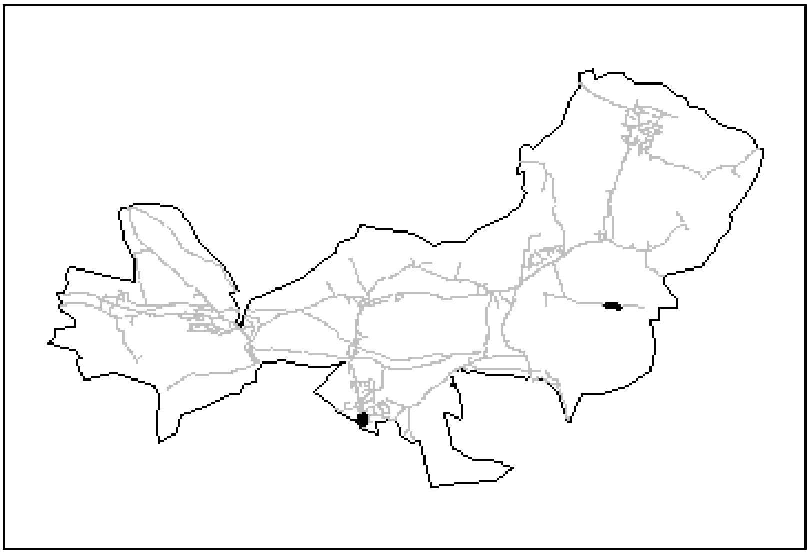

Figure 4 Mains for rehabilitation in WSZ230

Using the PHM and Poisson tools and running an analysis based on the length, diameter, and number of previous failures within the Water Supply Zone it is predicted in fact that four other lengths of main are at particular risk of failing in the next ten years (Figure 5).

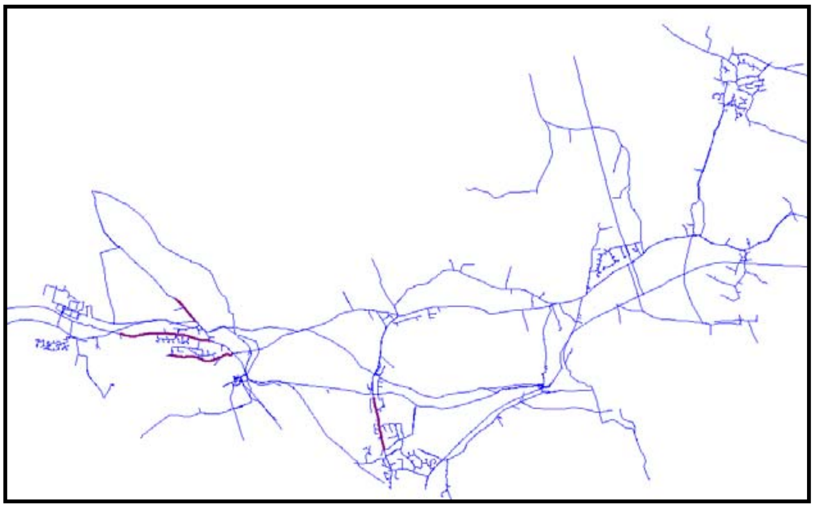

Figure 5 Mains at high risk of failure in next ten years in purple (from CARE-W).

The historical data available to the PHM forecasting tool for this particular scenario were seven years of failure (burst) data, which had been extracted from Bristol Water's corporate GIS.

The results can also be presented in a tabular manner that contains further details of the mains identified, and also the statistical background to the failure forecasting. It can be seen from Figure 6 that both failure forecasting methods have been utilised to validate the final selection of pipes. The four pipes chosen above refer to those with predicted failure rates in excess of 1 failure/km/yr using both Poisson and PHM forecasting techniques.

Failure Forecast Results Summary

Project:	BristolWater_2.MDB
Active Dataset:	BW_WSZ230
Dataset type:	Sector
Results dataset:	FF_17Nov03

To sort by any field, select all rows except the header rows and use the Sort function in the Tools menu

Failure Rate

User Ref	Main characteristics		Total length (m)	PFR_{10} No/km/yr	Conf. Intervals		FR (Poisson) No/km/yr
	Material	Diameter (mm)			PFR_{10_a} No/km/yr	PFR_{10_b} No/km/yr	
33113997	CI	100	1280.10	3.85	0.00	14.30	5.47
9674650	CI	75	735.57	1.53	0.27	4.49	4.08
9686496	CI	100	923.05	1.48	0.33	4.12	4.33
33159639	CI	100	423.93	1.08	0.24	2.59	9.44
41314978	CI	125	0.31	0.97	0.00	0.00	0.03
9681351	CI	100	889.01	0.91	0.11	2.25	4.50
33163271	AC	152	0.38	0.79	0.00	0.00	0.09
9684210	CI	75	491.03	0.73	0.00	2.04	4.07
9671945	CI	75	350.39	0.70	0.00	2.00	8.56
35670708	CI	75	0.53	0.57	0.00	0.00	0.16
9682642	Unknown	406	0.18	0.56	0.00	0.00	0.00
21381661	Unknown	50	2.00	0.55	0.00	0.00	0.03
9680733	CI	75	48.58	0.54	0.00	2.06	20.58
13740918	CI	75	1.31	0.53	0.00	0.00	0.16
9665385	CI	75	405.69	0.52	0.00	1.48	2.46
22419868	CI	75	176.29	0.52	0.00	1.70	5.67
222611178	Unknown	100	0.59	0.51	0.00	0.00	0.03

Figure 6 Tabular output of pipe failure forecasts from CARE-W

These results can therefore supplement the work processes that are currently undertaken and allow the capital planning process to be more fully informed.

9. CARE-W / BRISTOL WATER AND THE FUTURE

It is envisaged that the CARE-W tools will be used in addition to the tools currently used by Bristol Water. As the focus for future mains rehabilitation in the UK will be through the capital maintenance Common Framework it is important to consider how CARE-W and the Common Framework align.

It is considered that the CARE-W tools map onto the key steps in the Common Framework and go further in terms of providing decision support for rehabilitation implementation. The tools not only define broad budgetary needs but also identify the pipes that are most in need of rehabilitation. Furthermore, the long-term rehabilitation tools provide a basis for strategic failure forecasting and cost modelling for a variety of generic rehabilitation options. This is shown below in Table 1.

Table 1 How CARE-W addresses the key stages in the Common Framework

Framework Stage	Framework element	CARE-W tool/process
Historical analysis	A1 Expenditure review	Performance indicator tool: Trends and comparison of PIs and benchmarking with standard performance databases
	A2 Performance review	
Forward-looking analysis	B1.1 Focus analysis	
-preparation	B1.2 Planning objective	Selection based on end user preference
	B1.3 Monitor failures	PI tool and Rehab. Manager GIS
	B1.4 Customer survey	End user liaison
-service/cost forecast	B2.1 Failure modes	Failure modes already identified by CARE-W consortium
	B2.2 Observations	End user databases and GIS, which populate Rehab. Manager
	B2.3 Methods for:	
	- failure probability	PHM and Poisson tools, long term planning tools, reliability tools
	- consequence	ARP, Scenario writer
	- cost	Rehab. Programme Evaluator, Rehabilitation Scheme Developer: These tools estimate costs at the strategic level and for annual planning
	B2.4 Validate methods	End user testing and practical application
	B2.5 Forecast service	PHM and Poisson tools, long term planning tools, reliability tools
-intervention analysis	B3.1 Identify options	CARE-W team knowledge base
	B3.2 Estimate impact	Rehab. Programme Evaluator, Rehabilitation Scheme Developer, ARP
	B3.3 Estimate costs	
	B3.4 Value changes	
	B3.5 Select optimum	
	B3.6 Categorise costs	

The future position of CARE-W within Bristol Water capital maintenance planning process is seen as complementing the tools that are currently available. The suite would sit within the current network and must be able to accept data from, and pass information to, the various other corporate tools as and when required.

The data that it currently requires is principally held within the GIS and so it is envisaged that the failure forecasting results would be fed back to this central repository from which further extracts could be made to ensure that the information is used across the tool network.

10. SUMMARY

This report has presented the testing work that has been undertaken by Bristol Water up to mid November 2003. As can be seen, Bristol Water have progressed well with this testing and have given some positive and constructive feedback in the use of the CARE-W software and the failure forecast tools.

WRc has addressed a number of the issues raised by Bristol Water following the submission of the preliminary testing report in October 2003, and have provided a new version of the CARE-W software and some guidance notes for the preparation and importing of data.

Overall, the software is operating successfully with the data sets available. However, a significant user input is required to format the data correctly for migration between the various tools & main program. Therefore, some work is required to improve the User Interface and thus reduce the opportunity for user error.

Bristol Water recommends that further work should be undertaken to improve the user interface of a number of the CARE-W tools in order that they may be made more intuitive and thus simpler to use. We would also welcome the ability to enhance the integration of CARE-W with corporate data systems.

Report on testing carried out in Brno, Czech Republic

CARE – W

Computer Aided REhabilitation of Water networks. Decision Support Tools for Sustainable Water Network Management

WP6 – Testing and Evaluation of CARE-W Prototype

Final report from testing of the CARE-W Prototype and its tools in Brno

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Brno, November 2003

CARE – W

Computer Aided REhabilitation of Water networks. Decision Support Tools for Sustainable Water Network Management

WP6 – Testing and Evaluation of CARE-W Prototype

Final report from the testing of the CARE-W Prototype and its tools

Table of contents

1 DESCRIPTION OF TEST ZONE

1.1 Brno water distribution network

The CARE-W Prototype and tools have been tested on the Brno water distribution network, which is owned by the city of Brno and operated by the Brno Waterworks and Sewers, joint stock company (BVK) – one of the official end-users of the CARE-W project. The city of Brno and BVK have signed a contract for 20 years that gives the operator full responsibility not only for the operation of the network, but also for investment planning and asset management. However, all investment is financed by the city itself. Major shareholders of BVK are the city of Brno (51%) and ONDEO Services (46%).

Basic information on the water distribution network:

Length of water mains: 1 200 km

Number of service connections: 44 395

Population supplied: 392 000

The elevation of the Brno water distribution network is from 185 to 525 meters above sea level. As a consequence the network has been divided into many pressure zones. There are 5 basic pressure zones with smaller additional ones; the total number of pressure zones in the network is 39.

As shown in Table 1, the Brno water distribution network consists mainly of grey cast iron pipes (64 %). There are 14 % of ductile iron and 11 % of steel pipes. 58 km of steel pipes belong to the “Brezova II” transmission main, laid in 1975. It constitutes 44 % of all steel pipes. The other materials constitute less than 4 % each.

Table 1. Pipe material distribution in the Brno water distribution network

MATERIAL	**Length (km)**	**%**
GG	777.91	64.44
GGG	168.75	13.98
Steel	131.08	10.86
GRP	40.23	3.33
PE	37.74	3.13
PVC	23.83	1.97
Concrete	15.84	1.31
AC	10.68	0.88
Unknown	1.22	0.10
TOTAL	**1, 207.26**	**100.00**

Regarding the age of pipes, the oldest registered pipes (still in operation) were laid in 1872. Till 1944 grey cast iron was the only material used for water pipeline. 33.8 % of all grey cast iron pipes were installed before 1950, so they are more than 50 years old. At present the Brno water utility prefers ductile iron to PE or PVC pipes, therefore since 1990 the majority of new water mains are ductile iron. Distribution of pipe material by installation year is presented in Figure 1.

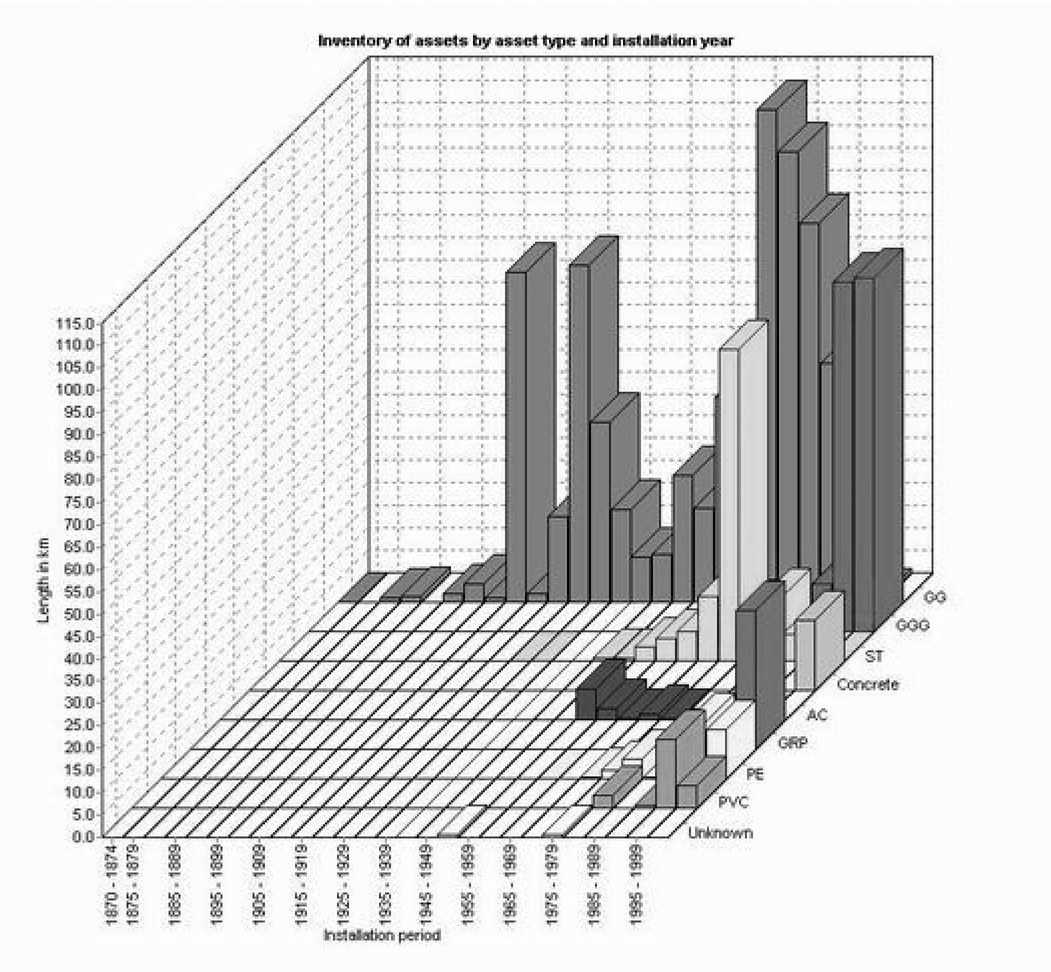


Figure 1. Inventory of assets by asset type and installation year of the Brno water distribution network generated with RSM.

1.2 Data availability at BVK

BVK uses for network operating, data processing and other agenda a GIS application called LIDS, where data of greater part of the water distribution network is held. The utility has digitalized approximately 90% of its network in recent years, but the data is not complete yet. Information on water mains and failures is also stored in two separate databases; their structure is unfortunately completely different from the structure of the CARE-W central database.

One of the databases stores complete data on water mains (i.e. pipe section ID, pipe length, type of material, profile, name of street, date of installation, etc.). The database comprises also information on rehabilitation, such as rehab date and technology. However, in case of water main replacement the row containing data on the existing pipe section is rewritten and actualised with information on the new one (new pipe material and new year of installation). It means that there are no electronic records on the origin pipe after its replacement.

The other database comprises data on failures (type of failure, date, street and profile) since 1994. Before that year failure data were registered on papers only, which is not applicable. These two databases are not interconnected and the failure records cannot be assigned with particular elements from hydraulic model, so we do not know, on which pipe section (of what type of material, age, length etc.) the failure occurred. It means that it is not possible to carry out any detailed analysis of failures in order to assess failure rates of particular pipe materials that are needed for ARP or Rehab Strategy Manager. All the failure rates and service lives of particular pipe categories for the need of ARP and RSM have been empirically estimated.

2 CARE-W TOOLS TESTING

BVK has tested the PI Tool, the long-term rehab planning tools (RSM and RSE), RelNet and ARP tool, as shown in Table 2. Some of the tools were tested on the whole Brno water distribution network, the others on one selected pressure zone of the network - “the 1st pressure zone” with 267.3 km of water mains. See Table 2.

Due to data availability only one from the group of technical tools - RelNet, which calculates HCI – has been tested on the Brno water distribution network.

The main goal of testing was to evaluate data availability and its structure in order to recognize end-user's priorities and points of view and to develop a standardized methodology for creating of rehabilitation plans in frame of CARE-W using entities as a basic rehabilitation unit.

On the beginning of the testing period we installed all the CARE-W software on one end-user's computer and arranged several training workshops on how to install and use the software and repair some of its known bugs and imperfections. During all the testing period we were in close contact and helped to solve all end-user's problems.

Table 2. CARE-W tools tested.

	CARE-W PI	**CARE-W REL**	**CARE-W ARP**	**CARE-W LTP**
CARE-W TOOL	PI Tool	RelNet	ARP	RSM and RSE
Priority *	1	2	2	1
Stand-alone	X	X	X	X
Within the Prototype	X	X	X	X
The 1st pressure zone		X	X	
Whole network	X			X

* 1: First priority
2: Second priority

2.1 CARE-W PI

The objective of the PI Tool testing in the scope of the CARE-W project was not only to test the functionality of the software itself but also to assess as many performance indicators (PIs) as possible to monitor data availability and their recording at the Brno end-user.

BVK has got its own system of data recording. Every year they have to report to the water authority (and to the Ministry of Agriculture) a statistical statement (No.VH8b). According to a new law on water supply and sewerage (No. 274/2001 Sb.), effective from 1 January 2002, the operator has to follow a new system of asset and operations recording. In addition to that, ONDEO Services – major owner of 7 large waterworks in the Czech Republic – aims to apply a uniform system of utility data recording. The IWA-PI system used in the scope of the CARE-W project is different from the above-mentioned systems of data recording. Many data are recorded in a different way using different units.

Data for testing of the PI Tool software have been collected for five years, from 1998 to 2002, for the whole distribution network of Brno. Therefore one dataset containing five periods has been created. An average of 81 UIs and 36 PIs were assessed for each year (see Tables 4 and 5). The numbers in brackets in Table 4 include 23 Physical UIs (*C18a - C18f,* see chapter 2.1.1), which are recorded in a different way. Therefore these 23 UIs were not assessed for the purposes of the PI tool testing, however the end-user is able to assess them.

Table 4. Number of collected utility information (UI)

Utility information	Total number of UIs	UIs collected in the year				
		1998	1999	2000	2001	2002
Physical	67	27(50)	27(50)	27(50)	27(50)	27(50)
Water volume	11	10	11	11	11	11
Operational	37	23	23	23	24	25
Quality of service	10	10	10	10	10	10
Financial	19	10	10	9	11	10
Total	144	80(103)	81(104)	80(103)	83(106)	83(106)

Table 5. Number of assessed performance indicators (PI)

Performance indicators	Total number of PIs	PIs assessed in the year				
		1998	1999	2000	2001	2002
Water Resources	2	1	2	2	2	2
Physical	2	2	2	2	2	2
Operational	18	13	13	13	14	14
Quality of service	20	15	15	15	15	15
Financial	7	4	4	4	4	3
Total	49	35	36	36	37	36

2.1.1. Physical assets data

From the total possible 67 physical UIs, 27 were collected without any problems. Six were estimated and 17 could not be assessed because the utility does not record these data at all. 23 UIs on water mains installation year (*C18a - C18f Mains laid between xxxx and xxxx*) are recorded differently. While the CARE-W PI system uses 5-year intervals, BVK uses 10-year intervals, for example *Mains laid between 1901 and 1910*. These data were not provided for the purposes of the testing but it is possible to assess them if needed.

2.1.2. Water volume data

All 11 water volume UIs were assessed without issue. See the Table 3 for the values of water volume UIs for the year 2002. Figure 1 represents an example of a Dataset comparison graph (generated with the PI Tool software) for the UI *A19 – Authorised consumption*.

Table 6. Water volume data

UI code	UI name	Year 2002	Unit
A1	Annual abstraction capacity	86 353 452	m^3/year
A2	Imported water allowance	158 000	m^3/year
A4	Water abstracted	34 898 000	m^3/year
A5	Imported raw water	0	m^3/year
A6	Exported raw water	0	m^3/year
A7	Water produced	34 610 000	m^3/year
A8	Imported treated water	125 505	m^3/year
A9	Exported treated water	1 052 206	m^3/year
A19	Authorized consumption	29 145 872	m^3/year
A20	Water losses	4 537 883	m^3/year
A24	Real losses	4 070 778	m^3/year

2.1.3. Operational data

The total number of the operational UIs is 37, 25 of which were collected without any problems. A further one was estimated, *D42a Taste tests performed* and *D51a Compliance of water taste tests* were not assessed because no such test is performed at the utility and 11 of them were not assessed because they are not recorded at all.

Figure 2 shows an example of a Time series graph for *D18 – Mains rehabilitation* generated with the PI Tool.

2.1.4. Quality of service data

There were no problems with the collection of these data and all 10 UIs were collected. The UI *F11 - Service customer complaints* includes valid complaints only. The Brno end-user records only official complaints addressed to the departments of inspection and the head manager. Other, mostly telephone, complaints are not recorded.

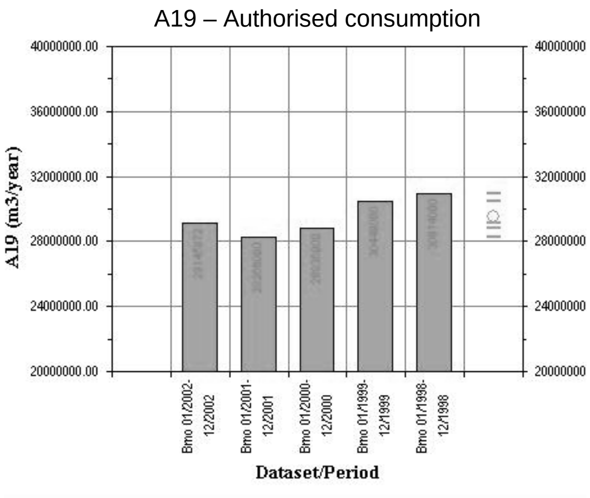


Figure 3. Dataset comparison graph of *A19 – Authorised consumption* generated by the PI Tool.

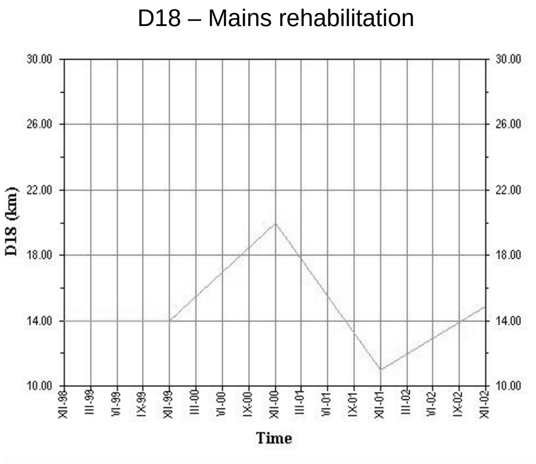


Figure 4. Time series graph of *D18 – Mains rehabilitation* generated by the PI Tool.

2.1.5. Financial data

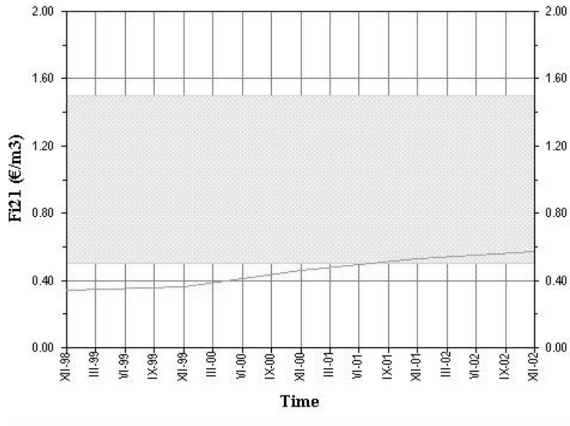
At present water supply in the Czech Republic is still in a stage of transformation, when the conditions of the co-operation between the owners and operators are being formed and there are still lot of problems in this area. The financial data is the group that presented the most difficulties in collection. This is due to the fact that financial data is normally available for the whole undertaking, which operates both water mains and sewers. Investment costs in particular are not registered separately for water supply and wastewater services. Many (re-) constructions are financed by particular district authorities or investors of the projects requiring some (re-) constructions of water distribution network, e.g. re-laying of water mains. The operator does not have the central recording of all investments and it is difficult for him to collect this type of data. As a result, if the total number of 19 financial UIs, only 9 of them were collected.

2.1.6. PI Tool testing results

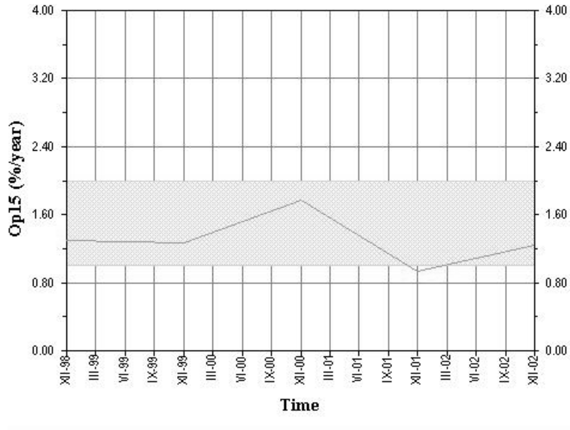
We have tested the PI Tool successfully both within the CARE-W Prototype and as a stand-alone tool.

The tool allows the user to present results (UI and PI values) in graphs. Figure 3 shows six time series graphs of selected PIs for the period 1998-2002 for the whole water distribution network of the city of Brno. The grey filled area in each graph indicates the proposed guidance range (see the CARE-W Report, No. 5 on Rehab PI guidance range).

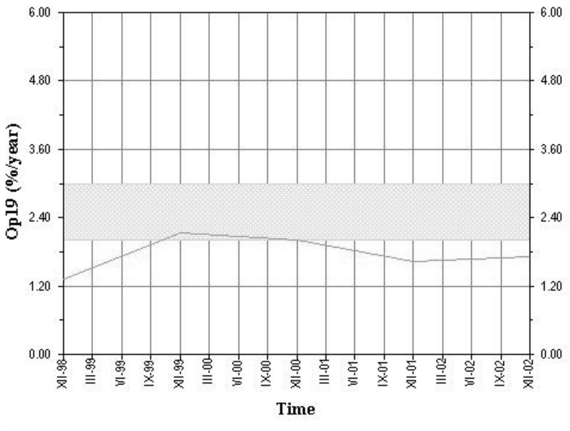
Fi21 – Average water charges for direct consumption



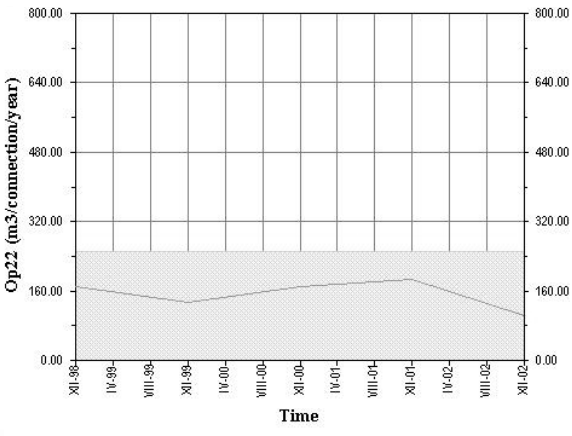
Op15 – Mains rehabilitation



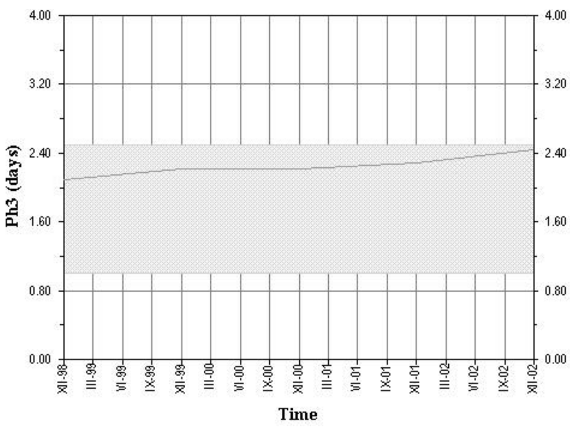
Op19 – Service connection rehabilitation



Op22 – Water losses per connection



Ph3 – Transmission and distribution storage capacity



QS15 - Quality of supplied water

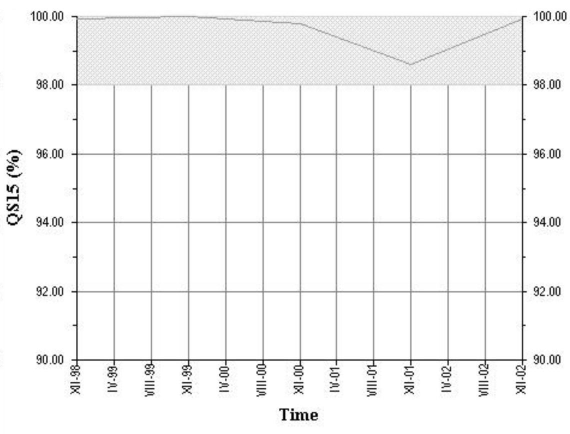


Figure 5. Time series graphs of some PIs generated by the PI Tool.

2.2 CARE-W REL (RelNet)

2.2.1. Data used for testing

For the needs of CARE-W technical tools testing and also for the operational needs of utility a new hydraulic model of the largest Brno pressure zone has been created and validated (see Fig.6). The new steady-state model is composed of 2,000 pipe sections, 1,631 nodes and 2 reservoirs. The total length of its water mains is about 267 km. Particular node demands have been calculated from real volumes of accounted water in the year 2002. The model of supply network is comprehensive and contains all pipe sections including DN 80. RelNet has been tested on this hydraulic model, which was created in several steps as follows.

2.2.2. Creating of hydraulic model

At first the requested data relating the first pressure zone was withdrawn from the LidsGIS database and imported into Mike Net, which is owned by BVK. As mentioned above, the structure of data held in the GIS database is different from the data required for the hydraulic model and this first version was composed of more than 6,000 pipe sections, which were usually very short and unsuitable neither for rehabilitation planning nor for mathematical modelling.

In the next step we used a specially developed simple software application (programmed in MS Excel VBA) for skeletonization of the network and reduced the number of hydraulic sections from former 6,000 to current 2,000. By means of Mike Net this model was subsequently edited, roughness coefficients were assigned due to material and age uniformly for each pipe section and finally exported into Epanet. We used Mike Net because Epanet is not so comfortable and user friendly. After that we imported the hydraulic model into the central CARE-W database, created its structure and founded a new CARE-W project. For details see Figure 7.

The basic element in the project database is hydraulic section. Average length of pipe section in the zone is about 134 m, which is not still enough for rehabilitation planning and we recommended to the end-user to plan the rehabilitations based on entities. In the next paragraph there is a description of the methodology of creating entities and their implementation in CARE-W database and software.

Figure 6. Hydraulic model of water distribution network of the 1st Brno pressure zone (2,000 pipe sections, 1,631 nodes, two reservoirs – total length 267 km) used for testing RelNet.

2.2.3. Entities

The idea of using entities as basic elements for rehabilitation planning is not new and we have some experiences from former works on CARE-W. The approach arose from requirement of utilities to plan rehabilitations for longer parts than only hydraulic sections, which are usually too short and not so suitable.

An entity is generally meant to be a set of several continuous hydraulic sections with the same (or similar) chosen attributes. Their great advantage is a logical relationship, which is established among several elements (pipe sections) with regard to the network topography, other networks, collectors, system of streets or traffic disruptions and enables fully automatic further data processing. In agreement with our end-user BVK we determined a methodology for creating entities as follows. All elements in one entity must be of the same material and diameter and their age must be in range of 10 years. Total length of entity is desired between 100 and 300 meters. In case of some short piece, up to few meters, of different material inserted into longer pipe section of another material, we put the short piece to one entity with the rest of pipe section without interruption. This is usually caused by failures, when utility repairs only the necessary part of the pipe section.

When we completely prepared the hydraulic model of the network and imported it into a newly created project in CARE-W Prototype, we started with defining entities. All entities were created manually straight in MS Access environment of the central database, where each not yet assigned pipe section was searched up in hydraulic model (in Epanet) and regarding to its position in the network topology and chosen attributes were searched all other suitable pipe sections to be assigned with it in the same entity. This way we chosen in each step several continuous pipe sections with the same attributes and assigned them as one entity. Number of entity we typed in column Criterion1- table PIPE in central database CARE-W. This enables to work with number of entity in CARE-W project as with any other conventional attribute of pipe section and highlight each entity in GIS window of the Prototype.

The whole 1st pressure zone was processed to entities and number of units for rehabilitation planning was reduced from 2,000 pipe sections to approximately 1,000 entities. Average length of unit increased from 135 m to 270 m. Creating of entities took about 60 hours of work. Figure 7 describes the entire process of the model and entities creating.

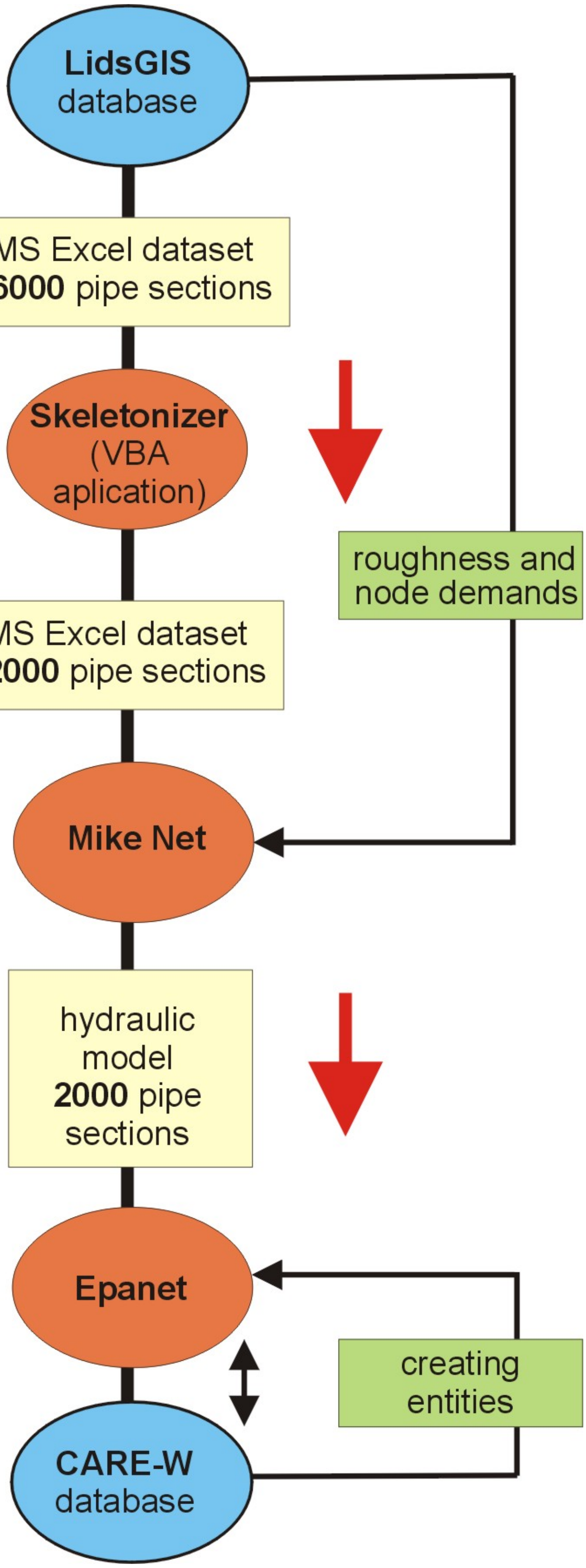


Figure 7. Process of creating the hydraulic model from end-user's GIS database and creating entities.

2.2.4. RelNet development

Development of RelNet for the needs of CARE-W project has finished. At this moment RelNet is fully compatible with Prototype and calculates HCI for hydraulic pipe sections. From the beginning of the CARE-W project many changes in the computing algorithm has been done and this paragraph describes the current face of affairs.

RelNet is a specialised application designed and developed to calculate an impact of each pipe section or entity on the total network reliability. Reliability of the water distribution network depends on reliability of network elements (pipe sections or entities). RelNet is based on Epanet computing core. As an input it requires *.inp files, which are produced by Epanet Export Network function.

The output value is HCI (Hydraulic Critical Index) - an impact of each element on the total network reliability. HCI is calculated from amounts of delivered and undelivered water. These amounts are depending upon real pressure in each node of the network. More detailed information on RelNet functionality can be obtained in either RelNet Brief Help file or in official CARE-W report on WP2 tools available on the bscw server (http://care-w.unife.it).

Because we are dealing with rehabilitation planning based on entities and one of the input values for ARP is HCI, there is a well-founded requirement of calculating HCI for entities.

There are two possible ways to determine HCI for entire entity. We can calculate some average value from all hydraulic sections assigned to the entity or we can calculate HCI for entire entity by RelNet. We have decided for the second approach.

Due to this fact RelNet is being upgraded in recent months, so as to calculate HCI for entire entities and to cooperate with CARE-W Prototype and ARP module as much as possible. The most prioritised task is data flow and preparing of input/output files based on entities. This version of RelNet is now developed and tested.

Current state of RelNet computing algorithm is described in Figure 8.

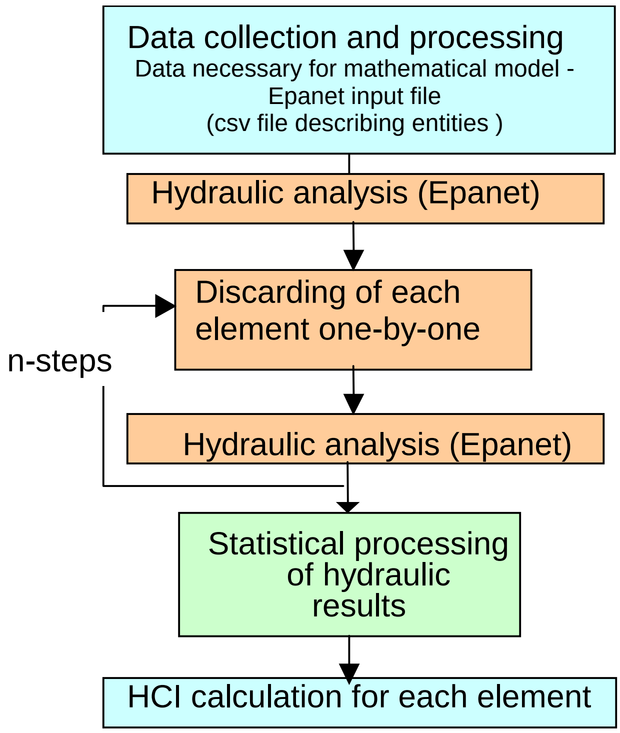


Figure 8. HCI processing by RelNet - algorithm description.

2.2.5. RelNet testing

Within the CARE-W project RelNet was tested on several water networks, such as Crissier, Sone Vest, the 1st pressure zone of Brno (1st PZ) and some smaller fictitious networks. The most in detail analysed one was the 1st PZ, where complete hydraulic and reliability analyses (based on hydraulic sections) have been done. HCI was calculated for each hydraulic section and its value was very frequently in range <0;0.3>, as expected. HCI of the most of pipe sections equalled to zero. Due to the network topology, there was only 25 pipe sections with HCI>0.1 there. RelNet was tested on the 1st PZ as a stand-alone application and also as a tool depending upon Prototype and these two result datasets were compared. Some conclusions on RelNet testing comparison are mentioned below.

Analyses have been done on several computers of different technical level. Because the 1st PZ is quite large and complicated network, these analyses took always at least several minutes (10min – CPU 1.6GHz/ 256MB RAM). Problems with lack of capacity of hard drives during analyses have occurred on some computers with small or full hard drives. These problems have been solved and new version of RelNet erases the internal process files, which caused the problem. To the new version a function of automatic running of the next processing (link - pressure – HCI processing) after the previous one has finished has been also implemented.

A very serious problem had occurred: missing paragraph "Options" in the *inp* file generated by Prototype. The paragraph contains data relating hydraulic analysis settings and is needed by Epanet for proper calculation. Epanet (RelNet) cannot run the hydraulic analysis properly in case of using D-W roughness coefficients. This problem had been already discussed with WRc team and will be solved in the next version of the CARE-W Prototype.

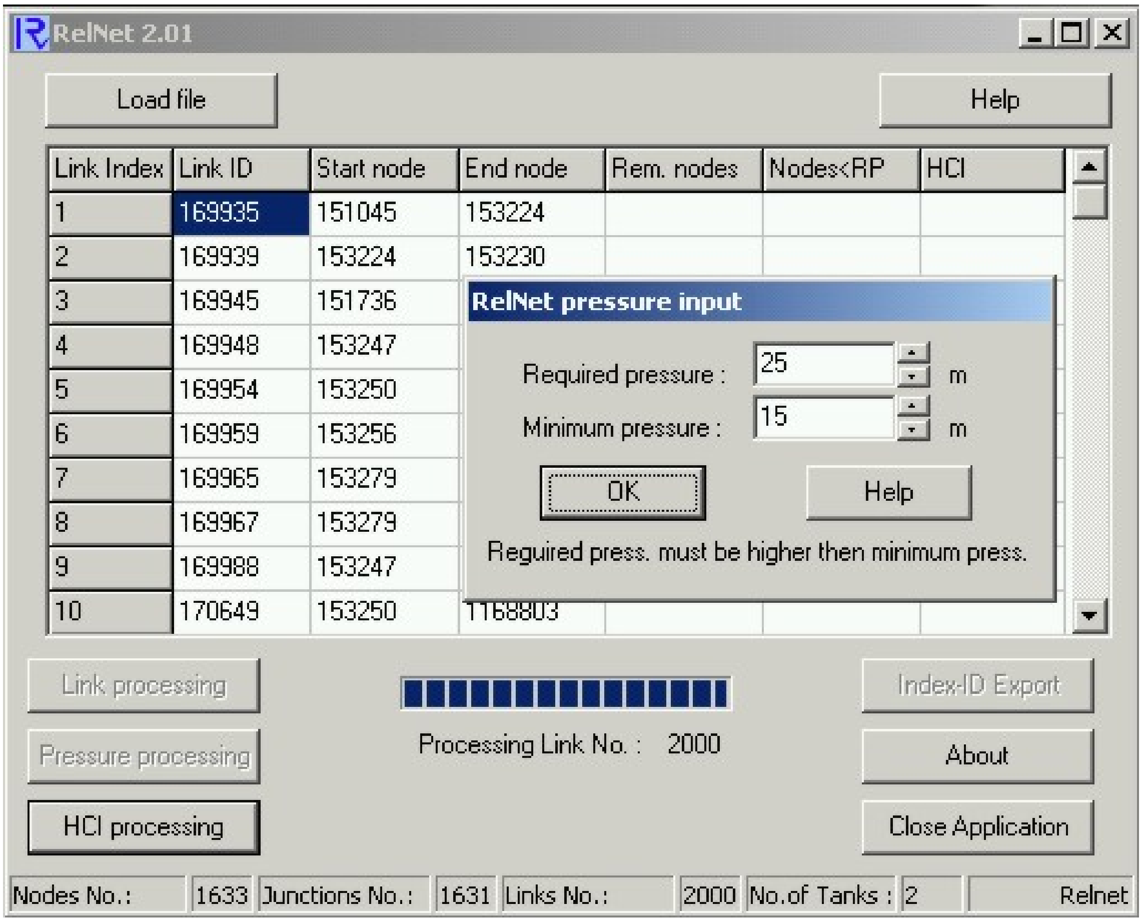


Figure 9. RelNet main screen – processing of the Brno 1st PZ data

Based on the testing results RelNet will be further developed. For example, the calculation of HCI for entities will be implemented. We suppose that the new version of RelNet will be involved in the final version of CARE-W Prototype.

2.2.6. Cooperation with the Prototype

The above-mentioned structure of the RelNet module (see Fig. 8) enables full compatibility with the CARE-W Prototype and ARP tool, which are supposed to work together. The *inp* file is a standardized input file for hydraulic module Epanet. The second input file describing entities can be created manually from table PIPE in the central database of CARE-W very simply. Data structure of these files is based on basic element in the database (usually hydraulic section). Both of these two files are to be uploaded to RelNet, which can process the data, calculates the lengths of entities and check the continuity of each entity and does the other steps mentioned above. Output file from RelNet is based on hydraulic sections and contains HCI for each hydraulic section or entity – so it can be returned back to the central database.

2.2.7. Results of RelNet testing

Some imperfections and bugs occurred during the testing. Some of them were already sent to WRc CARE-W team, but some of them occurred just in recent days. The problems concerning RelNet are as follows:

1) The Prototype does not import items “TAG” and “DESCRIPTION” from Epanet *inp* file into the central database, thus model is not comprehensively stored there and some columns have to be added manually. In case of BVK “Description” was used for name of the street.

2) Our end-user uses Mike Net software for mathematical modelling. It is very probable, that in the future somebody will need to import into the central database an *inp* input file created by Mike Net for Epanet as we did. This operation is possible, data flows, but the model is not imported perfectly and some items (like Pipe Status –open/close) do not appear in the database. To solve this problem we had to open the *inp* file in Epanet first, save it and this newly saved file import into the CARE-W database. This is not a bug, but only an imperfection.

3) Some system alert still occurs when RelNet is launched via Prototype. This is a very old bug, which was pointed on the Ferrara workshop.

4) When *inp* file for Epanet is generated from the central database and subsequently opened in Epanet, some vertexes (internal nodes) are missing (in comparison to original *inp* file). Lots of internal bends between nodes are missing (the links are connected directly from node to node without internal bends). So the topography of the network differs in detailed view.

5) As mentioned above (chapter 2.2.5), the paragraph “Options” in the *inp* file, which is generated by Prototype, is missing.

2.3 CARE-W ARP

2.3.1. Data used for testing

ARP module has been tested in a very close relationship to RelNet. ARP requires HCI, which can be calculated by Aquarel, Failnet Reliab or RelNet. Since RelNet has been developed at our institute, we used HCI calculated by RelNet for the needs of ARP testing.

ARP has been tested on the Brno 1st pressure zone. The entire network has been manually processed to entities and the annual rehabilitation plan has been evaluated on entities. For a detailed description of theory and rules for creating entities see chapter 2.2.3. The number of elements was reduced from 2,000 hydraulic sections to 1,000 entities of average length about 270 m. All the KB entering the optimisation process will be determined manually by the end-user, according to its possibilities and needs (see Table 2). Because the 1st PZ is very large and to recognize terrain and determine KB for 1,000 entities would take several weeks of work, we tested ARP on a smaller sub-zone, which is hydraulic sub-dataset of the 1st PZ (see Fig.11).

The sub-zone is located in relatively old part of the Brno city, close to the centre. It contains 189 hydraulic sections, which were assigned to 78 entities. Total length of water mains is 21.17 km and contains pipes of DN 80 – 400. Average year of installation is 1946. This location has been chosen for its high age of water mains. All the pipe sections in the sub-zone are grey cast iron. Coefficients of Knowledge Bases (KB) were determined manually by end-user for all the 78 entities.

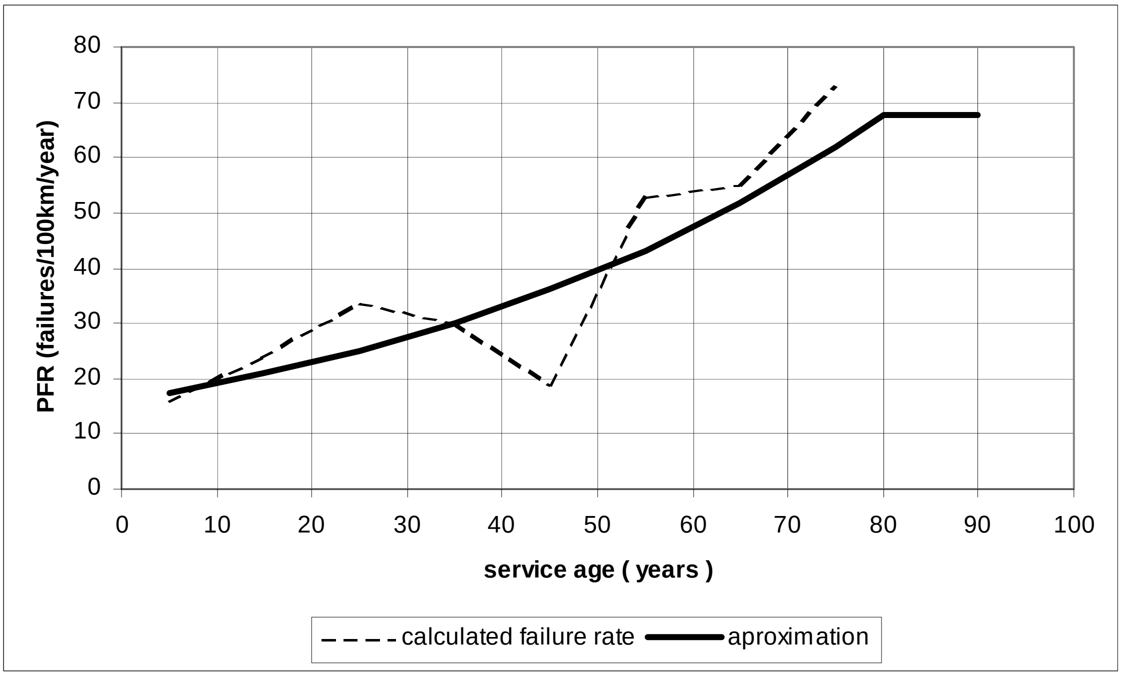


Figure 10. Failure rate of grey cast iron depending upon age of pipe – approximated.

Value of the failure rate for each element was determined according to its service age and material following Table 7.

Table 7. Estimated failure rates according to service life for grey cast iron pipes.

Service age (Years)	0 - 10	10 -20	20 -30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	> 80
PFR (Failures/100km/year)	17.5	21	25.1	30.1	36	43.1	51.7	61.8	67.7

Values from Table 7 were evaluated from end-user's main database of failures for this material for the years 1997 and 1998. The calculated values of failure rates have been approximated (see Figure 10).

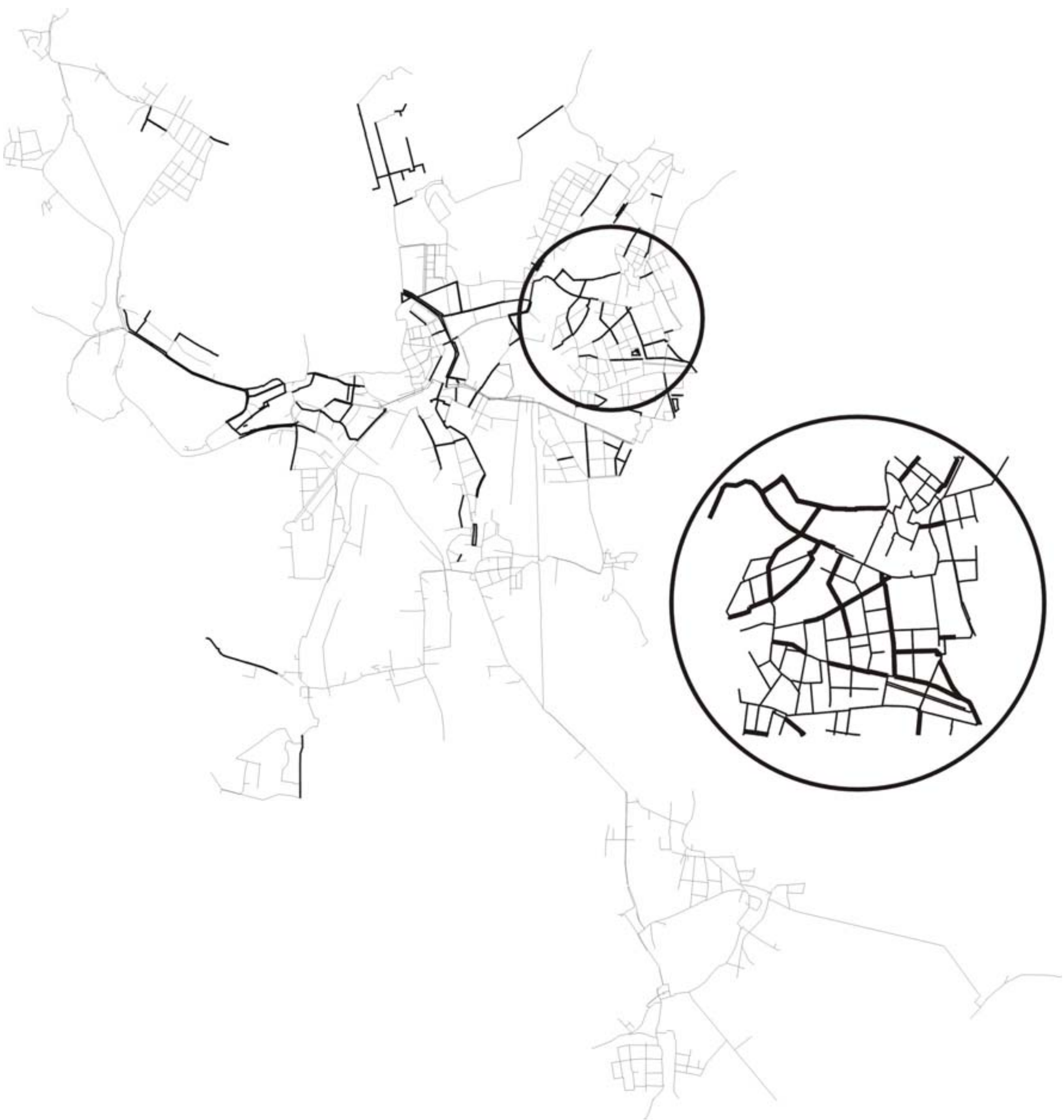


Figure 11. Water distribution network of the 1st Brno pressure zone. Highlighted elements were classified as suitable for reconstruction during next 5 years – according to middle-term rehabilitation plan created formerly by end-user's operators. The sub zone processed by ARP module is located in the circle. Detail of the sub-zone processed by ARP.

2.3.2. ARP testing

BVK has a middle-term rehabilitation plan of the water network for the next 5 years. BVK had created this plan independently on the CARE-W project (see Fig. 11).

Coefficients of KB have been determined only for the entities from the sub-zone at this stage. This data are stored in a separate *xls* file and we are now working on finishing the new version of RelNet, which is supposed to calculate HCI for the whole entities. Due to the fact, that the calculated value of HCI=0 for all pipe sections in the chosen subset, we did not use this criterion in ARP in this particular case. Table 8 describes particular KB as it was evaluated by BVK end-user.

Table 8. Evaluation of importance of particular KB according to BVK. Highlighted items were used for evaluation in ARP module.

1) Very important
KB 1: Co-ordination score KB 3: Unit cost of rehabilitation **KB11**: Street category factor
2) Important
KB 2: Unit cost of repair KB 5: Contribution to leakage KB 6: Contribution to water quality deficiencies **KB 7**: Expected duration of interruption **KB 8**: Sensitivity of housing areas to flooding
3) The others
KB 9: Sensitivity of industrial areas to flooding KB10: Risk of landslides KB12: Parallel infrastructure factor KB13: Intensity factor flooding in housing areas KB14: Vulnerable values in housing areas KB15: Vulnerable values in industrial areas KB16: Rehabilitation rules/ technologies

The following KB's from the table were chosen and used for evaluation in ARP: KB1, KB2, KB7, KB8, and KB11. Operators of BVK determined these values manually. Input file generated by Prototype contained items: ID, L, M, D, P, NPS, SC, C-COS, C-UCRp, C-UCRh, C-EDI, C-SFH, C-SR, Info2, PBR and PFR (where PBR = PFR). Values of PFR (PBR) for the chosen subset were calculated manually from data maintained in BVK's database of failures with the use of the same methodology as Poisson does. Unfortunately this was a very time-consuming process and for the rest of the network we determined these values only from material and year of laid (see Tab. 7 and Fig. 10). Based on these data the following criteria has been calculated:

Table 9. Review of criteria calculated by ARP module. Values of b1, b2, v, p, and g were adjusted manually for evaluation.

Criterion	b1	b2	v	p	q	min	max
Co-ordination Score (COS)	-0.5	0.5	2	1	0.3	-1	0.3
Annual Repair Cost (ARC)	2500.0	2800.0	4653.5	1551.2	775.6	381.5	21424.0
Predicted Water Interruption (PWI)	200.0	400.9	721.3	240.4	120.2	0.0	1581.6
Predicted Critical Water Interruption (PCWI)	0.0989	0.2968	0.4566	0.1522	0.0761	0.0000	2.6228
Predicted Frequency of Water Interruption (PFWI)	2.8655	7.3278	10.2976	3.4325	1.7163	0.1129	24.6316
Damages due to Flooding in Housing area (DFH)	348.0	907.2	1290.6	430.2	215.1	0.0	2832.3
Traffic Disruption (DT)	0.025	0.040	0.073	0.024	0.012	0.000	0.750
Year of laid (Info2)	-1991	-1945	69	23	12	-2002	-1912

BVK operator has determined values of weights for all calculated criteria. See table 10. for details.

Table 10. Weights of particular criteria, as operator BVK determined them.

Points of view	Criteria	Weights	Weights
Co-Ordination	Co-ordination Score (COS)	0.3	1.0
Repair Costs	Annual Repair Cost (ARC)	0.2	1.0
Water Losses	Water Losses Index (WLI)	0.0	1.0
Water Interruptions	Predicted Water Interruption (PWI)	0.2	0.3
	Predicted Critical Water Interruption (PCWI)		0.4
	Predicted Frequency of Water Interruption (PFWI)		0.3
Damages and disruptions	Damages due to Flooding in Housing area (DFH)	0.2	0.3
	Damages due to Flooding in Industrial or commercial areas (DFI)		0.0
	Damages due to Soil Movement (DSM)		0.0
	Traffic Disruption (DT)		0.7
	Damages and/or Disruption on other Infrastructure (DDI)		0.0
Water quality	Water Quality Deficiencies (WQD)	0.0	1.0
Hydraulic reliability	Hydraulic Criticality Index (HCI)	0.0	1.0
Year of laid (Info2)		0.1	1.0

2.3.3. Results of ARP testing

One of the aims of ARP testing was to compare the above mentioned middle-term plan of network rehabilitation with an annual plan evaluated by means of the ARP module. Prepared input file containing data of all 78 entities was uploaded and processed by ARP module. Table 10 refers to settings of weights, which were used for the analysis. Eight criteria were calculated and assessed. The entities were outranked into the particular categories and output file was generated.

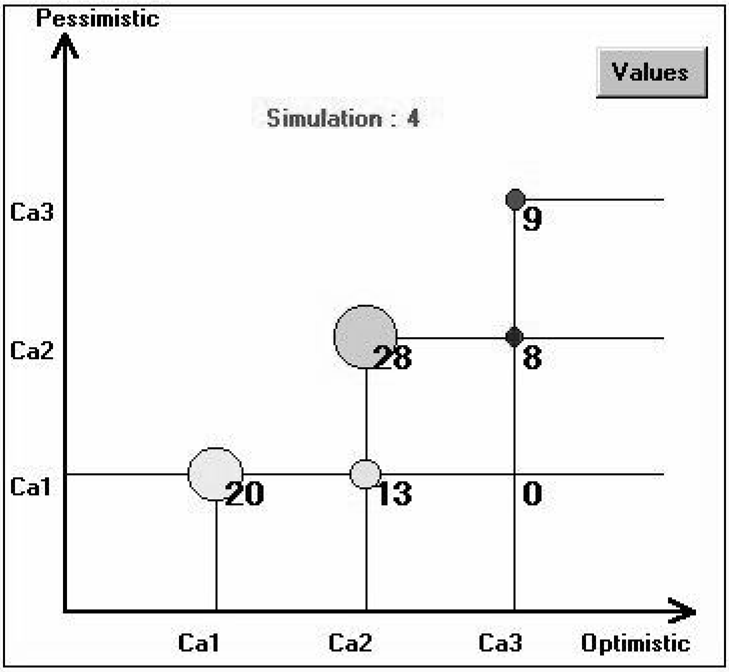


Figure 12. The 78 analysed entities were outranked by ARP module into particular categories

For comparison of former decision made by operators of BVK with decision supported by CARE-W software see figures 13 and 14. Highlighted elements in Figure 13 were classified as suitable for reconstruction during the next 5 years – according to the middle-term rehabilitation plan created formerly by end-user's operators. Figure 14 presents evaluation by ARP, highlighted entities were outranked into categories C33–best for rehab, C32–good for rehab.

Figure 13. Detail of 1st PZ's sub zone. The highlighted elements were classified by operators of BVK as suitable for rehabilitation (middle-term plan).

Figure 14. Detail of 1st PZ's sub zone. Results from analysis by ARP module.

Within the testing of ARP we tried to verify functionality of the Prototype and RelNet relating to ARP, to describe the methodology of using entities in rehab planning and to validate the procedure at our end-user. We also wanted to compare our results from ARP, based on end-user KB, to the group of elements formerly chosen for the rehabilitation by BVK – see fig. 13. Some conclusions from the ARP module testing are as follows:

We had no significant problem relating our rehabilitation approach based on entities as far as functionality of ARP module considered.

A problem on criterion UCRh (Unit Repair Cost for Rehabilitation) occurred; UCRh could not be calculated by ARP module in spite of the fact, that all necessary data for its calculation were available. We did not use this criterion.

Year of laid of each element should be automatically generated by Prototype into the ARP input file from central database if available. We had to add this figure manually into the position “Info2”, which is not user friendly.

We appreciate the possibility to add more items into the columns “Info”. It is very useful.

2.4 CARE-W LTP

In Brno there is no experience with the long-term rehabilitation planning of water networks so far. The Brno end-user makes only medium-term rehab plans for 5 years and one-year plans of concrete rehab actions.

Testing of the long-term rehab planning tools by the Brno end-user was focused on Rehab Strategy Manager and Rehab Strategy Evaluator. We have not tested Scenario Writer in the end, because we do not see any internal links and data or results transfer between SW and the two other LTP tools.

2.4.1. Rehab Strategy Manager (RSM)

Definition of ageing functions

The assessment of parameters of ageing functions for particular pipe material should be based on statistics of failure and rehab activities in the past. We find it to be one of the most problematic parts of the input data processing. Since there is no electronic evidence on water mains before replacement at the Brno end-user (see chapter 1.2), we cannot find out at what age pipes were being replaced. Also a failure analysis for particular asset type is difficult as described above, in chapter 1.2. Therefore the end-user had to provide qualified estimates of failure rates, leakage rates and theoretical service lives of pipe materials for each asset type.

Stock data import and analysis

The end-user has provided his water mains database in MS Excel format containing all information needed for RSM. We have created a *csv* file consisting of three columns: year of installation, asset type and length, and imported it into the RSM. With regard to the pipe material distribution in the Brno water distribution network (see Table 1) the end-user decided to analyse via RSM only the dominant pipe materials of high age (GG and steel) and he has defined 4 categories of asset types, which are presented in Table 11.

Table 11. Asset types and rehab methods for RSM.

Asset type		**Rehab method**	**Fraction**
Grey cast iron – 1st pressure zone	GG - 1st PZ	Reha 1: Replacement with GGG	100%
Grey cast iron – the rest of the network	GG - REST	Reha 1: Replacement with GGG	80%
		Reha 2: Lining (Epoxy or Cement)	20%
Steel – transmission main Brezova II	ST - BREZ II	Reha 3: Lining (Fabric pipe sleeve)	100%
Steel – water distribution network	ST - REST	Reha 1: Replacement with GGG	25%
		Reha 4: Replacement with GRP	25%
		Reha 5: Lining (Fabric pipe sleeve)	50%

Rehab Strategy Manager allows the user to analyse and display the asset information in charts. Figure 15 presents “Inventory of assets by asset type and installation year”.

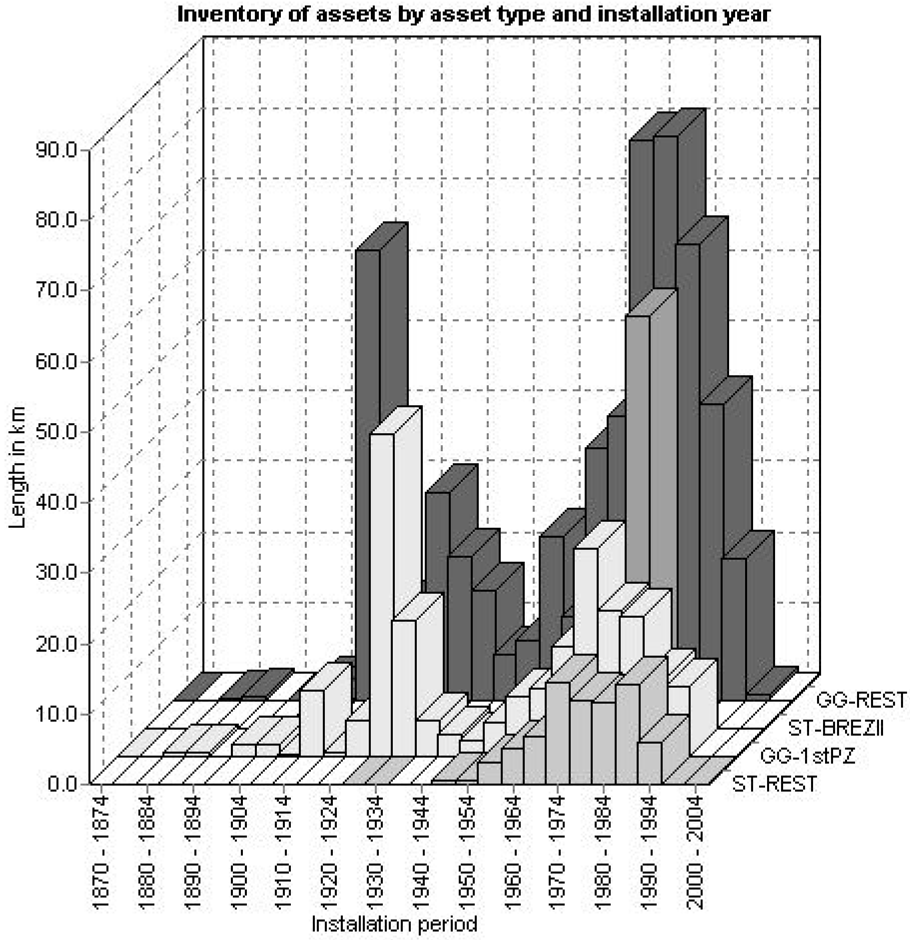


Figure 15. Inventory of assets by asset type and installation year for selected materials on the Brno water distribution network

Prognosis

In the RSM there are three different types of prognosis available:

1. *Forecast of future rehab needs* – it is calculated according to the ageing functions defined in the previous steps. This kind of prognosis does not require any additional data.
2. *Rehab strategy without economic evaluation* – the user defines a rehab strategy by setting a strategy period within the prognosis period and defining a particular rehab program consisting of rehab actions defined with rehab length and method for a certain asset type.
3. *Rehab strategy with economic evaluation* – for this type of prognosis it is necessary to give some additional input information on the efficiency of rehabilitation for particular rehab methods and economic data. The efficiency of rehabilitation is assessed by failure and leakage rate for the new rehab asset types after a certain resistance time and their yearly increase and the rehab efficiency factor. Furthermore the investment costs and their yearly increase rates of the particular rehab actions must be defined. Economic data comprises inflation and discount rates, repair costs and running cost for inspection and maintenance and variable costs for water production.

In order to gain input data for Rehab Strategy Evaluator or to be able to export the RSM results back into the CARE-W Prototype central database the user has to choose the third option and to define several rehab strategies with economic evaluation. To test the LTP tools properly we have decided to do this in spite of the fact that many of input data would have to be estimated, because they are not recorded by the Brno end-user. Table 12 presents reliability of data for RSM testing on the Brno water distribution network.

Table 12. Reliability of Brno input data for RSM.

Definition of ageing functions	
Service life expectancy	C
Failure rate	B
Leakage rate	C
Stock data	
Year of installation, asset type, length	A
Strategies	
Efficiency of rehabilitation	
Failure rate and its increase rate	C
Leakage rate and its increase rate	C
Resistance time	C
Rehab efficiency factor	C
Investment costs	B
Economic input data	
Inflation rate	A
Discount rate	A
Repair costs	A
Maintenance and inspection costs	A
Variable production costs and its increase rate	B

Data reliability definition:

A - Reliable
Exact data based on records.

B - Unreliable
Estimates based on real data.

C - Highly unreliable
Rough estimates.

For the most problematic part of the rehab strategy definition we consider the assessment of the efficiency of rehabilitation of particular rehab method. First, it is very difficult to assess or estimate the failure and leakage rate and the resistance time of a new pipe material. Second, due to the state of data recording at the Brno end-user described in chapter 1.2 it is not possible to assess failure rate of a particular asset type prior to rehabilitation and therefore the rehab efficiency factor of the used rehab method. And third, the investment costs are different for different pipe diameters. The question is, whether we should use an average value of these costs or weighted average value according to pipe diameter or to define a rehab method for each pipe diameter separately. We have chosen the second option.

Strategies

Within the testing work 4 rehabilitation strategies have been defined, all for a 46-year period, from 2004 to 2050. For the rehab strategies description see Table 13 and Figures 16 to 19. Rehab methods for particular asset types defined by the Brno end-user are described in Table 5.

After the rehab strategy definition and the calculation of prognosis the user can analyse and display results in 16 charts. Figures 16 to 19 present *Future rehabilitation needs of asset types* for all 4 rehabilitation strategies defined on the Brno water distribution network.

Table 13. Rehab strategies defined within the testing of RSM on the Brno water distribution network.

Strategy	Rehabilitated asset types	Strategy phases	START length [m]	END length [m]	Rehab method *	Fraction
A	GG - PZ I	2004 - 2020	3000	3000	Reha 1	100%
	GG - REST	2004 - 2020	7400	7400	Reha 1	80%
					Reha 2	20%
	ST - REST	2004 - 2020	370	370	Reha 1	25%
					Reha 4	25%
					Reha 5	50%
B	GG - PZ I	2004 - 2020	According to the forecast of future rehabilitation needs		Reha 1	100%
	GG - REST	2004 - 2020			Reha 1	80%
					Reha 2	20%
	ST - REST	2004 - 2020			Reha 1	25%
					Reha 4	25%
					Reha 5	50%
C	GG - PZ I	2004 - 2020	2 977	3 608	Reha 1	100%
	GG - REST	2004 - 2020	7 402	8 970	Reha 1	80%
					Reha 2	20%
	STEEL - BREZ II	2015 - 2020	11 700	11 700	Reha 3	100%
	STEEL - REST	2004 - 2020	0	1 575	Reha 1	25%
					Reha 4	25%
					Reha 5	50%
D	GG - PZ I	2004 - 2020	According to the forecast of future rehabilitation needs		Reha 1	100%
	GG - REST	2004 - 2020			Reha 1	80%
					Reha 2	20%
	STEEL - BREZ II	2015 - 2020			Reha 3	100%
	STEEL - REST	2004 - 2020			Reha 1	25%
					Reha 4	25%
					Reha 5	50%

* For legend on Rehab methods see Table 11.

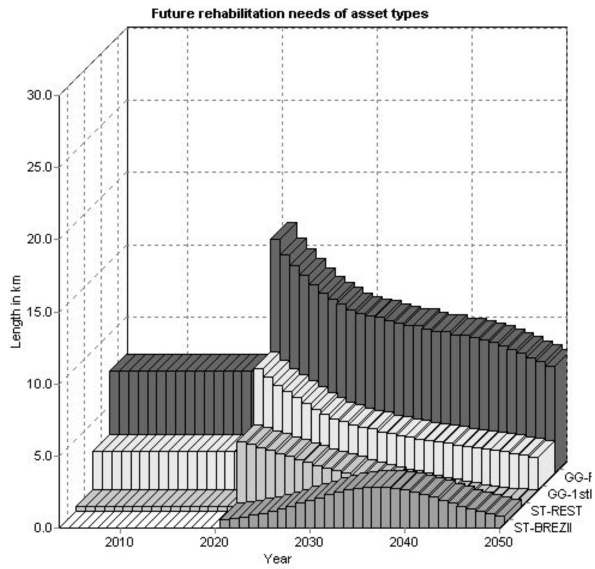


Figure 16. **Strategy A**:
Future rehab needs of asset type.

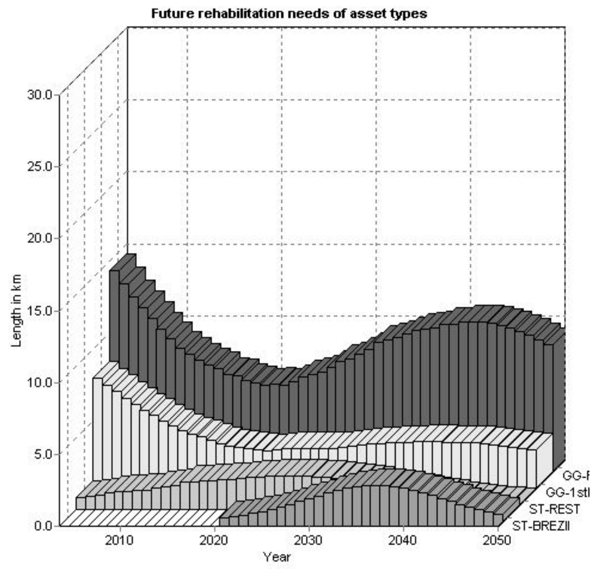


Figure 17. **Strategy B**:
Future rehab needs of asset type.

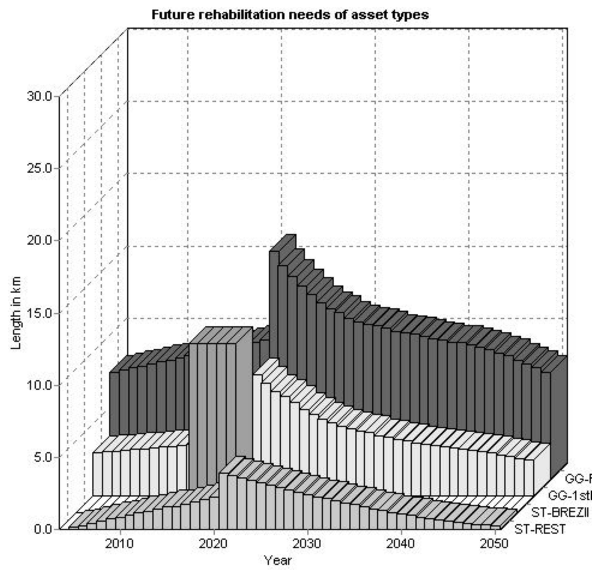


Figure 18. **Strategy C**:
Future rehab needs of asset type.

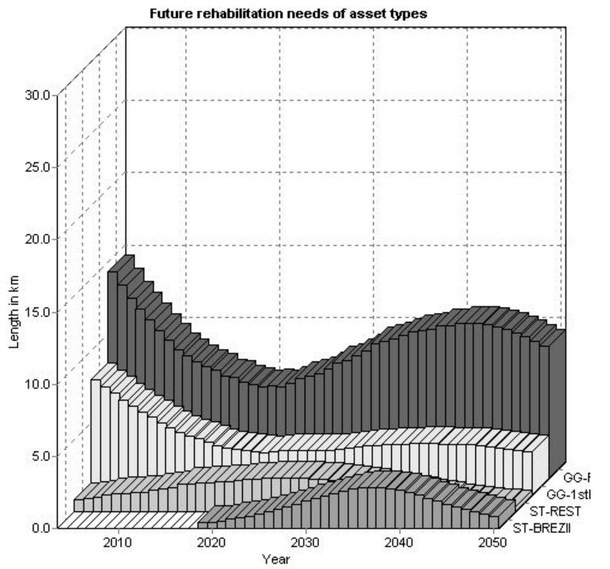


Figure 19. **Strategy D**:
Future rehab needs of asset type.

Other two possibilities of rehab strategy analysis are presented in Figures 20 to 23. It is the *Future average age and the residual service life* for strategies A and B and the *Stock during prognosis time* for Strategies C and D.

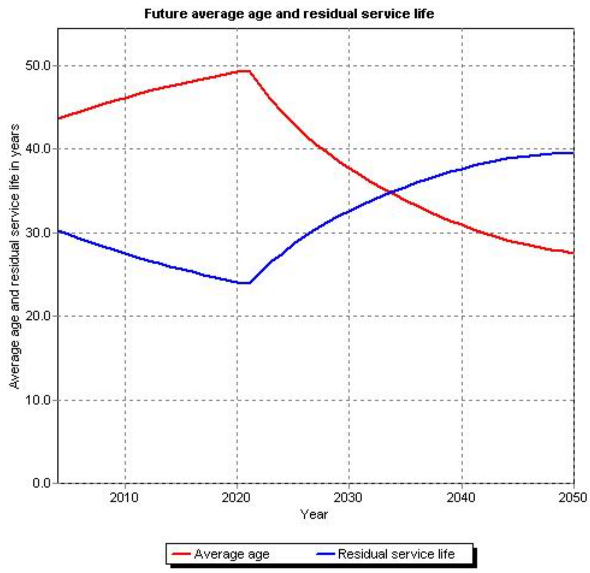


Figure 20. **Strategy A:** Future average age and residual service life.

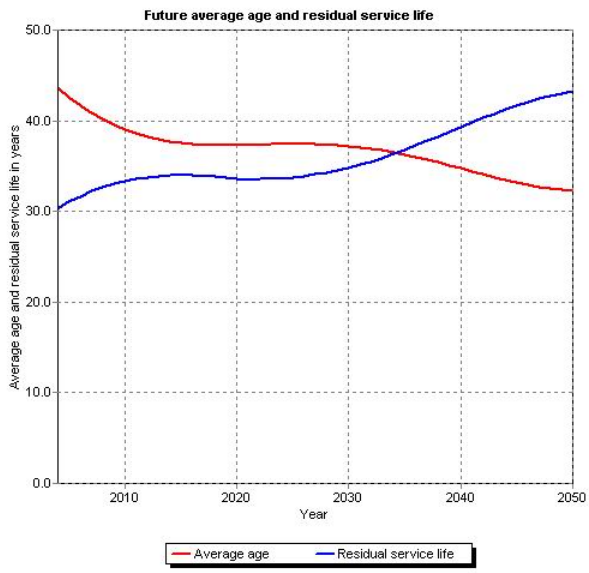


Figure 21. **Strategy B:** Future average age and residual service life.

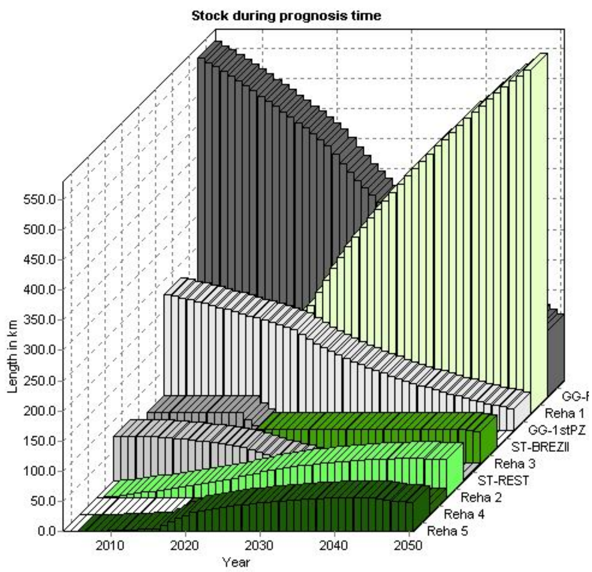


Figure 22. **Strategy C:** Stock during prognosis time.

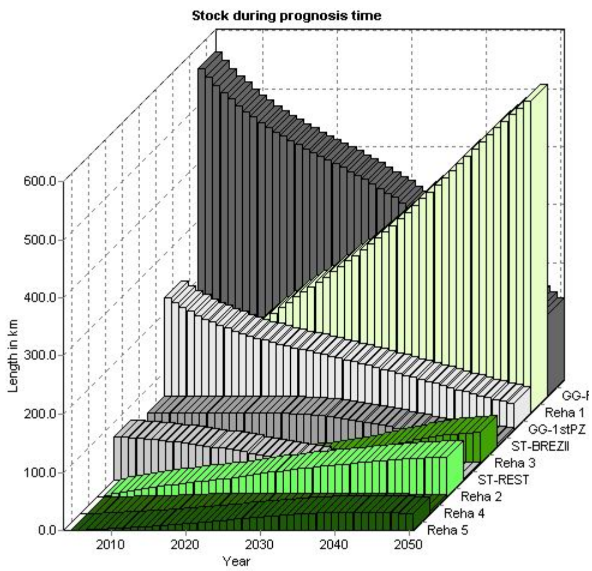


Figure 23. **Strategy D:** Stock during prognosis time.

2.4.2. Rehab Strategy Evaluator (RSE)

Within RSM we have defined 4 strategies of rehabilitation. All of them were imported into the Rehab Strategy Evaluator in order to find the best one. First we have set up constraints for the average age (not more than 47 years). We have selected the years 2005, 2010 and 2020 as the time points that should be compared. Due to the set constraint of average age the Strategy A has been eliminated by RSE. As you can see in Figure 20, the average age of asset in Strategy A in 2020 is almost 50 years. Final ranking is ABC (see Figure 24), i.e. Strategy B, Strategy C and Strategy D. So the “winner” is the Strategy B, however the Strategy C is more likely to be followed with regard to the amount of rehabilitated asset in the next few years.

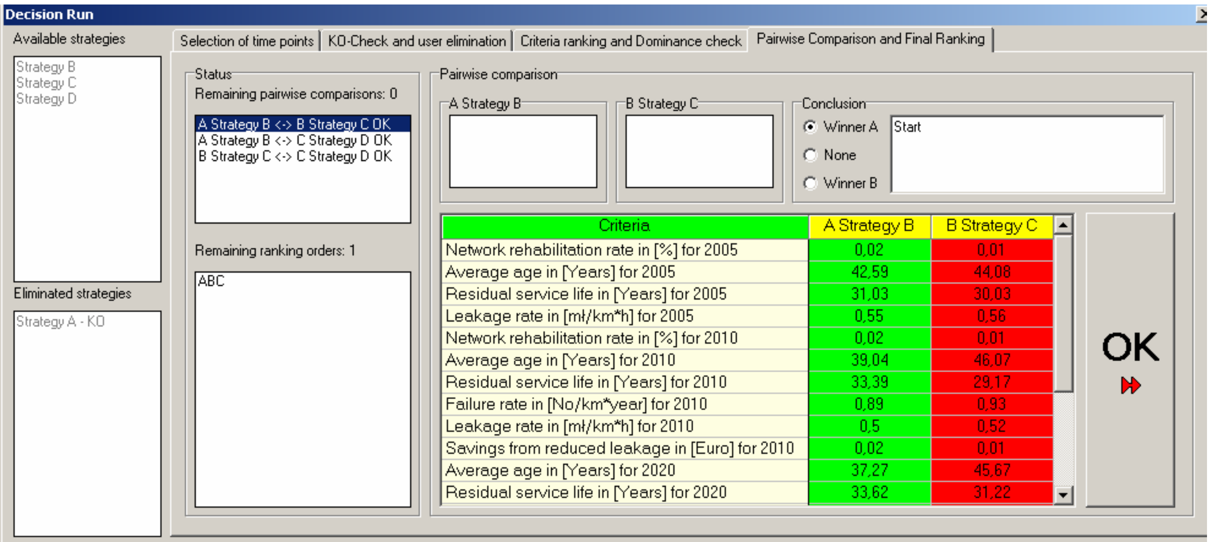


Figure 24. RSE – Pairwise Comparison in the Decision Run.

2.4.3. Concluding remarks on the LTP tools

So far we have mainly focused on testing of the LTP tools as stand-alone software. Regarding their cooperation with CARE-W Prototype we succeeded in the export procedure of the RSM results to the Prototype, however nothing has appeared in the report "Strategic rehab plan – global budget". We are going to focus on this issue and hope to bring some results soon.

Regarding RSM, we think that the user would appreciate the possibility to open more than one strategy at the same time to be able to compare the charts of more strategies without exporting them as bitmaps and displaying in another program. Also the setting of the chart properties should be saved after its closure. We find the work with RSM a little bit uncomfortable and time demanding.

For RSE we have one note on the Pair wise Comparison screen in the Decision Run: the appearance of the criteria table is not very systematic. It is quite difficult to compare the two strategies. The user should see all the available criteria without scrolling down and up.

2.5 CARE-W PROTOTYPE

During the testing period we discovered some bugs in the Prototype, which complicates its use. Some of them were already typed into the CARE-W issues form on BSCW server, but some of them were found during recent days. Bugs relating RelNet and hydraulic data storing can be found above. These, which are of general use, are as follows:

1) We could not upload any of proposed formats of background map (except of *shp*) into the GIS window of the Prototype.

2) Print device proposed on the tool bar of the Prototype is not available.

3) The "Import manager" does not work properly. We could not create any new protocol for import of a specific *csv* file and we even could not correctly use the edited one.

4) Prototype does not ask about saving the project when it is terminated.

From the end-user point of view: a possibility to export data from the central database to some data file (*csv, xls*) defined by the user is missing.

3 CONCLUSIONS

First, it is necessary to point out that all our concluding remarks are stated from the position of a partner and end-user of the CARE-W project, who is familiar with the software environment and the process of its development. Our experience has shown that it would not be possible to only pass the CARE-W Prototype and tools to the Brno end-user and want him to test it alone without consultation with us as a partner. During the testing of the Prototype and tools we have been cooperating with our end-user providing them all needed support. For some of the tools (e.g. RSM, PI Tool) the end-user provided only the input data and then we tested the tools only at BUT.

✓ Our end-user finds the CARE-W Prototype to be a comprehensive support tool for rehabilitation planning of water networks. He appreciates the possibility to use only some of the CARE-W tools independently from the others if needed.

✓ The CARE-W approach has brought some new suggestions for the methodology of data recording and analysis, e.g. within the GIS system, failure rate of pipe sections and some of the information used in the PI Tool.

✓ During the testing of the Prototype and its tools the end-user has finalised the system of data export from GIS into the MIKE NET software and the hydraulic model of the 1st pressure zone has been completed.

× The CARE-W software and its installation are rather complicated. A certain set up of Windows system is required. It means that the user has always to change the setting of his computer or to have the Prototype installed on a separate PC. For example, if the end-user changes his settings according to the Prototype, his costumer information system does not perform.

× The English language of the software and help files represents a barrier for its use in a wider context in the Czech Republic.

× The testing of the CARE-W Prototype and its tools has shown that the software is rather data-intensive. It was not possible to generate input data for the tools automatically. All data had to be pre-processed at first, many of them were not available at all and they had to be substituted with qualified estimates.

× Different CARE-W tools have got different level of their HELP functions. As an example we can point out the PI Tool help, which is very clear, complex and user friendly. On the other hand the help file of Rehab Strategy Manager should go more into detail and better explain the meaning of some of the required input data. For example, what does expressions, such as “Start”, “End”, “Complete”, in the *Future rehab work* input screen really mean? What are their units?

× During the testing of the CARE-W Prototype we have been facing some software bugs and instability. Sometimes it is very difficult to find out what is the problem, especially in case of a bigger network. Working with the Prototype and tools requires high computer skills and good technical knowledge of the water supply system. All the problems encountered during the testing are described above in this report.

Report on testing carried out in Codigoro and Ferrara, Italy

CARE-W PROTOTYPE TESTING

1 INTRODUCTION

This document describes the activities carried out by the University of Bologna and the University of Ferrara regarding the testing of the Care-W prototype and of some of the tools included in the package.

The report is organized as follows. First, the datasets used for the testing, as well as the type of data needed to prepare the input files for the tools, are described in detail. Second, the results of the testing phase are discussed, and the improvements of the tools since the pre-testing phase summarized.

Finally, the report includes a list of the comments and suggestions about the prototype and its use by members of the Bologna and Ferrara team, by our end-users, and by participants to the national CARE-W conference, that took place in Ferrara on November, 12.

2 DESCRIPTION OF DATASETS

2.1 CADF Network

CADF network is quite heterogeneous and has a total length of 1863,495 km (Table 1). Asbestos Cement constitutes the 67% of the network and is the oldest material of the network (first material that was laid). PVC constitutes the second material of the network, because during the last years asbestos cement has been partially substituted with PVC. The network is composed of 15 municipalities and has a population served of about 110.000 inhabitants, that during the summer increase to 200.000.

Material	Length per material (km)	%
Steel	69,26	3,72
Concrete	32,13	1,72
Asbestos cement	1263,56	67,81
Etp	1,26	0,07
Iron	4,21	0,23
Grey Cast Iron	3,51	0,19
Cast Iron	87,35	4,69
Not individuated	38,78	2,08
Pe	48,08	2,58
PVC	315,38	16,92
TOTAL	1863,495	100,00

Table 1: Length and percent of different pipe materials in CADF network

For the testing phase the entire CADF network was chosen to test Rehab Strategy Manager, while Massafiscaglia (municipality) and Mezzogoro (Codigoro sub-network) were chosen to test failure forecasting tools and reliability tools. As shown in Table 2, Massafiscaglia network has a total length of about 85 km and a quite high ratio between length of the network and population served.

Mezzogoro network is also quite heterogeneous, having a total length of about 15 km and a population served of 1750 inhabitants. As shown in Table 3, asbestos cement and PVC in Mezzogoro network have about the same length; a comparison with Table 1 shows that the composition of Mezzogoro network differs noticeably from that of the whole network.

Municipality	Population served	Total Length (km)	Km / inhabitant
Berra	6.311	111,795	17,714
Codigoro	13.591	223,025	16,410
Comacchio	21.679	356,180	16,430
Copparo	18.929	270,040	14,266
Formignana	2.891	46,420	16,057
Goro	4.325	41,305	9,550
Jolanda	3.712	130,730	35,218
Lagosanto	4.459	46,000	10,316
Massafiscaglia	**4.031**	**85,190**	**21,134**
Mesola	7.829	177,915	22,725
Migliarino	3.910	72,980	18,665
Migliaro	2.383	40,160	16,853
Ostellato	7.377	147,485	19,993
Ro	4.088	61,165	14,962
Tresigallo	4.823	53,105	11,011
TOTAL	110.338	1863,495	
AVERAGE			16,889

Table 2: Population served, Length and ratio Km/Inhab. for all the municipalities.

Material	Length (km)
Steel	0,145
Asbestos cement	6,751
Pe	0,2
PVC	6,105
Cast Iron	2,225
TOTALE	15,426

Table 3: Length of different pipe materials in Mezzogoro network

2.2 ACOSEA Network

ACOSEA network has a total length of 2364 km, it is composed of 12 municipalities and it is constituted principally, as CADF network, of asbestos cement (57,9%), PVC (15,86%) and cast iron (8,93%). Vigarano is one of the 12 municipalities, it has a population of 6610 inhabitants, a total length of 32,6 km, with a very high percent of asbestos cement (53,76%), PVC (22,35%) and Cast Iron (10,77%). For the testing phase Vigarano network has been chosen to test all reliability tools.

2.3 Data availability

2.3.1 CADF data

Arcview GIS data (provided by CADF) and an Access database (developed by Unibo) are available to get information on the CADF network.

In the Arcview GIS are included all data belonging to the topology of the network such as Pipe ID, head node, tail node, length, material, year laid, depth of installation, municipality, address, etc…Data about consumption and failures are not available and, for this reason, GIS data on CADF network have been used only to test the tool Rehab Strategy Manager.

The standard recording format in Access was developed to collect and classify network data and pipe break data for the system studied, by creating a two-fold computer database.

The first section contains the characteristic of every network link. Provided that all the information were available only in paper format, a different numeric code was attributed to each map; within each map, a further code was then attributed to every pipe and node. These codes were then registered in electronic format, specifying the starting and ending point, the material and the diameter of each pipe section.

The second section includes information relative to single failure events, as available in the 50,000 repair logs filled in on paper by CADF technicians.

According to a preliminary analysis of the paper archives, several events were found to be due to external causes and therefore were not considered of interest to our investigation. To select relevant data for further analysis, breaks were classified as i) due to external causes; ii) imputable to pipes intrinsic reliability. In case i), breaks are mainly due to excavations close to the pipe, due to contacts with other utilities (electric, telephone, gas); they are frequent, but not related to pipes reliability, and were therefore excluded. Data belonging to the resulting subset were analysed, and classified either as house connection breaks and main network breaks; a preliminary investigation showed that the break rate was higher in house connection than in the rest of the network. A possible explanation for the high incidence of breaks in house connections include: small diameter and low depth, which increases the likelihood of interfering with other underground services. We omitted any further analysis of house connections breaks, and focused on breaks in the distribution network.

At the end of the registration phase, data were analysed to determine the characteristics of the distribution network (total length, length per material and/or diameter, etc.) and the distribution of breaks in space and time for the system. With this Access Database all failures information were at hand and therefore it has been possible to test all Failure Forecasting Tools and all Reliability Tools, albeit only for Mezzogoro and Massafiscaglia network; in fact, consumption data were available only for those two network; moreover the pipe ID in the Access Database did not coincide with that of GIS Network and all the information (year laid, etc…) necessary to fill in the input files, were included in Arcview GIS.

2.3.2 ACOSEA data

For the ACOSEA network only an Arcview GIS of Vigarano Network was available, in which were included data about the topology of the network and the consumptions, but nothing about the failures history. For this reason we have been able to create input files only for Reliability Tools.

3 DATA REQUIRED FOR TOOLS USAGE

3.1 SDF and MDF files

SDF and MDF files are used to run PHM and POISSON tools. SDF is a file including information about the network, such as pipeID, diameter, length, year laid, depth of installation etc…MDF is a file including information about failures, such as pipe in which failure occurred, the date of the failure, the type of the failure, etc…

We have created those files for Massafiscaglia and Mezzogoro networks.

3.2 HLF and NDF files

The files HLF and NDF are used by the application F-Reliab; the first includes the network topology (pipeID, Head Node, Tail Node, Failure Rate, etc) and the second the information concerning the nodes.

3.3 INP files

The INP file is the typical text file used by EPANET, the program for the simulation of hydraulic behavior within pressurized pipe networks.

It is basically a text file containing information regarding nodes, pipes, tanks, reservoir, water demand, etc…(for example Massafiscaglia INP file contain 28 junctions, 36 pipes and 1 reservoir).

The file includes also the coordinates of the nodes, making possible to show the network layout in the prototype GIS window.

Three INP files were generated, on for each network studied: Massafiscaglia, Vigarano and Mezzogoro.

It has not been possible to generate the INP file by using the prototype because it has not been possible to populate the database with the GIS file data. The three INP file had to be prepared manually using EPANET.

3.4 CSV files

The CSV is used by Rehabilitation Strategy Manager to import network data inside its own database. The CSV file is composed by three columns, named respectively “length”, “material” and “Year laid”, and the data are separated by semicolon. The information contained in the file are not referred to every single pipe but they represent “cohorts”.

In our case a CSV file for the whole CADF network was prepared. It has not been possible to use the prototype to make the CSV file, because the CARE-W software did not succeed in importing the GIS network file. The file had to be prepared manually using the GIS information, making cohorts by grouping the pipes having the same material and laid in the same year, and by adding the length of each pipe.

There are five different materials in the network: Asbestos Cement, PVC, PE, Steel and Cast Iron, while the Years of laying goes from 1950 to 2002. As a result, 28 cohorts were defined, with a total length going from 20 m to 1126 km.

4 TOOLS TESTING WITHIN THE PROTOTYPE (Version 1.5.3)

Bologna and Ferrara, as planned, have tested all failure forecasting tools, all reliability tools and all long term planning tools. Table 4 shows the networks in which the Tools have been tested.

	Phm	Poisson	Relnet	F-Rel	Aquarel	R.S.M.	RSEvaluator
Massafiscaglia (CADF)	X	X	X	X	X		
Mezzogoro (CADF)	X	X	X	X	X		
CADF Network						X	X
Vigarano (ACOSEA)			X	X	X		

Table 4: Networks and tools tested.

After the first testing phase a State of the Art Table (Table 5) has been prepared to give an overview of the Tools tested within the Prototype.

Legend for Table 5:

1: Import Pre-existing Tool Input files necessary to run the Tool;

2: Create a Dataset from that files;

3: Generate all Input files for the Tool from the Dataset; for R.S.Evaluator input files are generated from Kanew;

4: Run the Tool;

5: Return the results to Care-W Central Database;

6: View results.

	1	2	3	4	5	6
POISSON **v 1.03**	■		■		■	■
PHM **v 1.2**	■		■			
AQUAREL **v 0.2.2**	■	■		■	■	■
F-RELIAB **v 1.1**	■	■	■	■		
RELNET **v 2.01**	■	■	■	■	■	■
LTP **v 3.17**	■	■	■	■	■	
EVALUATOR **v0.9**			■	■		

Table 5: State of the Arte after the first testing phase (pre-testing).

The following sub-chapters describe, when necessary in a more detailed way, the kinds of problems encountered that have not been reported in Table 5.

4.1 Poisson

- Importing two text files (sdf and mdf) and trying to create a selection to have a Dataset, on using the function "Expression Builder" the Programme asks to "select a map layer before attempting to use the query tool": in this way, having two text files, it is not possible to create a Dataset;
- On trying to create the categories, the Poisson tool shows minimum and maximum values belonging to other files;
- In the first column of the mdf file created by the Prototype, there is the Pipe Failure Id instead of the User Reference used in sdf file: in this way Poisson is not able to assign the failure to the right pipe.

4.2 Phm

- As for Poisson, importing two text files (sdf and mdf) and trying to create a selection to have a Dataset, on using the function "Expression Builder" the Programme asks to "select a map layer before attempting to use the query tool": in this way having two text files it is no possible to create a Dataset;
- It is no possible to create survive files and to run Phm.

4.3 Aquarel

- When trying to generate Input files, Care-W gives an error message.

4.4 F-Reliab

- Importing two text files (sdf and mdf) and trying to create a selection to have a Dataset, when using the function "Expression Builder" the Programme asks to "select a map layer before attempting to use the query tool": in this way, having two text files, it is no possible to create a Dataset;
- On trying to run F-Reliab often the programme does not run and shows the results of the last run.

4.5 Rehab Strategy Manager

It is not possible to view the results on Care-W Prototype. The Manger says that results imported from R.S.M. have a different number of column and cannot be copied in the Tabular Report of “Strategic Rehab Plan – global budget”. A comment from CADF (Consorzio Acque Delta Ferrarese) is the following: it would be useful if, establishing a future average age of a network and given all the survival function for each material, the R.S.M. was able to propose a strategy of Rehabilitation with relative lengths of material to substitute and costs.

5 TESTING OF TOOLS AS STAND-ALONE VERSIONS

In May a report regarding the Testing phase of the Tools as stand alone codes was produced and a table very similar to Table 5 about the working progress of the Tools was proposed. The intent now is to propose the old table (Table 6) and a new one (Table 7) regarding only the Tools tested from Bologna and Ferrara as planned. The result is that not all the Tools run correctly as stand-alone version.

1: Availability of the Tool (Yes/No) – No Beta Version

2: Theoretical Knowledge of the Tool (Yes/No)

3: Run with Example Data (Yes/No)

4: Run with Real Data not made by Prototype (Yes/No)

5: Results reliability (Yes/No)

	1	2	3	4	5
POISSON					**?**
PHM					
AQUAREL					**?**
F-RELIAB					
RELNET					
LTP					**?**
EVALUATOR					

Table 6. Old Table

	1	2	3	4	5
POISSON					
PHM					
AQUAREL					
F-RELIAB					
RELNET					
LTP					
EVALUATOR					

Table 7. New Table

6 TESTING RESULTS

This paragraph is about the results obtained running the tools on the different networks (Massafiscaglia, Mezzogoro, Vigarano, CADF). There is no comment about the results obtained using Poisson because, at this stage, it not possible to do any failure rate forecast, but only an analysis of the past failures, because the main part of the program has not been included yet (Poisson Regression). We do not consider the results obtained significant enough to be included in this paragraph.

Regarding Phm we have obtained preliminary results but a few doubts still exist on the code.

6.1 Aquarel

Massafiscaglia: to run Aquarel a sub-network of Massafiscaglia was created (36 pipes, 28 nodes, 1 reservoir) because data about consumptions were available only for the part regarding the main pipes of the network with diameter from 110 mm to 200 mm. To run Aquarel a critical pressure of 15 m it was used; double failures were included. Moreover, the frequency of the network is different from pipe to pipe with a value comprised between 0,00704 (pipe 12) to 0,15147 (pipe 33). The HCI is maximum for pipe 35 (1.00), 31, 32 and 10 (0,998) and the average value of the network is 0,608 (quite high). Those pipes constitute external links and with their break some nodes become isolated.

Mezzogoro: for Mezzogoro a network of 103 pipes, 92 nodes, 2 reservoirs was created. The frequency of the network is comprised from 0,005588 (pipe 97) to 0,2237 (pipe 5). The HCI is maximum for pipe 98 (0,75), 26 (1,00) and 1 (0,75). For pipe 1 is quite normal to have an high HCI because is the only pipe connected to the reservoir while pipe 98 and 26 are not strategic pipes and perhaps their frequency, the particular topology of the network and the consumptions result in an high HCI for them.

Vigarano (ACOSEA): for Vigarano a network of 156 pipes, 127 nodes, 1 reservoir was created. The frequency of the network is comprised between 0,036 (pipe 3) and 10 (pipe 113). The HCI is maximum for pipe 116 (1,00), 140 (0,75) and the average value is 0,6. For pipe 140 is normal to have an high HCI because it connects the principal network to a sub-network constituted from 3 pipes.

6.2 Relnet

Massafiscaglia**:** using a minimum pressure of 10 m and a required pressure of 25 m, the results are an high HCI (1,00) for pipe 1 and pipe 2, an HCI very close to 0 for pipe 10, 31, 32, 35 and 0 for all the other pipes.

Mezzogoro: using a minimum pressure of 10 m and a required pressure of 25 m, the results are a relative high value of HCI for pipes 62 (0,03), 25 and 26 (0,02), while all the other are very close to zero.

Vigarano: using a minimum pressure of 15 m and a required pressure of 30 m, the HCI for all the pipes of the network is 1. Also changing the roughness of the pipes and the head of the tanks the HCI is always equal to 1 for all the pipes and that doesn't make sense.

6.3 F-Reliab

Massafiscaglia: to run F-Reliab a desired pressure of 25 metres was chosen; other relevant data were the actual failure rate for each pipe and the total consumption of the network; the same importance was attributed to all the nodes. The same conditions have been used also for Mezzogoro and Vigarano. The global reliability index of the network is 0,9924; a very interesting result is the translation of the HCI for each pipe in non-supplied water volume per year. In this way a ranking of the pipes has been made from the worst to the best; under the previous condition the worst pipe is 36 with a value of non supplied volume per year of 31,28, followed from pipe 2 (4,93), pipe 4 (3,23) and so on.

Mezzogoro: the global reliability index is 1,00 and the worst pipes are 24 (0,24), 26 (0,23); for 61 pipes the non-supplied water volume per year is zero.

Vigarano: the global reliability index is 0,9999 and the worst pipes are 123 (6,33), 76 (3,16), 116 (3,14); also in Vigarano, as for Mezzogoro, 117 pipes have a non-supplied volume per year equal to zero.

6.4 Rehab Strategy Manager

To run rehab strategy manager, data for CADF network in CSV format were imported. Two strategies (rehabilitation and maintenance) were created, both for a period of 48 years (from 2002 to 2050). For **rehabilitation** two strategy phases (2020 and 2050) were chosen: during the first phase there is a rehabilitation of asbestos cement (in quantity depending from its survival function) with Rehab1 (PVC) for 70% and Rehab2 (PE) for 30% and steel (in quantity depending from its survival function) with Rehab1 for 100%. During the second phase period (from 2020 to 2050) there is a rehabilitation of asbestos cement with Rehab1 for 100%. The following tables, chose among the most significant ones, were obtained by introducing appropriate values of efficiency of rehabilitation (directly taken from the Appendix made by SINTEF in D10 report) and economic input data.

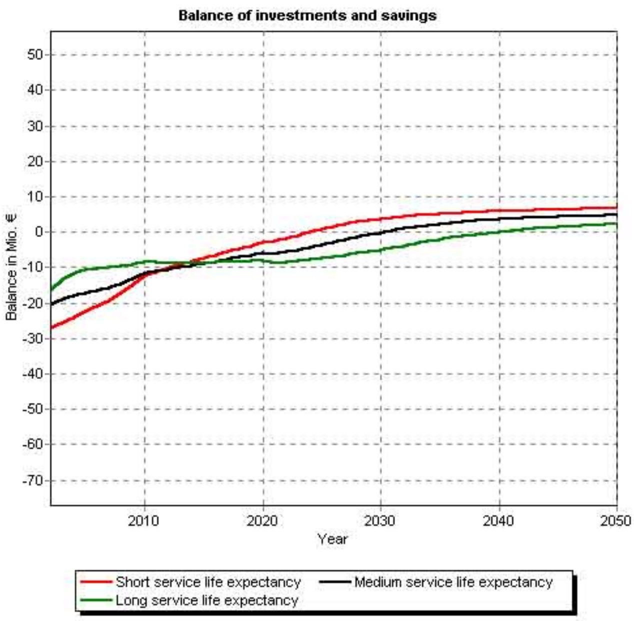


Figure 1. Balance of investment and savings

As showed in Figure 1 (Balance of investment and savings) positive values mean that the cost saving are higher that the investment needed for rehabilitation. In the figure, considering a short service life, this balance has a positive value from 2025 onwards, and the net gain increases contantly from 2025 to 2050.

As showed in Figure 2, there is an increased saving from reduced repair at the beginning of the strategy until 2010, then a constant value, an increase from

2020 to 2030 (for short service life expectancy) and finally a constant value until the end of the strategy.

Figure 3 shows a comparison of the failure rate in the future between the do-nothing strategy and the actual rehabilitation strategy. There is a great difference between the values shown, especially from the year 2005 to the year 2013.

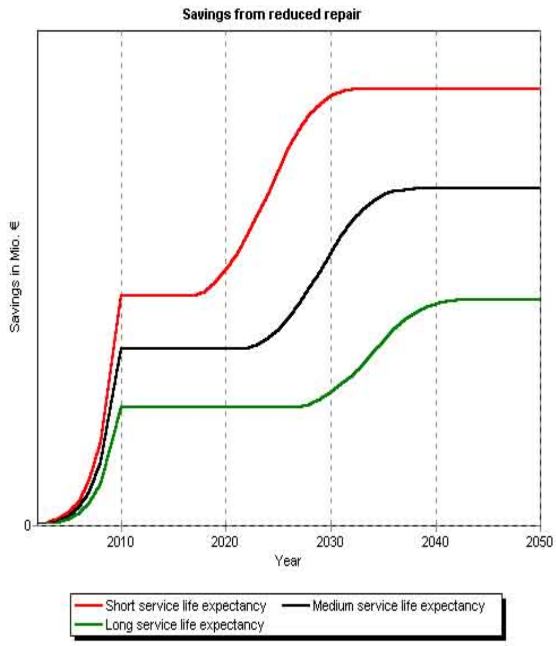


Figure 2. Savings from reduced repair

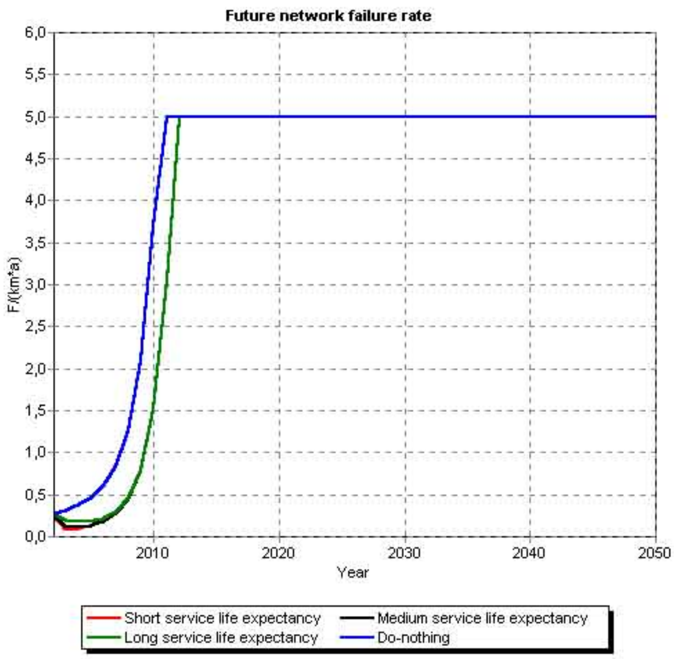


Figure 3. Future network failure rate

Regarding **spot repair** strategy, two phases (2040 and 2050) were chosen: during the first phase, after a break event there is a substitution of all the materials of the network (asbestos cement, steel, PVC, PE, cast iron), in quantity depending from their survival function, with Rep1 (PVC) for 70% and Rep2 (PE) for 30%. During the second phase period (from 2040 to 2050) there is a substitution of all materials with Rep1 for 100%. The following tables, chosen among the most significant ones, have been obtained by introducing appropriate values of efficiency of rehabilitation and economic input data.

An important result is that even if the two compared strategies seem very similar, their results differ significantly, given a difference in the value of the Efficiency Factor, which is a key point of Rehab Strategy Manager.

In Figure 4 the balance between investments and savings is reported; a positive value is evident from the year 2026. Moreover, if positive values start in the same year of the Rehabilitation Strategy, those values are higher than the values in Rehabilitation Strategy.

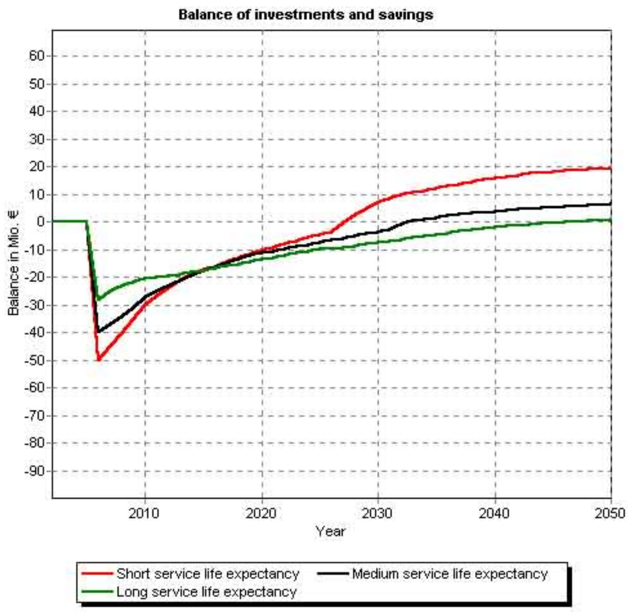


Figure 4. Balance of investment and savings

In Figure 5 there is an increased saving from reduced repair at the beginning of the strategy period until 2010, then a constant value and again an increase from 2025 to the end of strategy period.

In Figure 6 there is a comparison of the future failure rate of the entire network between the do-nothing strategy and spot-repair strategy. There is a large difference between the values especially from the year 2005 to the year 2013 and, differently from the rehabilitation strategy, again a very large difference from the year 2026 to 2034.

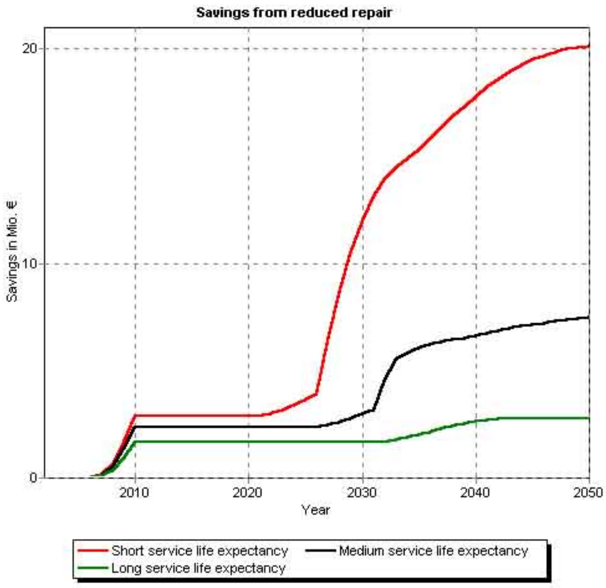


Figure 5. Savings from reduced repairs

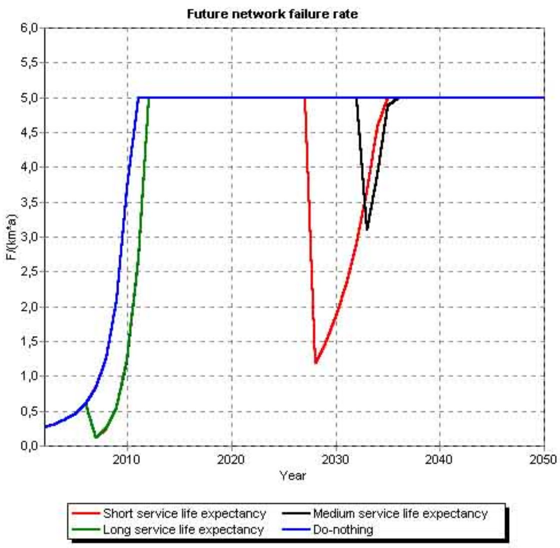


Figure 6. Future network failure rate

6.5 Rehab Strategy Evaluator

In Rehab Strategy Evaluator, the Rehabilitation strategy and the Spot Repair Strategy were imported to choose the best one, taking at the same time constraints into account. The constraints chosen are referred to two criteria: residual service life (at least 10 years) and investment costs (not more than 20 millions of Euro). The Decision Run started having chosen 3 time points (2005, 2025, 2050). In figure 7 all the criteria values for each time point chosen are showed for each strategy. Final ranking is AB because the rehabilitation strategy has better values especially regarding residual service life, failure rate, savings and investment costs in the first period of strategy, from 2002 to 2025.

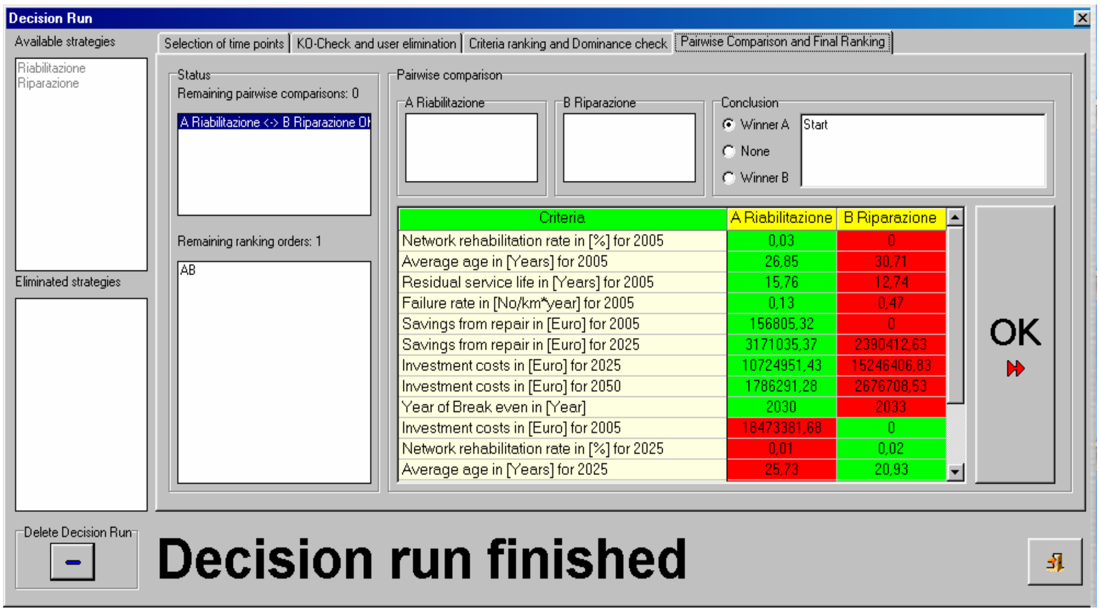


Figure 7. Decision Run

To run Rehab Strategy Evaluator 2, additional strategies (spot repair with metallic materials and spot repair with plastic materials) were created in Rehab Strategy Manager; however, there were some problems to import RSM results in Rehab Strategy Evaluator; for this reason, those two strategies were not presented in Rehab Strategy Manager.

7 FINAL CONSIDERATIONS

During the Testing phase so far, attention has been especially focused to obtain results, regarding all the problems related to the run of the tools; as a consequence, the following activities were initiated but not brought to an end: i) to develop a full testing of the propotype on a network of larger dimensions; ii) to interact to a lrger extent than done so far with our end user (CADF and ACOSEA) and illustrate them all the results of the Testing Phase. In the last weeks we have started to do so and our future plan (until and also after Swindon Conference) is to continue more deeply this kind of interrelation.

Regarding the key question on "how test results fit into the rehabilitation management of the respective end user", the rehabilitation strategy of CADF and ACOSEA is planned with a temporal horizon of 3-4 years; for this reason RSM can help them to have an overview of the strategies but it is difficult that our End-users will consider it for the management; on the other hand ARP (annual rehabilitation planning), thanks to the shorter time interval to which is referred, fits much better into their management choices.

7.1 Considerations from CADF and ACOSEA

On October the 31st, the Bologna Team had a meeting with Care-W Italian end-user CADF and ACOSEA, to illustrate them the Prototype functions and present the results of the testing performed by from Bologna University. In the following the main outcomes of that meeting are presented.

7.1.1 CADF

From the CADF point of view, the Prototype is a very good instrument; with specific regard to the use of Rehab. Strategy Manager, they said that it would be useful if, establishing a future average age of a network and given all the survival function for each material, the R.S.M. would be able to propose a strategy of Rehabilitation with relative lengths of material to substitute and costs.

7.1.2 ACOSEA

ACOSEA has indicated a need for the the Prototype to be able to import into the Database also data regarding the values of pressure of each node that, for example in Relnet, has a value of pressure lower that the Required pressure; the finality of importing those values is to visualize that nodes in GIS window.
Another suggestion is that it should be very useful if the Prototype should be connected in Real Time with other software which are used to update the network. In this way the user must only to run the Tools using the updated network; the same problem is when material and diameter of a part of a pipe change, how is possible to insert an additional node or a discontinuity point?

7.2 End-User considerations after Ferrara meeting on November the 12th

On November the 12th Bologna and Ferrara Universities have organized a national meeting to present to potential end-users, consultants, and other stakeholders the Care-W Prototype, its potentialities and all its Tools.
All the participants to the meeting, including representatives from several End-User, have provided a positive feedback and have given some good suggestions, listed in the following:

- Data availability is a crucial point since many agencies still record their break data on paper reports; therefore a painstakingly long and time consuming work is to be performed just in order to prepare the input data for all technical tools; many end-users doubt they will ever have the manpower to do this, thus seriously hampering the utility of the Prototype;
- an analysis involving the house connections is important because sometimes the leakage of water is larger than the leakage in distribution pipes;
- the presence of a tool for the management and the optimisation of leakage detection would enable a better analysis of the network;
- a complete example of a network with all the data to use to run all the tools of the Prototype it would be useful for commercialisation.
- Regarding more directly the use of the Prototype and of the Tools the following observations emerged:

- in Aquarel changing MTTR (from 8 to 800) for a pipe, the value of the HCI for that pipe does not change;
- a sensitivity analysis towards the values of some parameters would be useful in assessing the Prototype validity to tackle problems of specifc networks; examples of these parameters are in F-Reliab the function “importance of some nodes” (with a value comprised between 0 and 1), or in Aquarel the value of MTTR, as already noted in the previous point.

Report on testing carried out in Dresden and Stuttgart, Germany

CARE – W

Computer Aided REhabilitation of Water networks. Decision Support Tools for Sustainable Water Network Management

End user testing report

Ingo Kropp, Rolf Baur

TU Dresden

Dresden, January 2004

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1 CARE-W END USER TESTING

According to the end user testing matrix below, it was planned to test CARE-W ARP and LTP with the local end user Drewag, Dresden. The other end user Neckarwerke, Stuttgart, tried to test preferably all of the tools. The results of the testing period are included in this report in the following chapters.

Table 1: End user testing matrix

End user	**Care-W PI**	**Care-W FAIL**	**Care-W REL**
	Care-W Performance indicators	Care-W Failure forecasting	Care-W Water supply reliability
Bristol		*1*	
Brno	*1*		*2*
Codigoro		*1*	*1*
Dresden	***Done***		
Ferrara		*2*	*2*
Lausanne	*Ongoing*	*Done*	*1*
Lyon	*Done*	*Done*	
Oeiras/Amadora	*1*		
Oslo	*1*	*1*	*1*
Reggio Emilia	*1*		*1*
Roubaix Torcouing	*Ongoing*	*1*	
Stuttgart	***Done***	***2***	***2***
Trondheim	*Done*	*Done*	*Done*

End user	**Care-W ARP**	**Care-W LTP**
	Care-W Annual rehabilitation planning	Care-W Long-term rehabilitation planning
Bristol		
Brno	*2*	*1*
Codigoro		*2*
Dresden	***1***	***1***
Ferrara		*1*
Lausanne	*1*	
Lyon	*1*	*2*
Oeiras/Amadora	*2*	*1*
Oslo	*2*	*1*
Reggio Emilia	*2*	*2*
Roubaix Torcouing	*1*	
Stuttgart	***1***	***1***
Trondheim	*1*	*Done*

1: First priority
2: Second priority

2 DREWAG DRESDEN

2.1 Overview

As it was mentioned before, TUD has tested the CARE-W ARP and LTP tools for Drewag Dresden. The LTP package was applied to the whole network, whereas the ARP package was applied first to a very small zone and afterwards to the whole city centre. Unfortunately, the CARE-W ARP tool Electre Tri was not working with this dataset (problem solving is in progress). Thus, the tool SPARENET – a tool developed by TUD for the annual rehabilitation planning process – was applied to the sub network.

2.2 Testing LTP

Like for the majority of water supply networks in East-Germany and other formerly communist countries in Central and Eastern Europe, the network is relatively old and exhibits some typical characteristics: Cast iron pipes were laid until the late 1980s, considerable lengths of unprotected steel pipes are still installed, and especially after WWII manufactured of poor quality, and ductile iron pipes are used only since the early 1990s. Typically for East-Germany is the population-drain after reunification, which led to a reduction of approximately 15% of the service population between 1987 and 1997 for Dresden water supply and the decreasing water demand due to the decline of industry production. In recent years, the tendency is hold on, on the one hand due to population movements, on the other hand due to the extension of the supply area.
Information on the length distribution for different pipe types was available for the whole network, whereas information on the exact installation year was vague, at least for the years before 1960. However, based on utility internal knowledge and reasonable estimates according to the urban development of the supply area, existing pipe lengths before 1960 were equally distributed over five years construction periods, respectively over ten years periods for pipes installed before 1910 (fig.1). Previous studies' results showed that with an equal distribution of the pipe lengths over periods of five to ten years, the forecast results are affected only in a smoothening of the curves for future rehabilitation needs but not in the qualitative and quantitative result.
The definition of 13 pipe types was not only according to the ageing behaviour of particular groups of pipes, but also with respect to specific construction or material characteristics. Even if some of these pipe types have a small or negligible length compared to the complete network, and will not significantly affect the result for the total network rehabilitation rate and the overall future investment needs, they can give additional information to the forecast result with respect to the question where and at what pipe types considerable attention must be paid in the future rehabilitation activity.

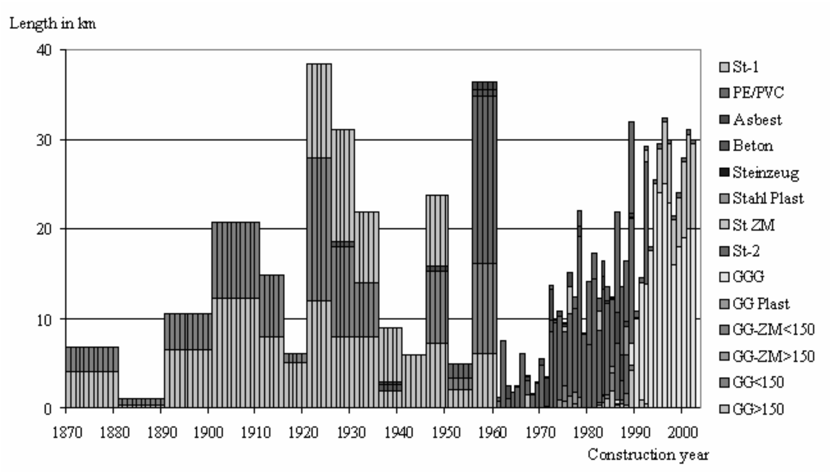

Figure 1: Lengths of pipe types by construction year

Future rehabilitation needs

For the distribution network of Dresden a previous study was carried out in 1995. Service life expectancies were estimated within large ranges. Due to the different rehabilitation policies before 1989, with a rather repair and fire brigade strategy, and the new, yet unknown strategy under different economic circumstances after 1990, the estimates were uncertain. The ageing functions were defined based on experts' estimates and oriented towards experiences from previous studies for other networks (mainly in the South-West of Germany with much better maintained assets), because no reliable information on failure statistics and rehabilitation activities in the past was available for Dresden at this time. Result of the study was a recommended network rehabilitation rate of about 1.7% of the network length, which was oriented towards the estimates for longer service lives. The actual rehabilitation rates were much lower, between 0.9 and 1.4% p.a.

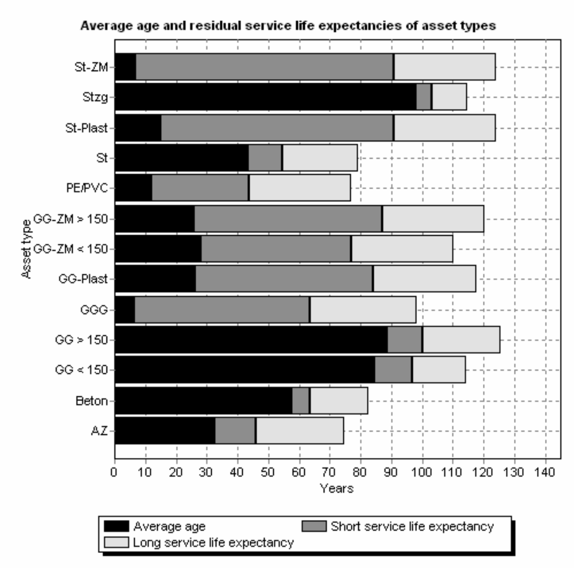

Figure 2: Average age and residual service life expectancies for asset types

Within the CARE-W testing, the rehab activities from 1995-2002 were subject of a strategy simulation. The ageing functions defined in the first study were inadequate for the description of the real network behaviour: In figure 2, the average age in 2003, and the mean residual service life expectancies for all pipe types are given for short and long service lives taken from the estimates of the first study. The fact that the average age of some pipe types in 2003 is already exceeding the expected mean age according to the short service life, showed that ageing functions found to be suitable for one network, can not be easily transferred to another water service.
So, with the experience of 8 years of rehabilitation activity since the last study, the life time expectancies for all pipe types were modified. Compared to the 1995 study, unprotected steel pipes laid before 1990 (St-old), which represent more than 30% of the inventory, were divided now into two groups according to their construction period, before 1950 and from 1950 to 1989, with modified ageing functions (fig.3). Life time expectancies have been reduced for the weaker steel pipes that are installed between 1950 and 1989 (St-2), and the expectancy values have been increased for the steel pipes installed between 1920 and 1950 (St-1).

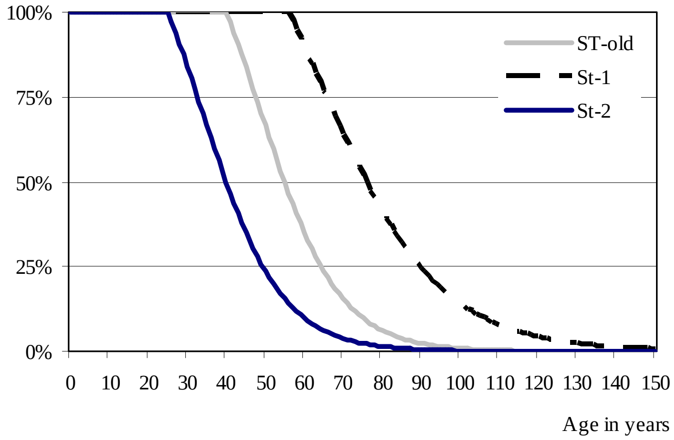

Figure 3: Modified ageing functions for steel pipes (long service life expectancy)

In figure 4, the forecast rehabilitation needs of the network for short, medium and long service-life expectations are drawn until the forecast horizon in 2040, for the stock of the Dresden water supply network in 1994, calculated with the modified ageing functions. Simultaneously, the actual rehabilitation rates between 1990 and 2002 are plotted.
After a period of increasing rehabilitation efforts between 1990 and 1996, an almost constant rehabilitation activity of about 1.2% of the network length can be observed, which is still below the forecast rehabilitation needs under optimistic, longer life time expectancies. There are two possible explanations for the discrepancy between rehabilitation needs calculated from the service life estimates for the pipe types and the actual rehabilitation length: life time expectancies are still systematically underestimated for the network, or obvious rehabilitation requirements are postponed to the future. The consideration of the consequences of such a rehabilitation policy is the objective of the exploration and comparison of rehabilitation strategies.

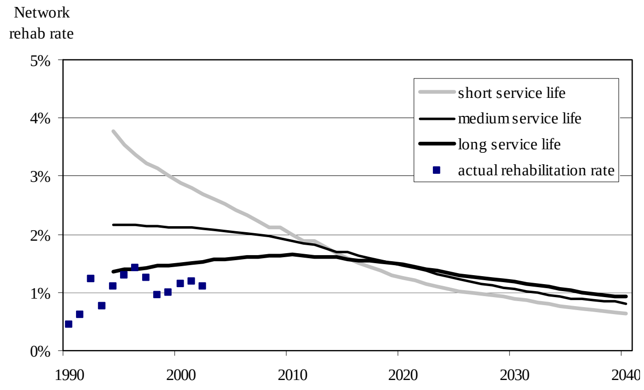

Figure 4: Forecast rehabilitation needs, and actual rehabilitation rates from 1990 to 2002

Strategy development and evaluation

An important goal in the exploration of a rehabilitation strategy is to get information on how selected key performance indicators (PI) will develop over time (5). The network failure rate is such a PI for the evaluation of a rehabilitation strategy. The Rehab strategy manager accounts for the efficiency of a specific rehabilitation programme with respect to reducing the network failure rate by an efficiency factor considering the failure rate of a pipe prior to rehabilitation in relation to the average network failure rate.
In Dresden, network failure statistics are available from 1990 on. Despite the low rehabilitation rate, numbers of failures in the network since 1990 decreased continuously until 2001. With the observed network failure rate and the annual rehabilitation lengths, an efficiency factor of 8 was calibrated by simulating the realised rehabilitation programme since 1995 with the Rehab strategy manager.

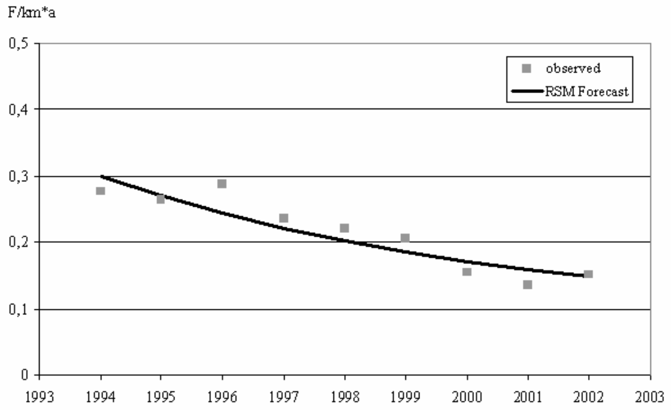

Figure 5: Observed and forecast network failure rates

During the first years after reunification in Dresden, rehabilitation projects were mainly chosen by the utility itself, but since the end of the 1990s, co-ordination projects together with road-works cover about 90% of the annual rehabilitation investments. In general, externally determined projects have a lower efficiency with respect to the failure rate, but are associated with lower investment costs. Reasons for increasing failure rates in 2002 and 2003 may be found in the consequences of the big floods in 2002, and the very dry summer in 2003, but also in the increasing number of externally determined rehabilitation projects.

According to the today's fixed annual investment budget for five years periods, a strategy was defined over two periods, i.e. the next ten years. The chosen rehabilitation length was 1.2% of the total network length, distributed over the most critical asset types within the next years, steel (St) and cast iron (GG) pipes. Rehabilitation lengths calculated from this strategy show that there are still needs postponed, even for the increased rehabilitation rate and the assumption of longer service lives (fig.2). Thus, an even higher rehabilitation rate of about 1.7% should be strived for. Especially the younger steel pipes (St-2) will probably cause problems in the near future, and should be subject of a special rehabilitation programme. This will be difficult to realise in a situation where the budget must be spent more and more on co-ordinated projects, which are determined by third parties. Consequently, a smaller rehabilitation efficiency factor was assumed in the strategy, thus avoiding less future failures. Nevertheless, the forecasting results give reasonable information at hand, to argue here for more self-determined projects.

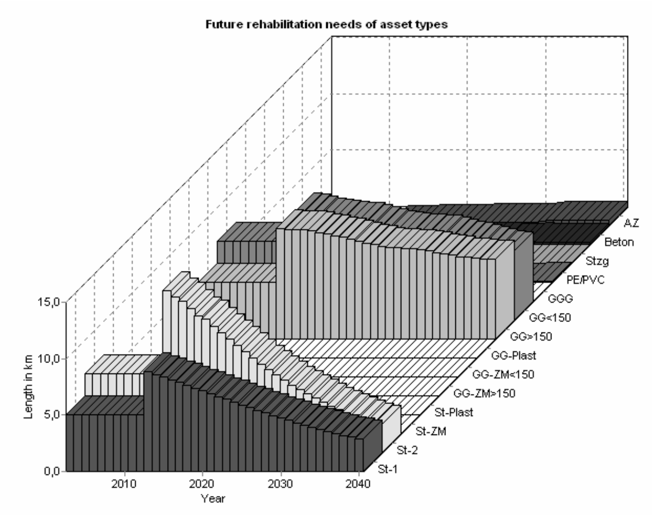

Figure 6: Forecast rehabilitation needs of pipe types

Failure rates and associated leakage are not only technical indicators of the network performance, but have also economic consequences. The replacement of an old pipe by a new one avoids failures and leakages not only in the rehabilitation year but in future years as well. These are the financial benefits of a rehabilitation programme. In figure 7, the balance of investment costs and benefits for the above mentioned strategy shows the break-even for the year 2023, when the benefits are higher than the investment costs.

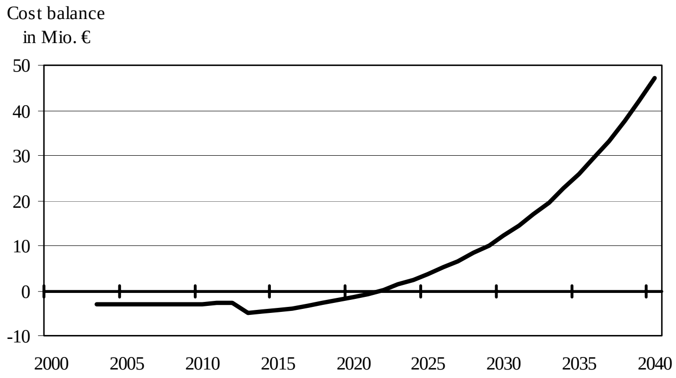

Figure 7: Cost balance (long service life expectancies)

The investment costs have a significant influence on the economic result of a strategy. The internal rate of return of the chosen strategy is calculated between 4.8% for long service life expectancies and 5.6% for short service life expectancies (Figure 8).

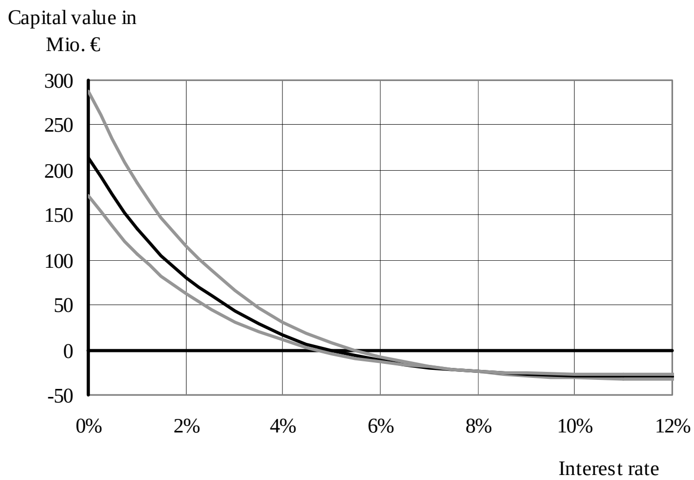

Figure 8: Internal rate of return (for long, medium and short service life expectancies)

Here, an increasing rehabilitation rate would be less efficient in economic terms. With respect to the decreasing tendency of failures in the network, keeping the present level of rehabilitation seems to be an appropriate strategy for the Dresden network. The fixed level of the present rehabilitation budget will concentrate the utility's efforts in the near future in exploring a strategy for selecting the most efficient rehabilitation projects within the framework of the given budget. Tools are developed, which support this decision: an ELECTRE method within the annual rehabilitation planner (ARP) of CARE-W, and an interactive elimination procedure.

2.3 Testing ARP

For the application of the ARP tool, Drewag provided network data of the zone "Trachau" in the first run. The sub-zone "Trachau" is located in the north of Dresden with an entire of 11 km (including service connections). The water supply network of Drewag has a total length of more than 2000 km. Data for "Trachau" was provided graphically in dxf-Format and the according MS Excel-sheet with information on 'street', 'pipy type', 'material', 'diameter', 'laying year' and 'pipe length'. Due to missing data and the small size of the zone it was decided to prepare a larger zone for the application of the ARP tool.

This second sub-zone was the whole city centre – the so-called "26^{th} ring", the number of a tram line in Dresden. The kind of data available for this part of the network was the same as for the sub-zone "Trachau".

The "26^{th} ring" consists of 7872 pipe sections (ca. 92.2km) with the main materials cast iron, steel, ductile iron, PE and PVC (fig.9). Diameters range from DN32 up to DN1500.

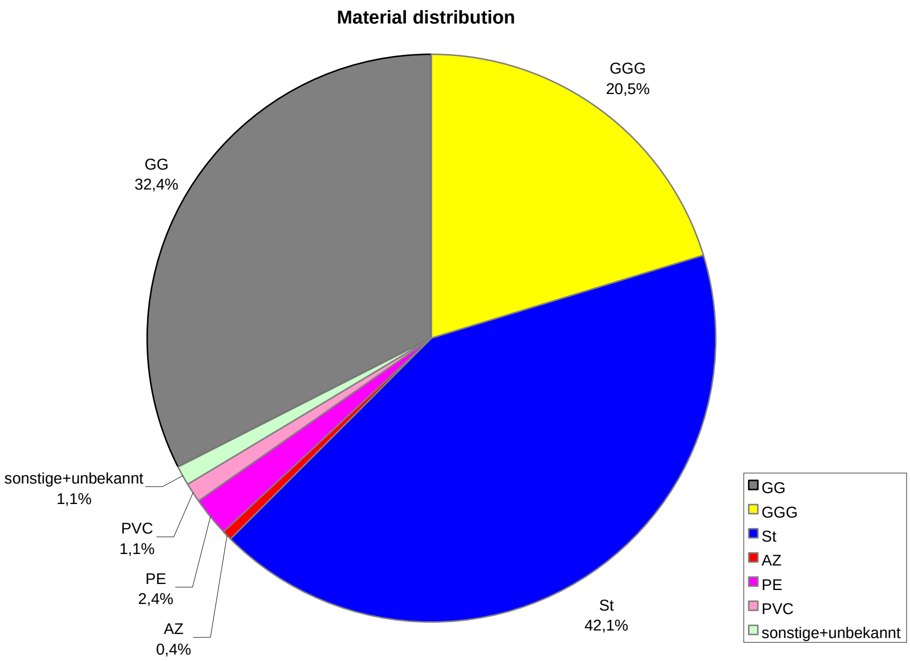

Figure 9: Material distribution of the "26th ring"

In addition, we assigned street categories (federal, main and other streets) and the location of the tram lines to each section (fig.10).

Figure 10: location of tram lines

Between 1994 and 2003 78 failures have been registered in the “26th ring”. About 60% of the failures have been occurred on cast iron pipes and 35% on steel pipes. The percentage of failed pipes is about 0.3% of the whole “26th ring”. A plot of the failures can be seen in figure 12. Figure 11 shows the development of failures (yellow bar) and failure rate (blue line) compared to the network failure rate (green line) during this period. The reason why the failure rate in the “26th ring” is only half of the network failure rate is due to the fact that during the last 10 years this area has been prioritized regarding rehabilitation activities. This can be confirmed by the average annual rehabilitation rate of 2.2% per year during this decade.

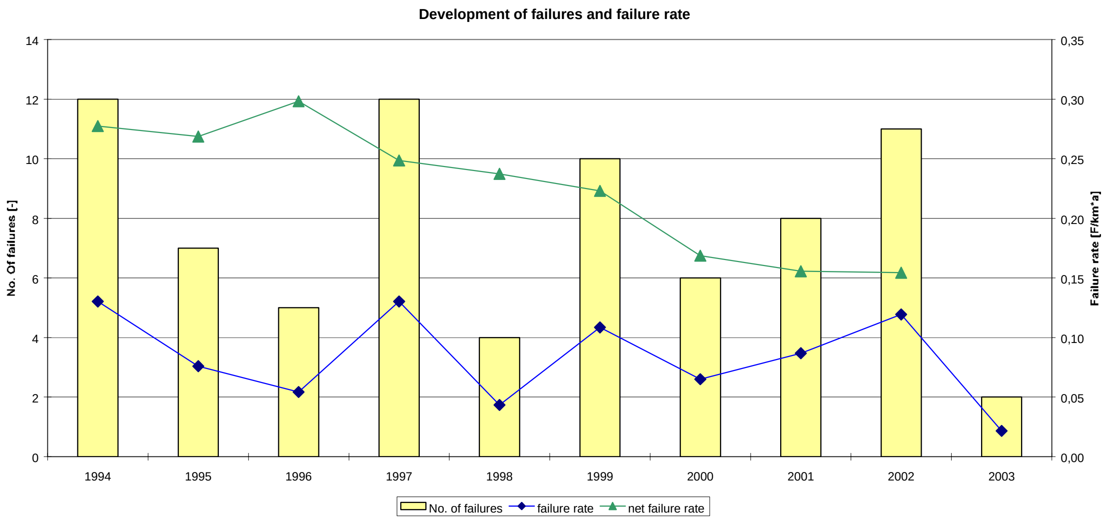

Figure 11: Development of failures and failure rate

Figure 12: Distribution of failures

With this information on the network the data was imported into the application SPARENET to set up an annual rehabilitation plan. The proposed annual rehabilitation rate was fixed to 0.9% per year which is the average rate in the network today. Unit costs of 150€/m for rehabilitation activities were assumed. Figure 13 shows a screenshot of the tool.

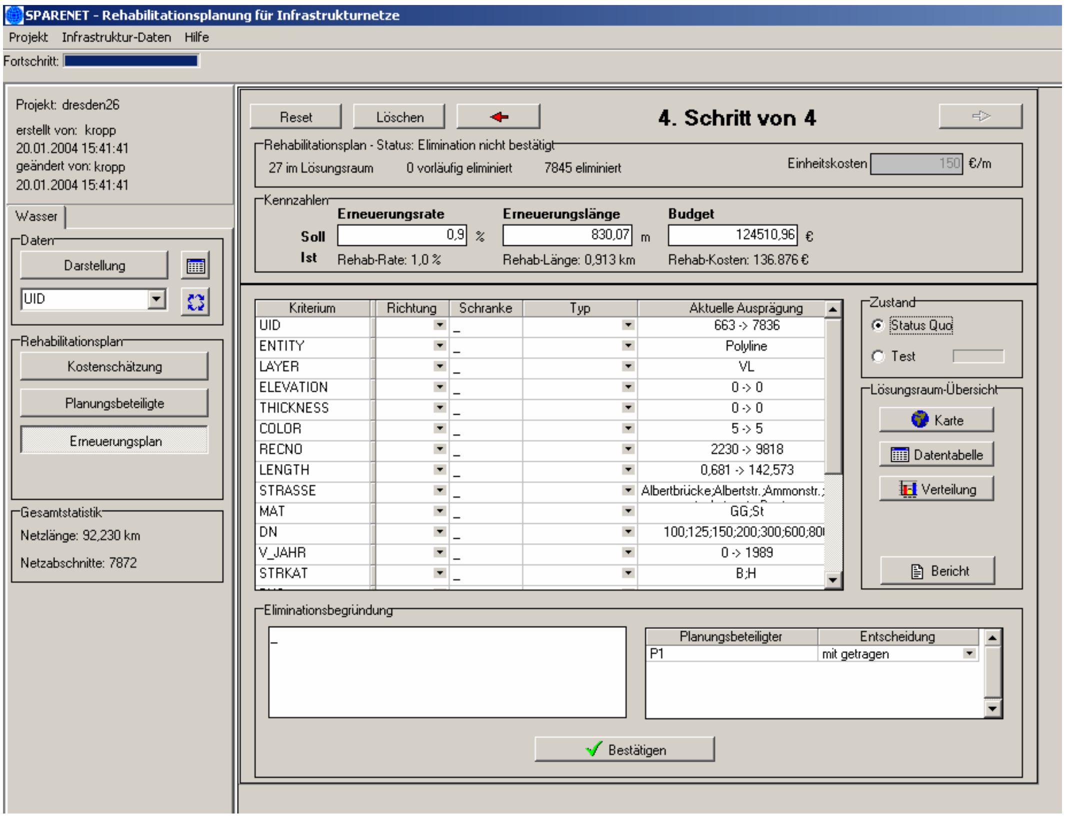

Figure 13: Screenshot of the ARP tool SPARENET

According to the underlying interactive elimination method, three elimination steps in total have been carried out. In the first step all pipe sections were eliminated which have had no failures until today. In the second step all new pipes, laid after 1990, have been eliminated. These are mainly ductile iron and PE pipes. Ductile iron was not available before. The last step was the elimination of all pipes in less important streets due to the fact that a burst in an federal streets or a commercial street causes more overall damage.
Figure 14 shows the final plot of the selected pipes for the annual rehabilitation plan. It consists of 30 pipe sections with a length of about 1km and according 150,000€ of rehabilitation costs.

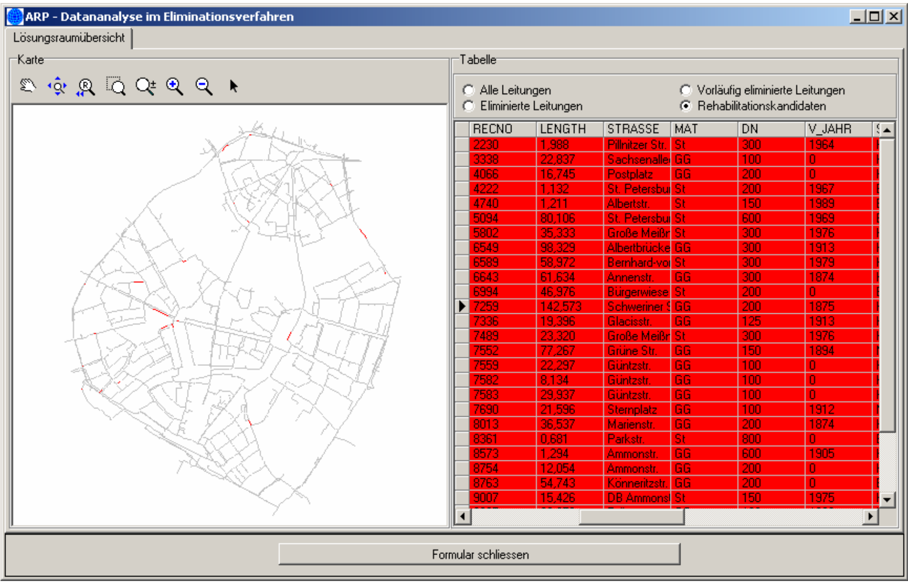

Figure 14: Final plot of the ARP

The final comment for the application of the ARP tool on the “26th ring” is that in comparison to the total network and its condition, the “26th ring” is of minor importance for rehabilitation plans in the near future, if only hard facts such as bursts and leakage are considered. Once socio-economic issues – here: importance for tourists and commercial activities - are addressed, the results will look different. Thus, rehabilitation activities will be carried out in the “26th ring” despite the missing hard facts.

3 NECKARWERKE STUTTGART

3.1 Overview

The plan of Neckarwerke Stuttgart was to test all CARE-W tools by themselves.
The first step should have been the evaluation of each tool regarding data availability and benefit for Neckarwerke Stuttgart. For each tool a short rating should be given.
In the second step it was planned to apply all tools where Neckarwerke Stuttgart can see a profit for their operations.
Due to a companywide restructuring process the application of the tools can't be done. Thus, Neckarwerke Stuttgart has only given a statement on their point of view for the CARE-W tools.

3.2 Statement of Neckarwerke Stuttgart

Evaluation of the CARE-W software package from the EnBW-Regional-AG (Neckarwerke Stuttgart) point of view

<u>PI-Tool</u>
The performance indicators, derived from the information interrogated by the PI tool are appropriate to provide a sound overview of the condition of a water network.
The particular benefit of the tool is the listing of indicators which will be used by us partly as stimulation for the establishment of extended PI indicator systems and criteria catalogues. The use of the software is of less importance since the calculation steps for the determination of PI can be easily done without computational support respectively within commonly used spreadsheet applications.

<u>Failure forecast and hydraulic reliability models</u>

The underlying assumptions of the developed models for the prioritisation of rehabilitation measures pick up the existing problems of network operation. Failure forecasting combined with hydraulic measures in the supply network is appropriate to derive potential consequences of pipe failures
However, the software won't be used by us since our hydraulic network modelling is carried out already by a software which was developed internally. The CARE-W tools would require a re-mapping of the network and the pressure ratios. The individual observation of failure consequences will be continued on the basis of general network plans.

<u>ARP-Module</u>

Generating a list of urgent rehab projects by using network data and various decision criteria has been implemented in an appropriate way by the ARP-Module. The subject of short term rehabilitation planning to prioritize projects, respectively pipe sections, is complex. In the ARP-Module, the necessary decision steps are undertaken by the software and calibrated with network information. The results can facilitate the work of the planner as well as keeping the decision process on a systematic basis. However, the experience and the knowledge of the planning engineers can't be replaced since there must be always considered local particularities adjacent to the common evaluation criteria.

Prerequisites for a successful application of the program are extensive network data for all essential influence factors based on pipe sections. Here, the information needs are high with respect to the available data basis. For example, at EnBW Regional AG data of pressure ratios cannot be assigned to pipe sections in an appropriate way. Thus, the program won't be applied in short term. In the medium-term a combination of all available network data on a common data basis is advantageous. After this has been realized, the potential benefit of the ARP-Module appears to be very high.

Scenario Writer

The scenario writer is a useful tool for the definition and verification of long term strategic business objectives by forecasting future developments and their effects. The chosen method of a "soft" prognosis of developments within defined upper and lower boundaries enables the assessment of uncertainties in long term planning. Hence, the results are appropriate for discussion of further procedures from the user's perception. Positive aspects of the scenario writer are the clear design and usability. Indeed, the application needs an extensive preparatory work for the definition of key factors. The application won't be used right now at ENBW, due to the prevailing circumstances resulting from the reorganization of the company structure at the moment.

If the software is going to be further developed, it would be beneficial to include other utility sectors (gas, electricity). Especially for those utilities that operate not only water supply networks it is of great importance in the long term strategic planning to explore future scenarios for more than one utility sector as many key factors (e.g. population development) affect more than one sector.

The notes apply correspondingly the rehab Strategy Evaluator.

Rehab Strategy Manager

The software couldn't be tested by us yet. Thus, the following comments result from the available description as well as our experiences with the application of the former KANEW software.

The implemented KANEW model is still proving for the medium and long term forecast of future rehabilitation needs. The extensions of the Rehab Strategy Manager through updating stock with respect to defined rehabilitation measures and the option for dynamic investment calculation are of great interest for us. The differentiation of renovation and replacement methods according to their rehab efficiency is reasonable.

For the practical use and acceptance of the software it is of great importance

- that the methodology, underlying assumptions and data are comprehensible
- and that import interfaces for common data formats are available.

Both requirements are fulfilled by the Rehab Strategy Manager. This software is the most important part of the package from our point of view.

General comments on the used software

The software developed within the CARE-W project and the included know-how extends and improves the present options for the rehabilitation planning of water networks. We would like to point out the clear tool application and the possibility to influence planning preferences by weighting and evaluating individual factors in spite of the complex approaches of some tools.

Report on testing carried out in Lyon, France

CARE – W

Computer Aided REhabilitation of Water networks. Decision Support Tools for Sustainable Water Network Management

WP6 –CARE-W Prototype Testing

Case study: Greater Lyon

Lyon, January 2004

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Table of contents

1 INTRODUCTION

CARE-W project aims at developing methods and software that will enable engineers of the water undertakings to establish and maintain an effective management of their water supply networks, rehabilitating the right pipelines at the right time. The results shall be disseminated as a manual on Best Management Practice (BMP) for water network rehabilitation.

This project is organised in the following Working Packages (WP):

• WP1: Construction of a control panel of performance indicators for rehabilitation;

• WP2: Description and validation of technical tools;

• WP3: Elaboration of a decision support system for annual rehabilitation programmes;

• WP4: Elaboration of long-term strategic planning and investment;

• WP5: Elaboration of CARE-W prototype;

• WP6: Testing and validation of CARE-W prototype;

• WP7: Dissemination;

• WP8: Project management.

This report presents the results obtained on Lyon within the framework of the WP6.

2 DESCRIPTION OF TEST ZONE

2.1 Lyon water supply network

The CARE-W Prototype and tools have been tested on a part of the Greater Lyon water supply network , which is owned by the Greater Lyon and operated by the *Compagnie Générale des Eaux* (CGE) – one of the official end-users of the CARE-W project. The Greater Lyon and CGE have signed a contract that gives the operator responsibility not only for the operation of the network, but also for investment planning and asset management.

Basic information on the water distribution network:

Length of water mains:	3000 km
Water production:	300 000 m^3/day
Population supplied:	1 100 000

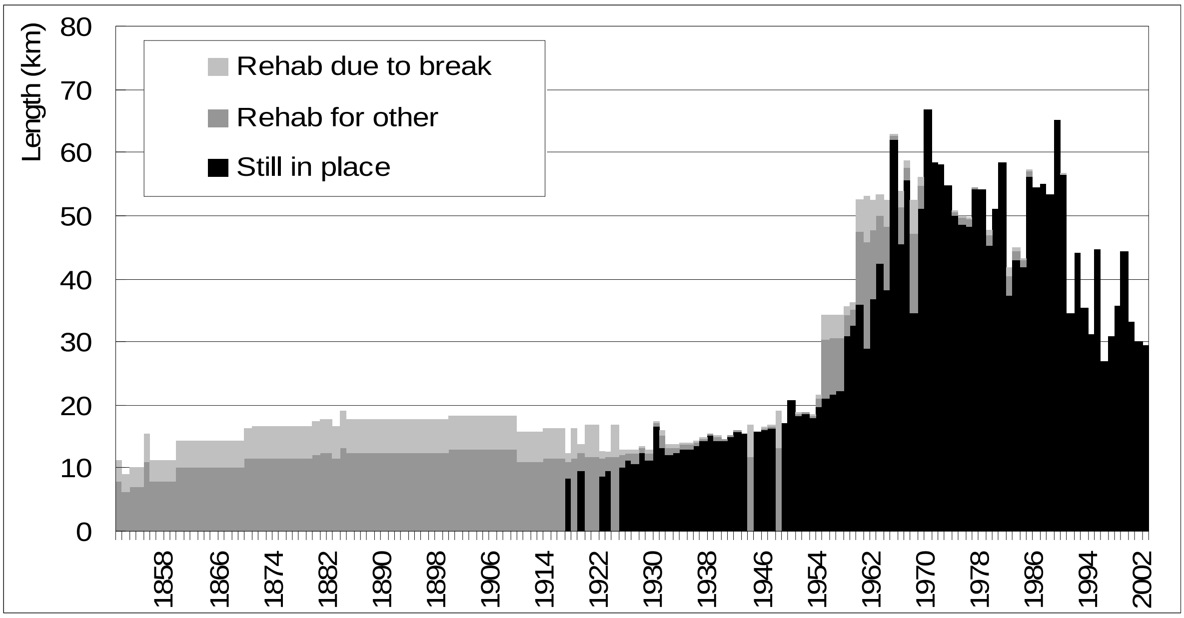
The elevation of the Lyon water supply network is from 160 to 600 meters above sea level. As a consequence the network has been divided into many pressure zones. There are 3 basic pressure zones with smaller additional ones; the total number of pressure zones in the network is 23. As shown in Table 1, the Lyon water supply network consists mainly of grey cast iron pipes (52 %). There are 37 % of ductile iron and 11 % of other material pipes.

Table 1. Pipe material distribution in the Lyon water distribution network

MATERIAL	Length (km)	%
GCI	1563.85	52.2
DI	1105.58	36.9
Steel	34.12	1.1
Bonna	119.22	4.0
PE - PVC	15.45	0.5
Unknow	158.17	5.3
TOTAL	**2996.38**	**100.00**

Regarding the age of pipes, the oldest registered pipes (still in operation) were laid in 1900. Distribution of pipe by installation year is presented in Figure 1.

Figure 1. Length of pipes being laid and rehabilitate per year



2.2 Data availability at CGE

CGE uses for network operating, data processing and other agenda a GIS application, where data of greater part of the water distribution network is held. The utility has full digitalized of its network in recent years, but databases are not complete yet. Information on water mains and failures is also stored in two separate databases; their structure is unfortunately completely different from the structure of the CARE-W central database.

One of the databases stores complete data on water mains (i.e. pipe section ID, pipe length, type of material, name of street, date of installation, etc.). However, in case of water main replacement the row containing data on the existing pipe section is rewritten and actualised with information on the new one (new pipe material and new year of installation).

The other database comprises data on failures (pipe section ID, type of failure, date) since 1993. Before that year failure data were registered on papers only, which is not applicable. These two databases are interconnected but their is not a link between the SIG database and the hydraulic database. So hydraulics tools (RelNet, Aquarel, …) are not used in this case study.

3 CARE-W TOOLS TESTING

CGE has tested the PI Tool (Work Package 1), PHM and Poisson tools (Work Package 2) and ARP tool (Work Package 3), as shown in Table 2. Some of the tools were tested on the whole Lyon water distribution network, the others on one selected zone of the network - See Figure 2.

The main goal of testing was to evaluate data availability and its structure in order to recognize end-user's priorities and points of view and to develop a standardized methodology for creating of rehabilitation plans in frame of CARE-W using entities as a basic rehabilitation unit.

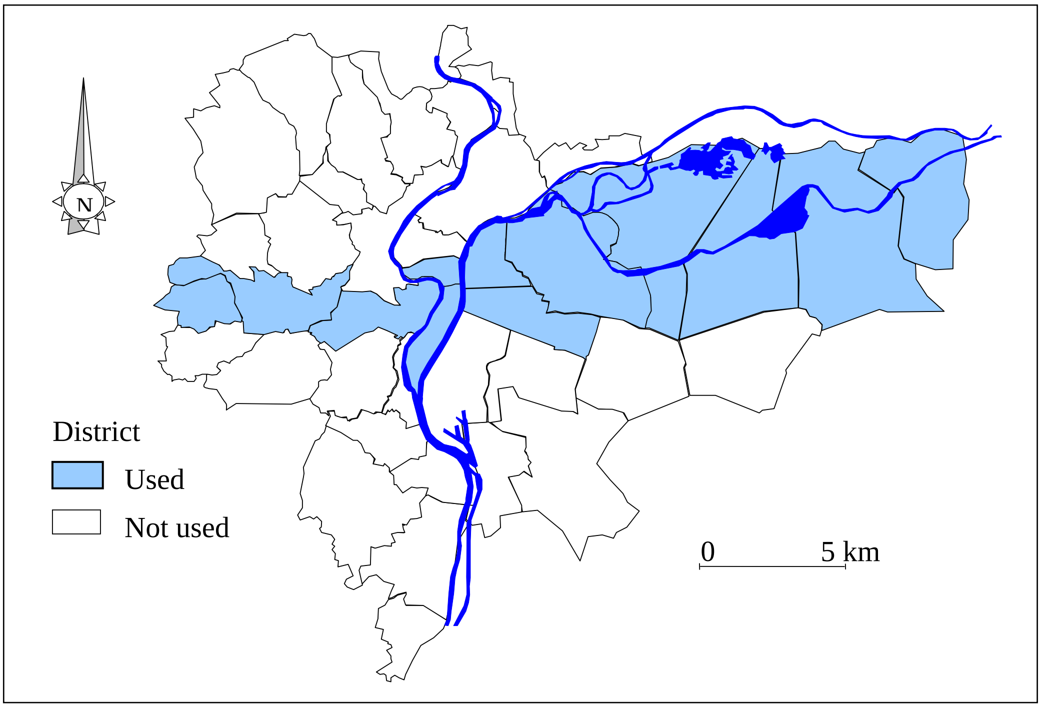
On the testing period all the CARE-W software have been installed on one end-user's computer.

Table 2. CARE-W tools tested.

	CARE-W PI	**CARE-W PHM**	**CARE-W Poisson**	**CARE-W ARP**
CARE-W TOOL	PI Tool	PHM	Poisson	ARP
Priority *	2	2	1	1
Stand-alone	X	X	X	X
Within the Prototype	X	X	X	
Sample		X	X	X
Whole network	X		X	

** 1: First priority 2: Second priority*

Figure 2. Network sample of CGE used for testing



Characteristics of this sample are showing in the Table 3.

Table 3. Basic characteristics of network data used for testing

Characteristics	Whole Network	Sample
Length (km)	3000	1100
Number of pipe segment	47000	19000
Population (inhab.)	1 100 000	470 000
Area (km²)	350	120
Diameter (mm)	30-1800	30-1800
Failures observation time	1993-2003	1993-2003
Number of failures*	1683	517

**No. Failures since 1993 on pipes, no accidental failures.*

3.1 CARE-W_PI (LNEC)

In the CARE-W water supply network rehabilitation procedure, a system of PIs has been developed specifically for pipe network rehabilitation. A control panel of performance indicators for water network rehabilitation - is an information system for the calculation, storage, update, retrieval and analysis of performance indicators and their associated information.

The system also provides complete information on all their features, properties and relationships.This system is inspired on the International Water Association (IWA) PI system for water supply services (Alegre et al., 1999) and is described in full detail in Care-W Report 1.2 (Baptista & Alegre, 2002). The objective of the PI Tool testing in the scope of the CARE-W project was not only to test the functionality of the software itself but also to assess as many performance indicators (PIs) as possible to monitor data availability and their recording at the Lyon end-user.

Data for testing of the PI Tool software have been collected for 2001, for the whole distribution network of Lyon, 112 UIs and 26 PIs were assessed (see Tables 4 and 5).

Table 4. Number of collected utility information (UI)

Utility information	Total number of UIs	Number of UIs collected
Physical	67	57
Water volume	11	10
Operational	37	27
Quality of service	10	4
Financial	19	12
Total	**144**	**112**

Table 5. Number of assessed performance indicators (PI)

Performance indicators	Total number of PIs	Number of PIs calculated
Water Resources	2	1
Physical	2	2
Operational	18	14
Quality of service	20	4
Financial	7	5
Total	**49**	**26**

3.1.1. Physical assets data

From the total possible 67 physical UIs, 47 were collected without any problems. Ten were estimated and 10 could not be assessed because the utility does not record these data at all.

3.1.2. Water volume data

Ten on 11 water volume UIs were assessed without issue. See the Table 6 for the values of water volume UIs for the year 2001.

Table 6. Water volume data

UI code	UI name	Year 2002	Unit
A1	Annual abstraction capacity	200000000	m^3/year
A2	Imported water allowance	0	m^3/year
A4	Water abstracted	102922180	m^3/year
A5	Imported raw water	0	m^3/year
A6	Exported raw water	0	m^3/year
A7	Water produced	102922180	m^3/year
A8	Imported treated water	0	m^3/year
A9	Exported treated water	9355120	m^3/year
A19	Authorized consumption	88891015	m^3/year
A20	Water losses	12178069	m^3/year
A24	Real losses		m^3/year

3.1.3. Operational data

The total number of the operational UIs is 37, 20 of which were collected without any problems. A further one was estimated, and 10 of them were not assessed because they are not recorded at all.

3.1.4. Quality of service data

Only 4 of the 10 quality of service UIs were collected, this is due to the local context. Few quality complaints were collected in Lyon, this is not a priority and there is no electronic distinction between the different complaints.

3.1.5. Financial data

The financial data is the group that presented the most difficulties in collection. This is due to the operator does not have the central recording of all investments and it is difficult for him to collect this type of data. As a result, if the total number of 19 financial UIs, only 12 of them were collected.

3.1.6. PI Tool testing results

We have tested the PI Tool successfully both within the CARE-W Prototype and as a stand-alone tool. This tool presents the advantage to stock and manage data with facility. This tool is used for long term planning in following PI evolution and for the benchmarking.

3.2 FAILURE FORECAST MODELS ANALYSIS (CARE-W FAIL TOOLS)

All the models are presented in a detailed way in the D3 Report (Eisenbeis et al, 2002). The paragraphs below give a synthesis of objectives, methods, input and output of each model testing with Lyon data. These models aim to provide methods to assess Failure risks. Their objectives are multiple:

- defining influences of pipe related and environmental variables: significance of the variables is tested and their weight is computed,
- defining failure risk functions: based on previous outputs and on chosen model (Weibull, Poisson), Failure risk functions are built pipe by pipe, category by category,

3.2.1. CARE-W_Poisson (INSA-Lyon)

CARE-W_Poisson computes mean failure rate by pipe group, where groups are established according to pipe characteristics, such as diameter and material, or the environment, such as soil type and traffic loading. The influence of these factors can also be studied by a statistical analysis based on Poisson law. If a pipe that has been repaired has an individual failure rate higher than that of its group, it retains its individual failure rate in the results rather than that of the group.

3.2.2. CARE-W_PHM (Proportional Hazard Model) (Cemagref-Bordeaux)

The main objective of PHM model is to portray approximately the distribution of the random variable consisting in the number of predicted failures. A given section of drinking water network is likely to be subjected to in a given time horizon.

The main output of the model is the predicted failure rate (PFR, number of future failures per km per year) of each section of the network. This value can finally be also aggregated at the level of a category of pipes (e.g. of same material and diameter), or a sub network, or the whole network.

CARE-W_PHM uses data from previous failures to develop failure forecast models, based on specific methods used in epidemiology called survival analysis. These methods analyse the time between two failures and assess the influence of different risk factors specific to the pipe or to its environment. They lead to the production of failure models, based on the Weibull model and described by the survival and hazard functions. After defining significant variables, predicted failure numbers and rates at 5 or 10-year horizons may be computed for each pipe.

3.2.3. Data used for testing

Care-W Fail Tools use two data files, the structure data file ("sdf" files) for the description of the pipes and the maintenance data file ("mdf" files) about the description of their failures. The format and the structure of theses files is defined in the Care-W project.

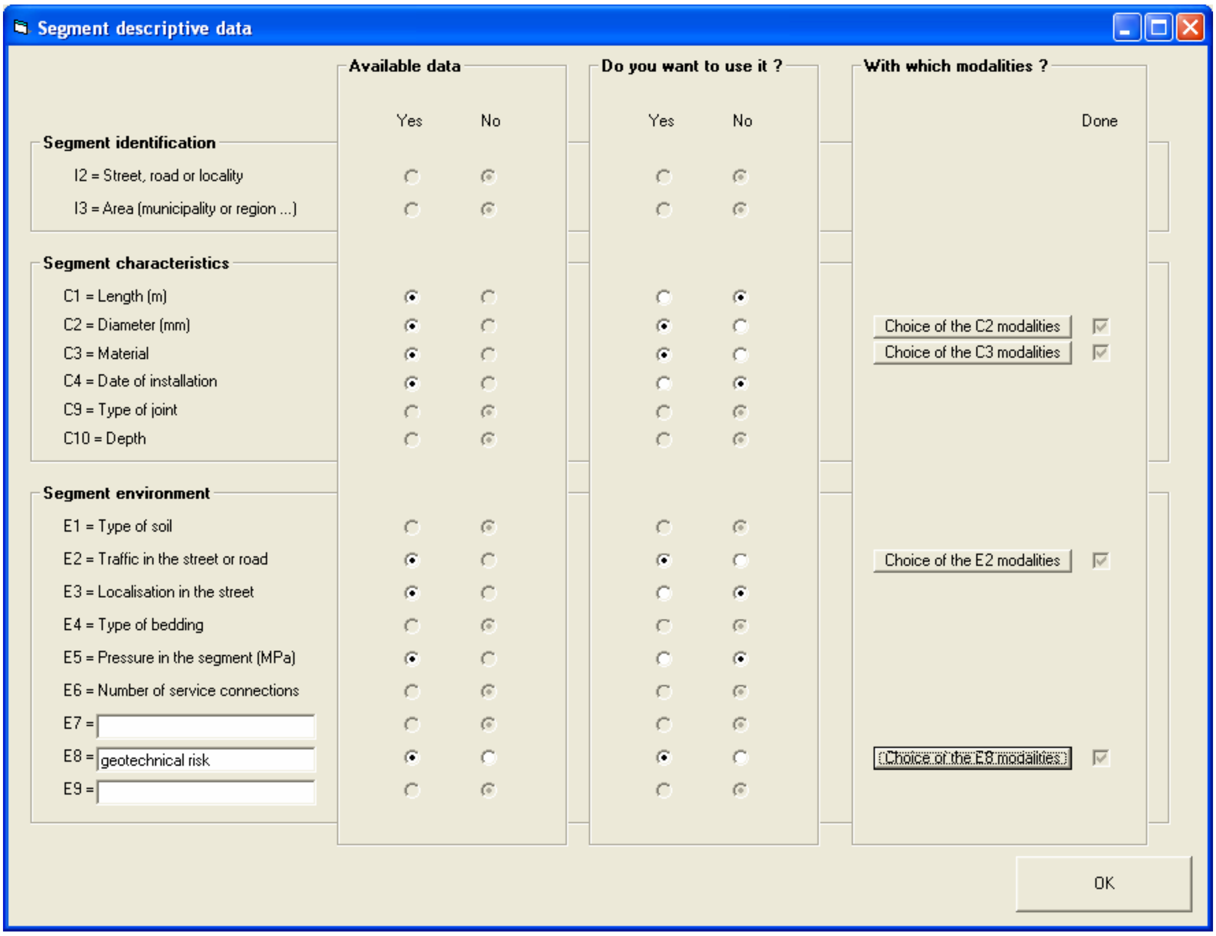
The Table 7 presents the sdf file used for case study of Lyon. Gaps are not allowed in this file so its construction requires to define rules and hypotheses for each missing data. Some data were not taking account to define pipes categories due to uncertainties (e.g. localisation in the street) (Figure 3). Others data were not collected according to the local priorities or local condition (e.g. depth). On the other hand, some data were added according to their local stakes like the geotechnical risk.

Table 7. sdf file used for case study of Lyon

I1	I2	I3	C1	C2	C3	C4	E2	E3	E5	E6	E8
Pipe ID	street	area	length	diameter	material	year laid	traffic in street	Pave-ment	average working pressure	nb of service connections	Geotech. Risk

Some data were not taking account to define pipes categories due to uncertainties (e.g. localisation in the street) (Figure 3). Others data were not collected according to the local priorities or local condition (e.g. depth). On the other hand, some data were added according to their local stakes like the geotechnical risk (landslide).

Figure 3. pipes categories with Care-W_Poisson

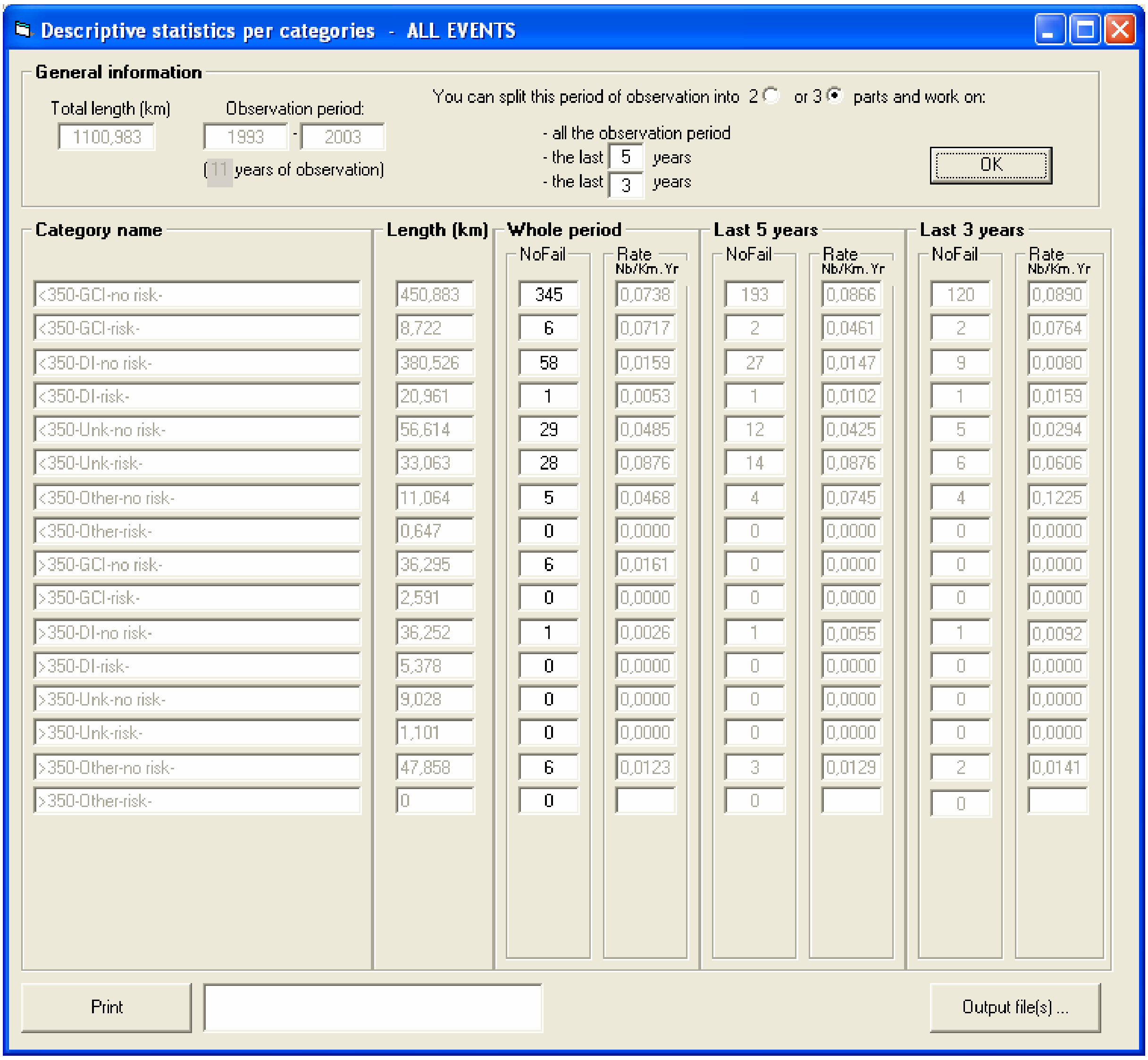


3.2.4. CARE-W_FAIL TOOLS testing results

Figure 4 presents the result of CARE-W_Poisson for the sample zone with all failure data (11 years) and with three parameters (diameter – material – geotechnical risk). The failure rate could vary according to the period of observation used (here: whole period, last 5 years and last 3 years).

We notice that it is not necessary to multiply the number of categories. The risk is to have many categories with few length and no failures observed. We must define the pipes categories according to existing data's.

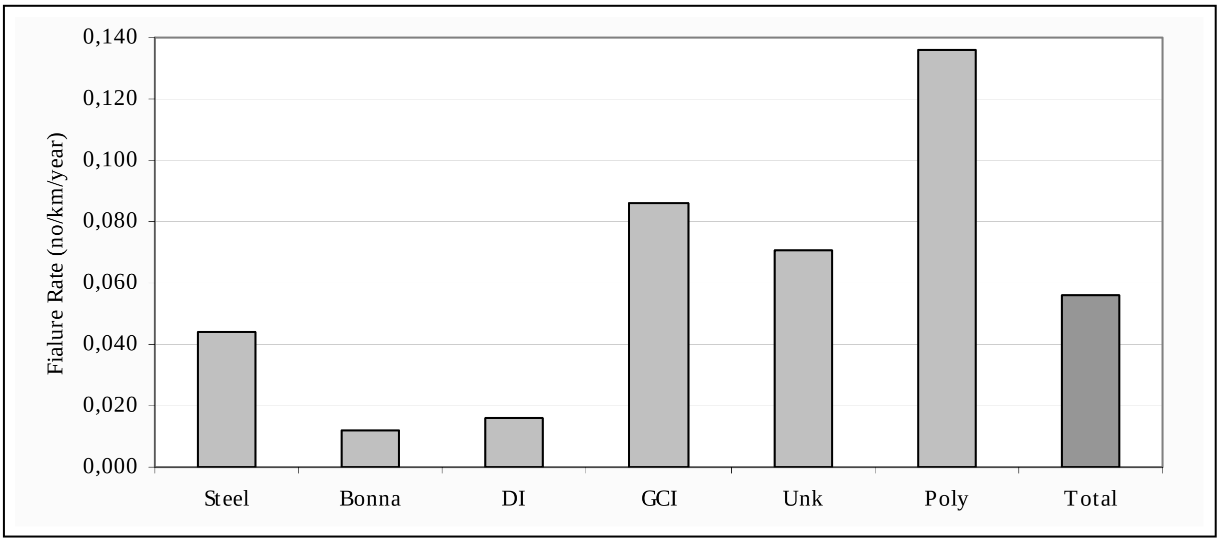
Figure 4. Failure rate by pipes categories calculated with CARE-W Poisson



Category name	Length (km)	Whole period NoFail	Whole period Rate Nb/Km.Yr	Last 5 years NoFail	Last 5 years Rate Nb/Km.Yr	Last 3 years NoFail	Last 3 years Rate Nb/Km.Yr
<350-GCI-no risk-	450,883	345	0,0738	193	0,0866	120	0,0890
<350-GCI-risk-	8,722	6	0,0717	2	0,0461	2	0,0764
<350-DI-no risk-	380,526	58	0,0159	27	0,0147	9	0,0080
<350-DI-risk-	20,961	1	0,0053	1	0,0102	1	0,0159
<350-Unk-no risk-	56,614	29	0,0485	12	0,0425	5	0,0294
<350-Unk-risk-	33,063	28	0,0876	14	0,0876	6	0,0606
<350-Other-no risk-	11,064	5	0,0468	4	0,0745	4	0,1225
<350-Other-risk-	0,647	0	0,0000	0	0,0000	0	0,0000
>350-GCI-no risk-	36,295	6	0,0161	0	0,0000	0	0,0000
>350-GCI-risk-	2,591	0	0,0000	0	0,0000	0	0,0000
>350-DI-no risk-	36,252	1	0,0026	1	0,0055	1	0,0092
>350-DI-risk-	5,378	0	0,0000	0	0,0000	0	0,0000
>350-Unk-no risk-	9,028	0	0,0000	0	0,0000	0	0,0000
>350-Unk-risk-	1,101	0	0,0000	0	0,0000	0	0,0000
>350-Other-no risk-	47,858	6	0,0123	3	0,0129	2	0,0141
>350-Other-risk-	0	0		0		0	

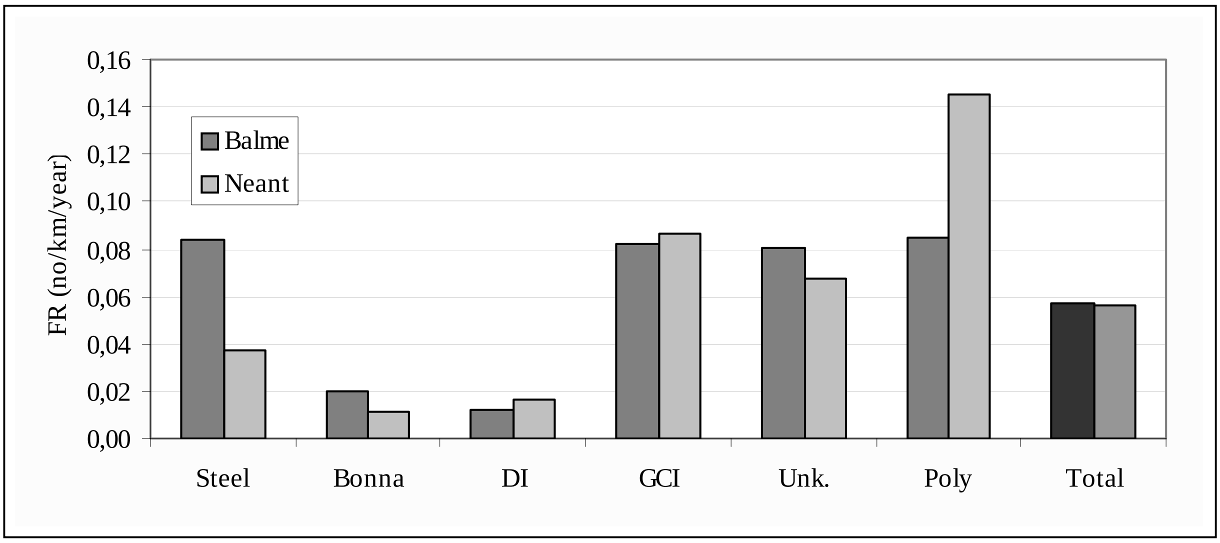
The Figure 5 illustrates the failure rate per material. The Grey Cast Iron (GCI) category present a high failure rate compared with Ductile Iron category (DI). If "Poly" pipes (polyvinyl chloride plastic and high-density polyethylene pipes) have a very high failure rate is due to their environmental conditions, they are laid in the places with high environmental risks. With this figure, the unknown material could be supposed like a similar category with the GCI one.

Figure 5. Failure rate by material



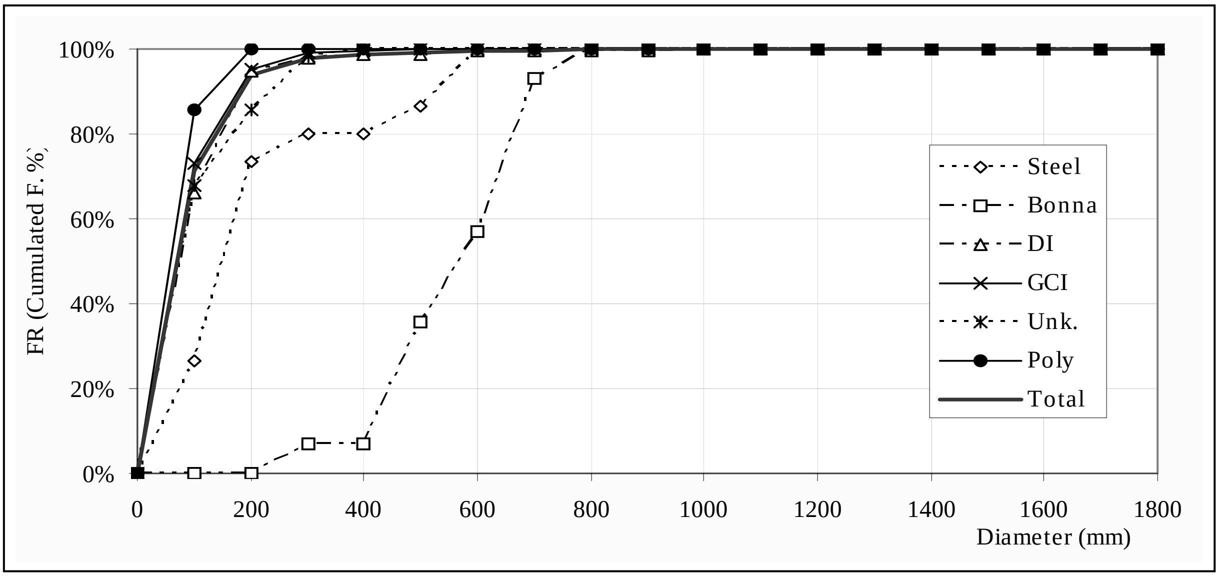
The Figure 6 illustrates the failure rate per material and per geotechnical risk. We see that the failure rate in geotechnical risk zones ("Balme") is relatively controlled. It is not higher (Total) in spite of more important requests. This is due to the marked attention of the manager in these significant zones.

Figure 6. Failure rate by material and geotechnical risk



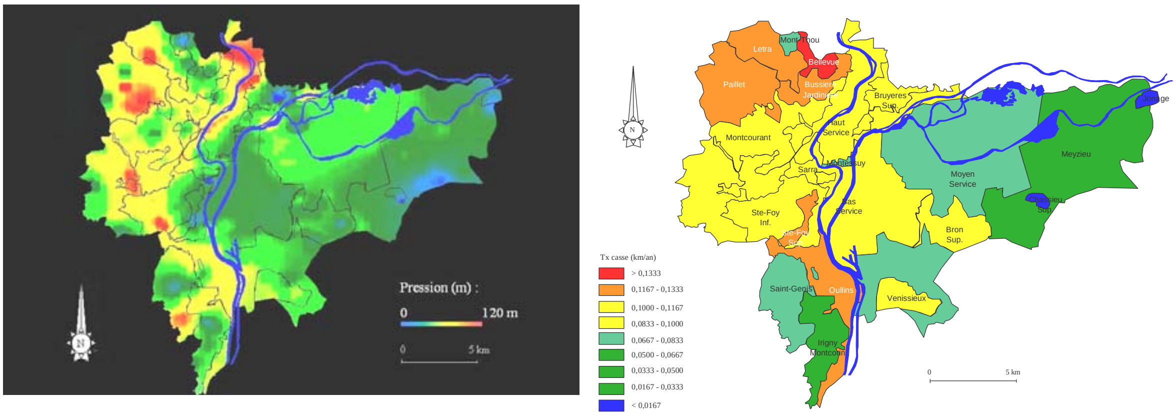
The Figure 7 presents the cumulative frequency of the number of the failures following the class diameter and the material of the pipes. 99 % of failures occur on the diameters lower (or equal) than 350 mm.

Figure 7. Cumulative Frequency of Failures according to the diameter of the pipes



The figure below (see Figure 8) shows a correlation between pressure zone and failure rate. But if it is possible to show a correlation at this scale, we have some difficulties to collect pressure data at the scale of the pipe.

Figure 8. Pressure zones (left) and failure rate by pressure zone (right)



3.3 CARE-W_ARP (INSA-Lyon)

CARE-W_ARP, the annual rehabilitation programme module of the CARE-W suite of software, is dedicated to the definition of rehabilitation priorities. Each pipe is represented by a multi-criterion profile. Criteria are calculated using information from various sources: CARE-W modules, user databases, and local knowledge. With the ELECTRE TRI decision support procedure each multi-criterion profile is compared to two reference profiles and pipes are ranked by virtue of their position in one of six possible categories.

3.3.1. Data used for testing

ARP has been tested on the sample zone. The number of elements was reduced from 47,000 pipes to 19,000 pipes of average length about 60 m. All the Knowledge bases (KB) entering the optimisation process, were determined manually by the end-user, according to its possibilities and needs (see Table 3). Information required for the calculation of these criteria needs to define rules and hypotheses as for CARE-W FAIL Tools. Some criteria have been evaluated (or collected), like Co-ordination score (COS) or Annual Repair Costs (ARC), but will be used in a second step-analysis.

Table 3: Criteria used in experiments of Care-W_ARP

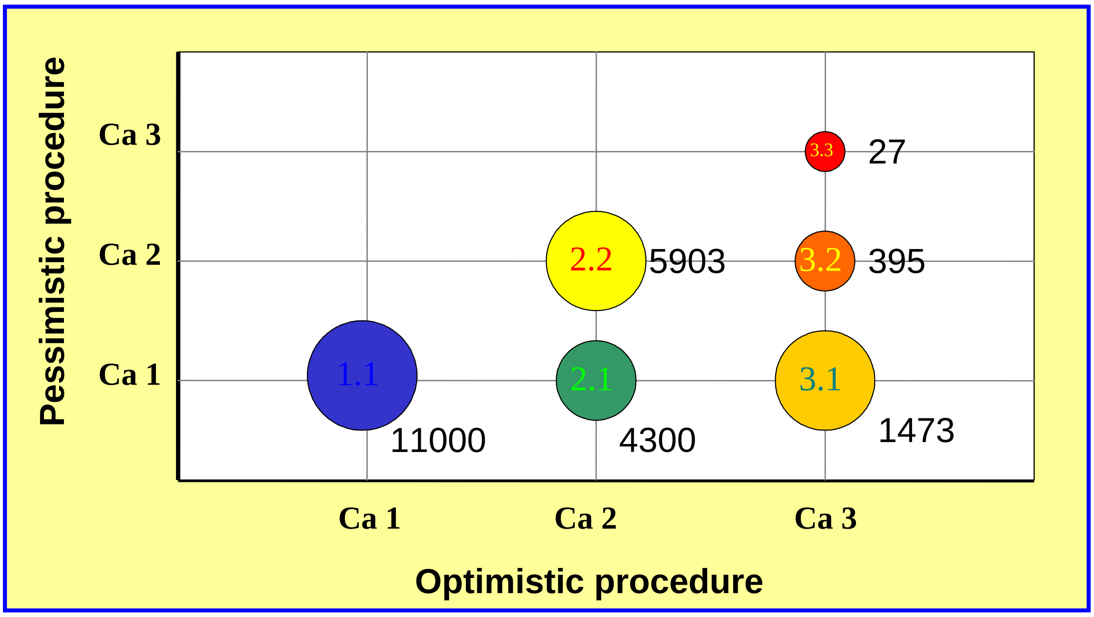
	Length (km) :	**1100**
	Number of pipes :	**19000**
	Criteria	
COS	*Co-ordination score* …………………………………….	✓
ARC	*Annual Repair Costs* ………………………………….	✓
WLI	*Water Losses Index*……………………………………	
PWI	*Predicted Water Interruptions* ……………………...	✓
PCWI	*Predicted Critical Water Interruptions* ……………….	✓
PFWI	*Predicted Frequency of Water Interruptions* ………..	✓
DFH	*Damage due to Flooding … in Housing areas*	✓
DFI	*… in Industrial or Commercial areas*	
DSM	*Damage due to Soil Movement* …………………….	✓
DT	*Traffic Disruptions* …………………………………..	✓
DDI	*Damage on other Infrastructure* …………………….	
WQD	*Water Quality Deficiencies index* …………………….	✓
HCI	*Hydraulic Criticality Index* …………………………….	

3.3.2. ARP testing results

CGE has a short-term rehabilitation plan of the water network for the next 3 years. CGE had created this plan independently on the CARE-W project with a method based on a statistical ranking. Coefficients of KB have been determined for the whole network and applied to the sample zone.

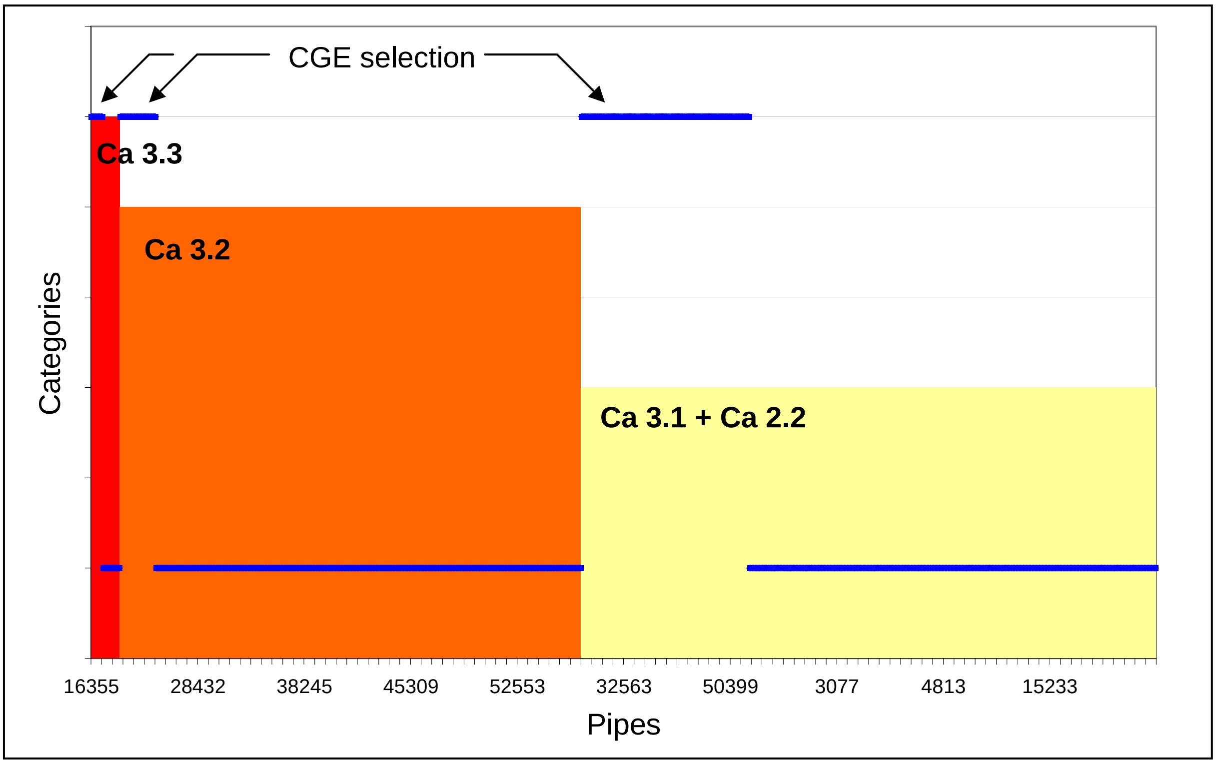
Within the testing of ARP we tried to compare our results from ARP, based on end-user KB, to the group of elements formerly chosen for the rehabilitation by CGE. The three-year program of CGE contains about 100 projects ranked (a mark is calculated by project according to its priority and several criterion) and 100 other projects "not ranked" (project with not assessable criterion). Our goal was to select with ARP a number of pipes equivalent to the number of pipes selected by CGE. The second condition was to use ARP with the originals values of each parameter except reference profiles. Figure 9 presents the result obtains with ARP.

Figure 9. ranking result with ARP



The Figure 10 presents the final result with the comparison of the both treatments. Each pipe is represented by a histogram for the ARP selection and by a point for the CGE selection. The figure represents only the 1000 pipes defining as the most critical pipes by ARP. Selection operated by CGE is made with fewer criterions than ARP, so some pipes are missed with the first selection. We can remark that projects of CGE are build with several pipes, so with several pipes categories. A project with several pipes in medium priority could be preferred behind a project with only one pipe in high priority.

Figure 10. comparison between ARP selection and CGE selection



4 CONCLUSIONS

It is necessary to point out that all our concluding remarks are stated from the position of a partner and end-user of the CARE-W project, who is familiar with the software environment and the process of its development. Our experience has shown that it would not be possible to only pass the CARE-W Prototype and tools to the Lyon end-user and want him to test it alone without consultation with us as a partner, future user will need training session.

- ✓ End-user finds the CARE-W Prototype to be a comprehensive support tool for rehabilitation planning of water networks. He appreciates the possibility to use only some of the CARE-W tools independently from the others if needed.

- ✓ The CARE-W approach has brought some new suggestions for the methodology of data recording and analysis, e.g. within the GIS system, failure rate of pipe sections and some of the information used in the PI Tool.

- × The CARE-W software and its installation are rather complicated. A certain set up of Windows system is required. It means that the user has always to change the setting of his computer or to have the Prototype installed on a separate PC.

- × The English language of the software and help files represents a barrier for its use in a wider context in France.

- × The testing of the CARE-W Prototype and its tools has shown that the software is rather data-intensive. It was not possible to generate input data for the tools automatically. All data had to be pre-processed at first, many of them were not available at all and they had to be substituted with qualified estimates.

- × During the testing of the CARE-W Prototype we have been facing some software bugs and instability. Sometimes it is very difficult to find out what is the problem, especially in case of a bigger network. Working with the Prototype and tools requires high computer skills and good technical knowledge of the water supply system. Optimisation of the calculating times would be welcome.

Report on testing carried out in Oslo, Norway

Analysis of water distribution network in Tøyen, Oslo, using tools developed in the CARE-W project (final report)

Matthew Poulton, Marcella Volta, Paula Vieira, Jon Røstum, Sveinung Sægrov

Summary

Tøyen is a small part of the Oslo Municipality water distribution network and consists of just over 200 pipes of total length, 8km. Around 25% of the pipes are over 100 years old, and hence it is relevant and important to consider rehabilitation options now. Indeed, with approaching 100 documented breaks in the area since records began in the mid 1970s, the structural integrity of the network could well be an issue. To perform a thorough diagnosis of the network, several of the tools that have been developed in the *CARE-W* project have been applied to Tøyen. These include performance indicator evaluation, failure prediction, hydraulic reliability, long term and annual rehabilitation planning. This report presents the final results from the testing.

Introduction

The final part of the *CARE-W* project has concentrated largely on testing the rehabilitation software tools developed over the last three years. Besides evaluating the individual programs, it is also very important to determine a methodological approach for how to use them and to gauge what size of networks and quantity of data are most suitable, if meaningful results are to be achieved. This report is split into the following parts:

- Data cleansing and preparation
- **CARE-W PI**: Performance Indicator (PI) assessment
- **CARE-W Fail**: Failure Forecasting using Proportional Hazards Model (PHM)
- Spatial Cluster Analysis (external to *CARE-W*)
- **CARE-W Rel**: Hydraulic reliability using Relnet and Aquarel
- **CARE-W LTP**: Long term planning using Kanew
- **CARE-W ARP**: Annual rehabilitation planning

Data cleansing

This is a vital stage of the whole procedure, in order to prevent garbage in – garbage out. Much of the cleansing – or data validation – must be carried out prior to *CARE-W*. Indeed, as different utilities collect and store data differently, there is no fixed procedure for it. However, there are a number of problems common to several utilities. These include:

- Missing data
- Inconsistencies in dates (e.g. break recorded before pipe was laid)
- Incorrect material assigned (e.g. PVC for pipe laid in 1920)
- Maintenance data not corresponding to pipe data (could be service pipe or sewer)
- Old pipe data not maintained (required for statistical analysis and failure prediction)

Data for Tøyen were supplied in *ArcView GIS* shapefile format (pipe and maintenance attribute data) and *Epanet* format (hydraulic model data). They had already been subjected to a data quality check and hence the need for further data cleansing was limited. The key data fields (length, diameter, year laid) were complete for all the pipes. Environmental data (such as soil and traffic type) was lacking – although variation of the former may have been negligible in such a small area. The maintenance data file required more extensive cleansing as it contained information on sewers and non-break activities too. Some breaks would also have been excluded in the PHM program, if they were not consistent with when the pipe was laid, or were over-reported (two or more breaks on the same pipe on the same day).

CARE-W PI: PI Assessment

PI – Performance Indicators

This tool enables the network owner to measure the performance of the network against a range of key performance indicators. Network development over time can be carefully studied, and benchmarking with other networks or between clusters within the network is also possible. The PIs can be presented in different ways, e.g. GIS, tabular or time series.

CARE-W PI has only been partly tested for Tøyen, as it is more appropriate to apply it over a larger area. Based on the available data, *Op15* (mains rehabilitation) and *Op26a* (pipe failures) were calculated. The analyses was carried out with rehabilitation and failure data from 1987 to 2001 and are presented as time series (figs. 1 and 2). The total length was considered to be the same year by year as there were no new pipes laid after 1993. For the whole network (Oslo), values for the year 2001 are also shown.

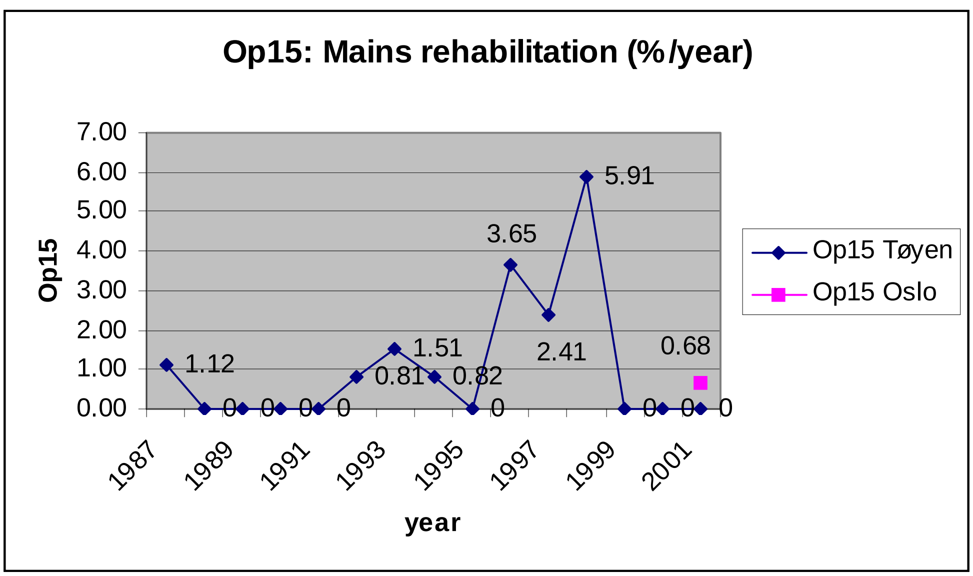


Fig. 1 PI Op15 – mains rehabilitation

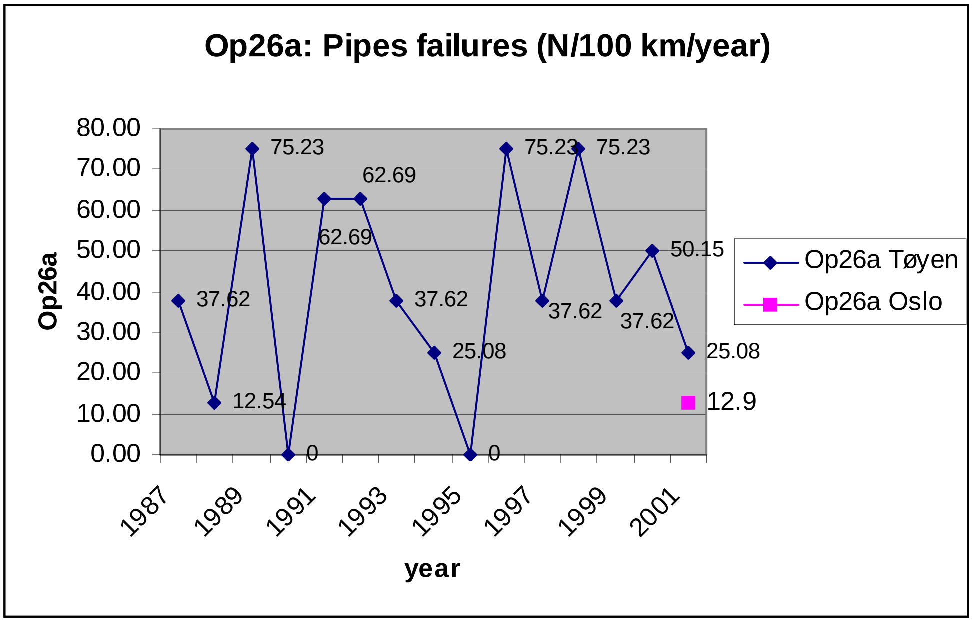


Fig. 2 PI Op26a – pipe failures

Op15 reflects that since 1996 a lot of rehabilitation work has taken place in Tøyen. Furthermore, Op26a indicates that the failure rate reduced following this rehabilitation. Thus *CARE-W PI* can be useful in indicating the effects of a previous rehabilitation programme.

However, the reduced failure rate is still higher than the average for Oslo and it would have been useful to have similar graphs for other zones in order to decide where to act next. In summary, *CARE-W PI* is useful both for finding the areas with problems and evaluating the effects of rehabilitation.

CARE-W Fail: Failure Forecasting using Proportional Hazards Model (PHM)

CARE-W PHM uses pipe and break data to predict future break rates. Its accuracy is dependent on both the number of pipes and breaks, as both must be statistically significant. Generally, separate models are applied for pipes with no recorded breaks and those with one or more. However, this is not always appropriate and a single model may be better, depending on the significance of the variables used. Conversely, if extensive data are available then the number of models may be increased as the time between successive failures can give a strong indication when the pipe is likely to break again.

The data were analysed in two stages. Initially, just the data from Tøyen was used, but later, a larger part of the network was chosen to calibrate the model (determine the parameters) and only the predictions for Tøyen pipes considered.

In the first case, running two separate models was not possible, as none of the explanatory variables were significant. Instead, one model was applied for all the pipes. Figures 3 to 6 show various stages of the program and figure 7, the results exported to *ArcView GIS*. The results can also be shown in the prototype as tables or in GIS format.

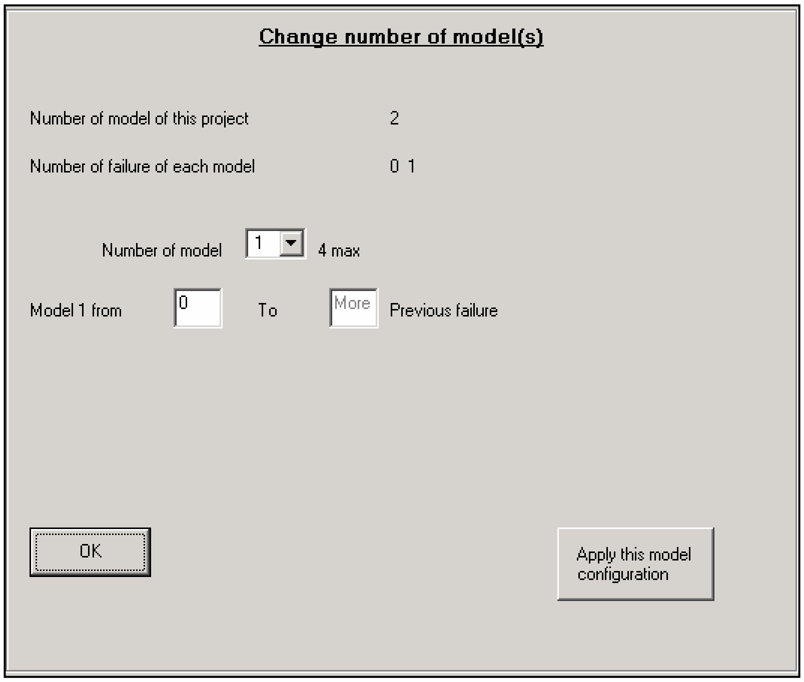


Fig. 3 Choosing the number of models in PHM

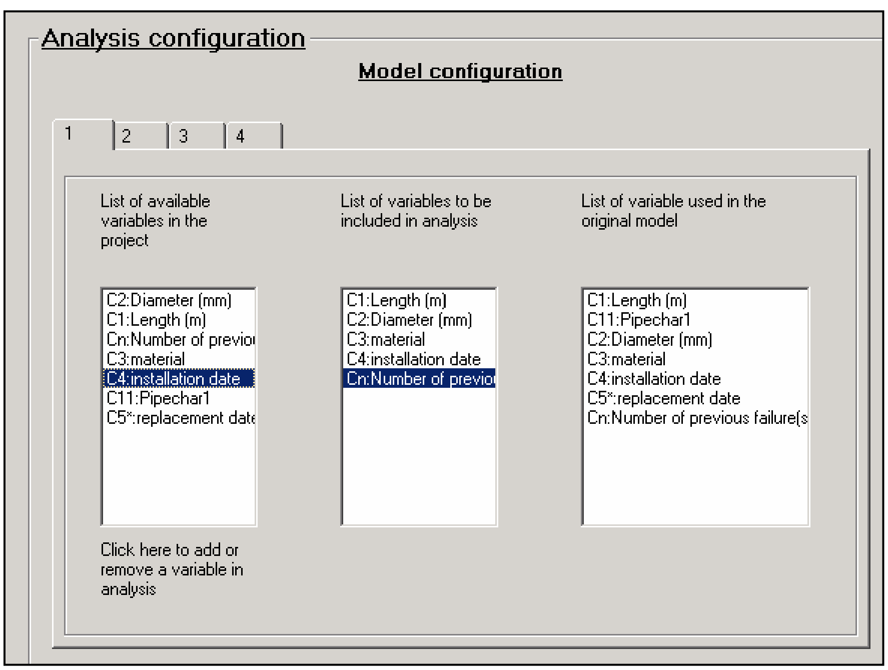


Fig. 4 Selecting the variables to be used in PHM

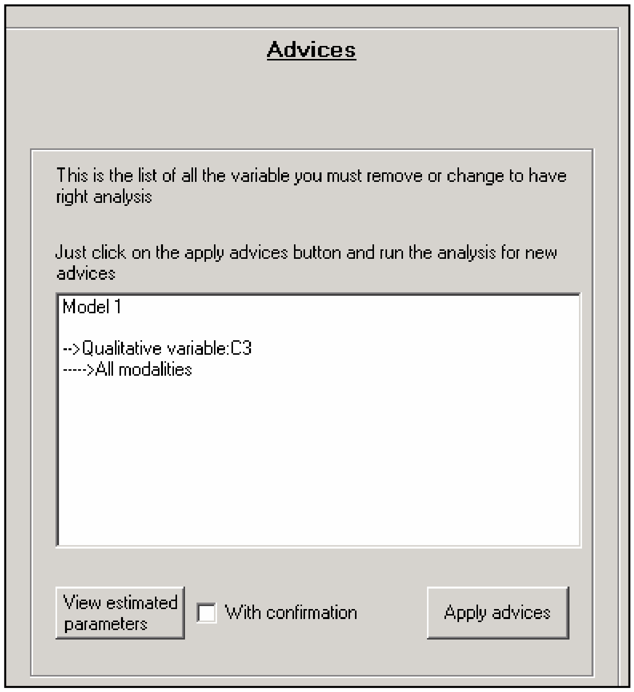


Fig. 5 Initial statistical evaluation performed by PHM and advice given on ignoring insignificant parameters

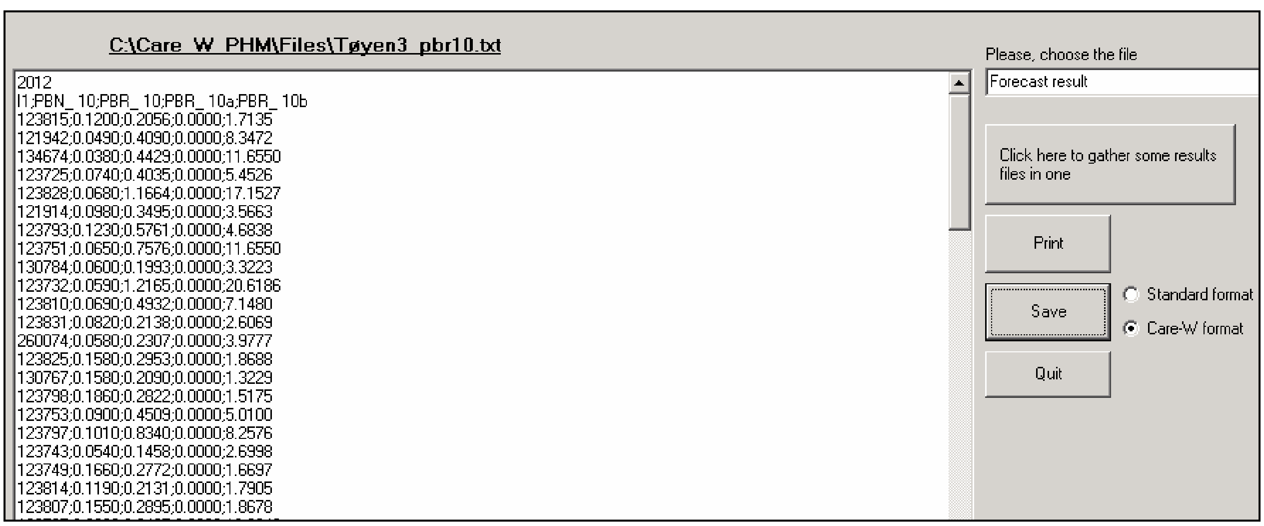


Fig. 6 Initial results from PHM

Fig. 7 Results displayed in ArcView GIS

The results produced by just analysing the Tøyen network were rather poor. So few pipes affected the reliability of the model and one or two breaks on a pipe could significantly effect the failure predictions for similar pipes. Better results were obtained using a larger part of the Oslo data to calibrate the model. Figure 8 shows a comparison of these results with Oslo's own assessment.

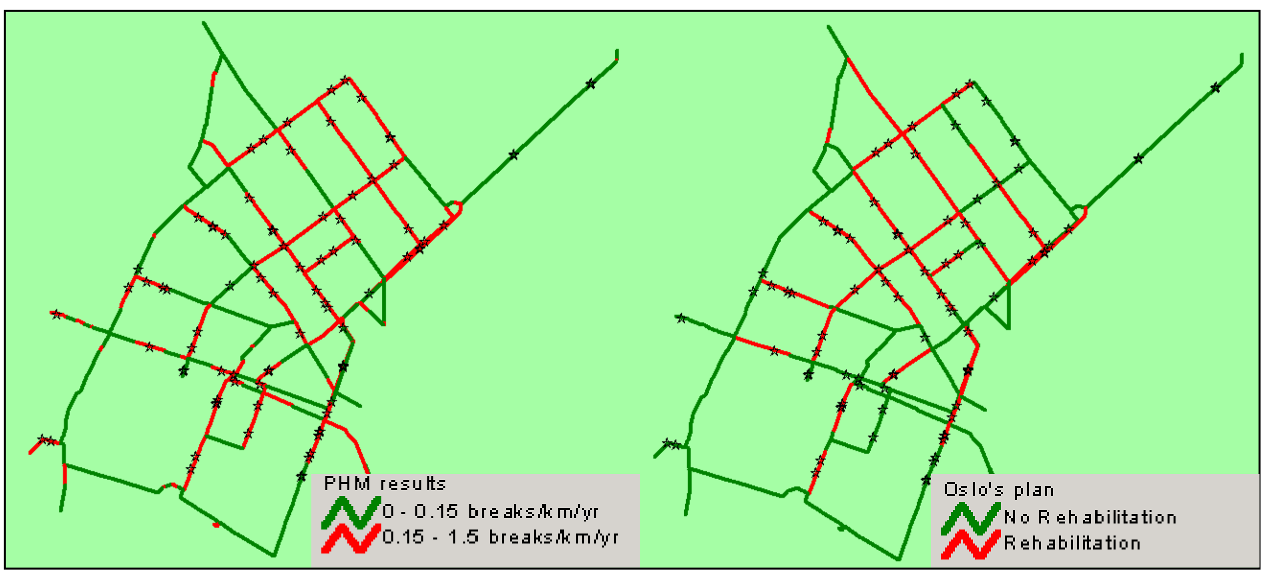


Fig. 8 Comparison of CARE-W PHM results and Oslo Municipality's own assessment

Several further simulations were performed using *CARE-W PHM*, with changes to the parameters and number of models, including:

Using two models (0 failures and 1 or more failures)
Using a single model
Only modelling SJG pipes
Only modelling SJK pipes
Using log of length and age as parameters (rather than length and year laid)
As above, modelling only SJG pipes
As above, modelling only SJK pipes.

In each case, break records were used from 1975 until the end of 1999. This allowed for predictions to be compared with actual breaks in the period 2000-2002. This model validity procedure required the production of a **Benefit Index**. This is defined as the percentage of actual failures that would have been avoided, if a certain percentage of pipes (ranked by decreasing predicted failure probability) had been replaced at the end of the break observation period. Figure 9 shows the Benefit Index based on PHM results from approximately20000 pipes (half of the network). For comparison purposes, the Benefit Indices are also shown for pipes ranked by number of previous failures (NPF) and the "average" case where pipe are not ranked.

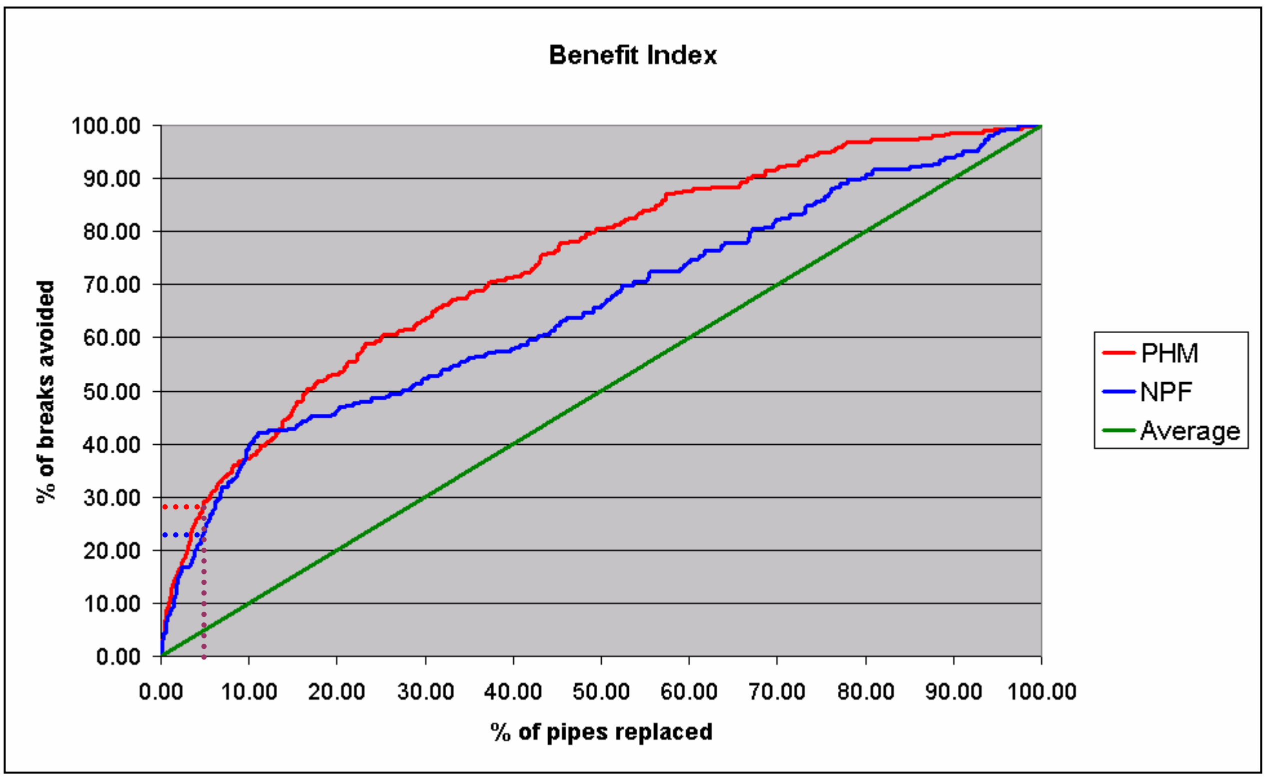


Fig. 9 Benefit Index

The key part of the Benefit Index chart is the bottom left hand corner, as there is clearly a limit to how much rehabilitation can be done during any particular planning period. To decide the exact number of pipes that could feasibly be rehabilitated, it is obviously necessary to consider the cost of rehabilitation. An approximation of costs could be calculated for each pipe in the ranked list based on its diameter and length. Once the cumulative cost exceeds the budget, the maximum number of pipes can be defined and the likely benefit assessed.

The results show that if 5% of the network had been replaced/rehabilitated in 1999, according to PHM ranking, then 29% of the breaks in the next three years would have been avoided. This figure would have been 23% if only the number of previous failures was considered. It would appear in this dataset, that the difference between the two ranking methods is not particularly large. This is because the historical data is good and the number of previous failures is a key factor in the PHM model. Nonetheless, the PHM results are slightly better for the first 11% of pipes. Thereafter, the NPF ranking is meaningless, as the remaining pipes have no previous recorded breaks.

The major advantage of ranking according to the PHM results is that all the pipes can be ranked, rather than just those with previous breaks. This is useful for two reasons:

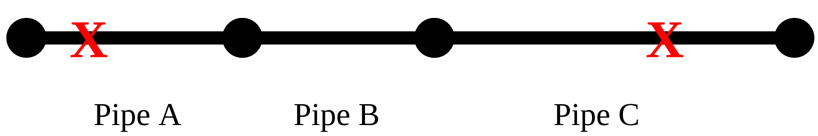
- Pipes that may be included as rehabilitation targets for another criteria can be additionally ranked according to structural failure probability.
- The ranking can be used in deciding which pipes to inspect, e.g. thickness measurements using RTM scanner.

In summary, CARE-W PHM is a useful tool, but requires a significant amount of pipe and failure data to be statistically valid.

Spatial Cluster Analysis

There are two types of spatial cluster analysis in the context of water distribution system performance – one relates to the *pipes* themselves and their physical attributes, and the other to the *breaks* occurring on them.

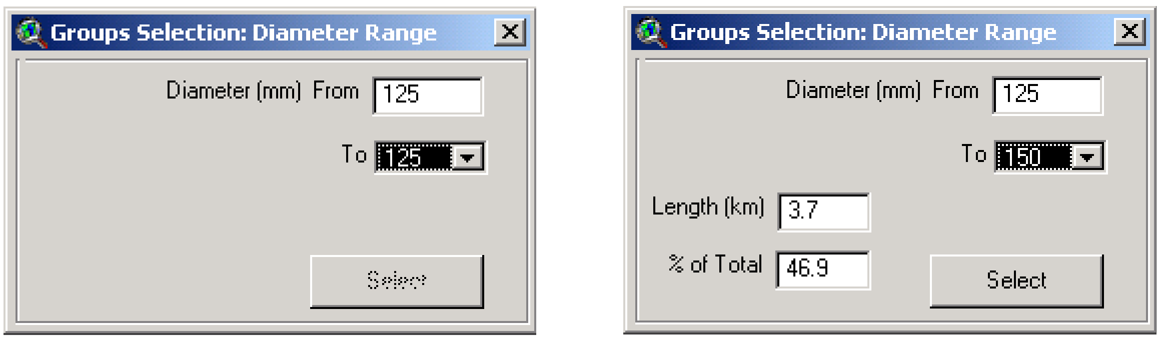
Pipe Attributes: Often pipes with the same or similar diameter, age and material can be found in close proximity. This is to be expected, as multiple pipelines are generally laid at the same time. It is also practical and more economic to rehabilitate them at the same time. Therefore, when the rehabilitation is being planned, it is necessary to consider the spatial distribution of similar-attribute pipes. A classical example could be a chain of three pipes, as shown:



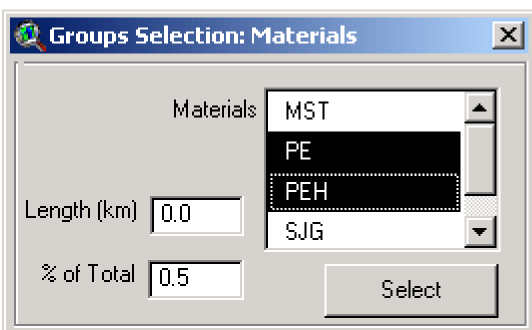
All three pipes have the same material, diameter and age, but pipe A and pipe C have previously broken, whilst pipe B hasn’t. If the sole criteria for rehabilitation was the previous break rate, then A and C might be ranked high amongst rehabilitation candidates, whilst B would not. There is then the distinct possibility that following rehabilitation of just A and C, B breaks soon afterwards resulting in excess costs to the water company and extra disruption to nearby residents. For a small network, it is fairly easy to cluster such pipes manually. For a larger network however, it is desirable to have some form of automatic detection.

In *CARE-W PHM*, this is at least partially included intrinsically – the very fact that there are similar pipes to B, with previous breaks, will increase its own predicted break rate, despite it not having failed itself. There is no guarantee though that all three pipes would make the shortlist of rehab candidates. It is also feasible that pipes A and C could be targeted for rehabilitation based on separate criteria. For example, one could be critical as it supplies a hospital, and the other may lie on a street that is due to be dug up for other purposes. In such situations, the decision of whether to replace B as well may be less clear.

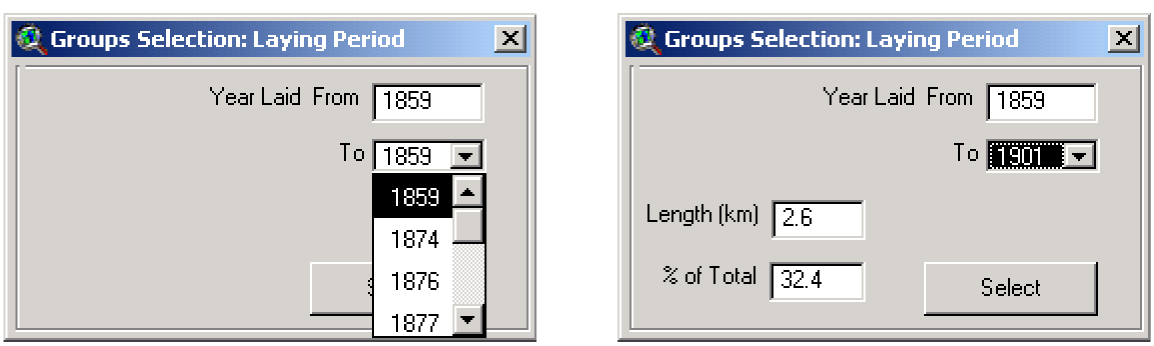
There are currently no tools in the *CARE-W Rehab Manager* to assist the user in grouping pipes. However, this can be done in a GIS. An example is shown for *ArcView*, where scripts were written to allow the user to group and view multiple attributes.



Step 1: Create groups of pipes based on diameter ranges



Step 2: Create groups of pipes based on materials



Step 3: Create groups of pipes based on laying period

Step 4: View pipes according to their grouped attributes

Spatial clustering of breaks can be included in *CARE-W* directly or indirectly. If there is a direct correlation between these break clusters and a particular attribute, such as soil or traffic type, then *CARE-W PHM* will model the phenomena. If the reason for the clustering is unclear (e.g. lack of data to explain it) then an additional parameter can used. Typically, this would be a binary variable, pipes associated with break clusters being assigned a value of "1" and all the others, "0".

<u>Hydraulic reliability models</u>

REL – Water supply RELiability

This module assesses the hydraulic service reliability of the distribution system. The tool checks the network for weak points using an existing hydraulic model, describing the result of one or two pipes being out of service (e.g. after a break). The main outputs are reliability indices and link importance (Hydraulic Criticality index, HCI). There are three alternative tools for calculating the critical pipes in *CARE-W*, two of which were tested on the Tøyen network. *Aquarel* and *Relnet* both aim to determine the most critical pipes in the network, in terms of the impact created when the pipe is out of service (e.g. after a break). The main difference between the two models is that Aquarel takes into consideration the predicted failure rate. Hence a pipe with medium criticality may become highly critical if the perceived risk of failure is also high. Criticality values are calculated by closing each pipe in turn and running the hydraulic model.

Table 1 and figure 10 show the critical pipes as calculated by Aquarel and their position in the network:

Tab. 1 Aquarel results

Link ID	HCI	Importance	Unav. imp.	Freq. imp.
122034	1,000000	137,799600	2,157635	1200,096000
123771	0,059489	8,197621	0,151603	84,566660
123883	0,122807	16,922800	0,109036	120,168800
130760	0,313400	43,186360	0,753179	419,685100
130761	0,159794	22,019580	0,312971	173,822600
260066	0,407001	56,084500	0,259853	285,862700
260074	0,204787	28,219580	0,166806	183,737700

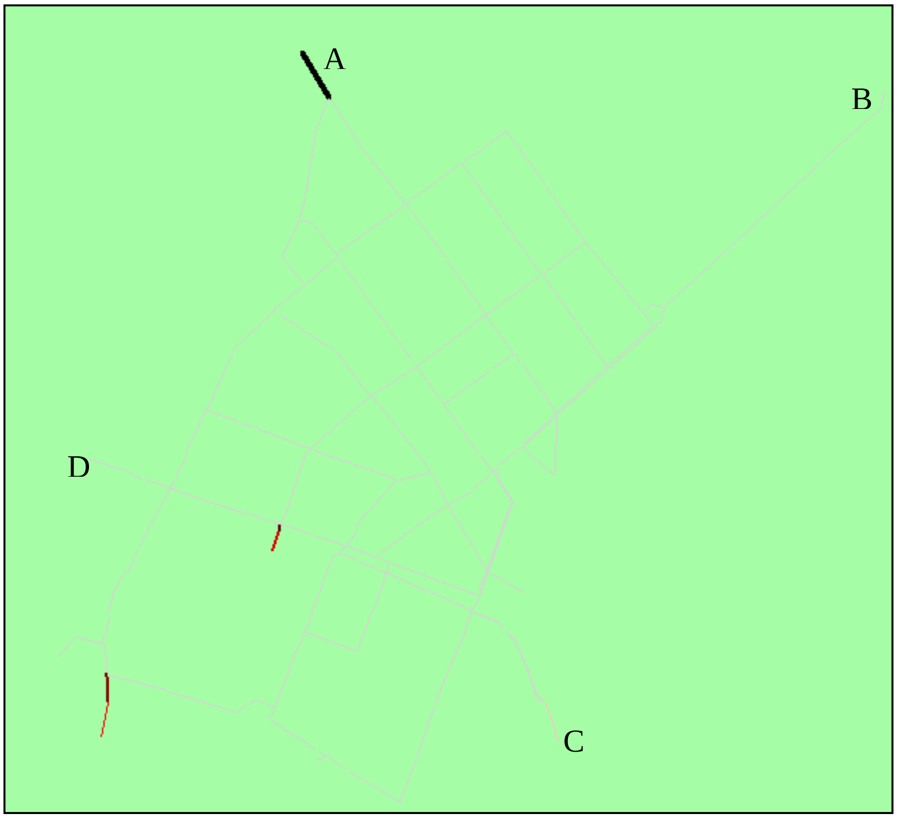
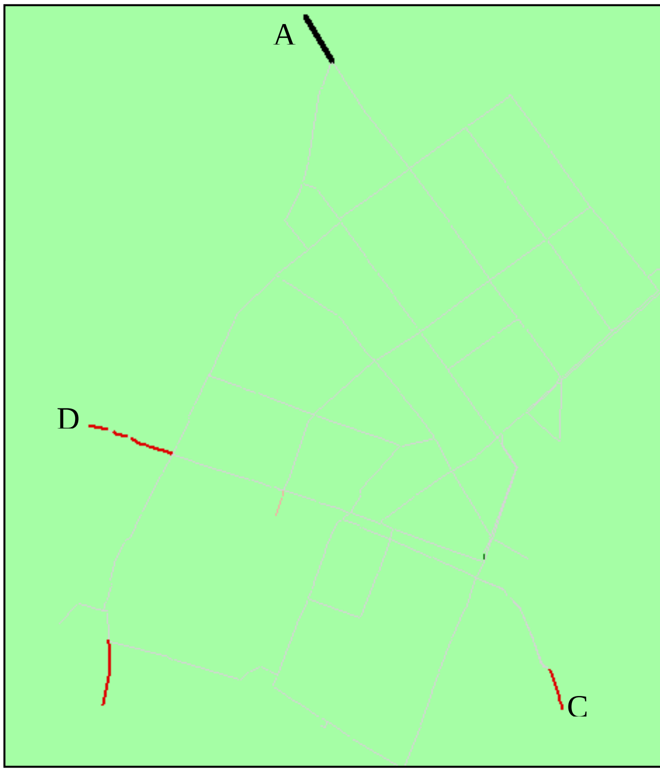


Fig. 10 GIS display of Aquarel results

Figure 11 shows the critical pipes as calculated by Relnet and their position in the network:



Link ID	HCI
122034	1.000
92993	0.257
92991	0.257
123771	0.256
130760	0.256
130761	0.256
92941	0.256
92988	0.256
92989	0.256
92990	0.256
93427	0.256
260066	0.027
260074	0.027

Fig. 11 GIS display of Relnet results

The two models do not differ greatly – in both, by far the most critical pipe is the supply pipe (A). This carries the bulk of the water to the network, with the second supply pipe (B) mainly bypassing this network and supplying other zones. If (A) is closed then many pipes will have insufficient pressure. The network has many loops and hence there are always a number of paths through it. Consequently, many pipes are non-critical, regardless of their predicted break rate. Instead, the critical pipes tend to be in branched parts of the network. At first glance there appears to be an anomaly with the branch culminating with pipe (C): The end pipe is the only critical pipe, whereas pipes further up the branch should logically be critical too. However, on closer inspection, there are in fact two parallel branches leading to pipe (C). Pipe (D) leads to another network zone. The Aquarel model lists it as non-critical, however, if a larger part of the network was modelled, it could be critical in supplying other pipes. For this reason, it is important to distinguish between end nodes and zone-boundary nodes.

In conclusion, it is better to use a larger network, even if it is just a skeletal model, to ensure that the calculations are correct for the boundary pipes. With so many loops in the network (and hence reduced number of critical pipes), it is difficult to assess the effect of using predicted failure rates in the Aquarel model. Generally, hydraulic criticality in such cases should not be considered a major rehabilitation criterion. However, if there are sensitive customers requiring a certain supply pressure then the results should be looked at more closely.

Long term planning (Kanew)

Kanew enables rehabilitation planning on a strategic level, by considering the ageing functions of different cohorts of pipes. Pipe classes were created according to age, diameter and material (table 2, figure 12):

Tab. 2 Stock classification

class 1a	Diameter <=150; formstøpte SJG; laid year: 1858-1929
class 1b	Diameter >=151; formstøpte SJG; laid year: 1858-1930
class 2a.I	Diameter <=150; sentrifugalstøpte SJG; laid year: 1930-1945
class 2a.II	Diameter <=150; sentrifugalstøpte SJG; laid year: 1945-1964
class 2b.I	Diameter >=151; formstøpte SJG; laid year: 1930-1945
class 2b.II	Diameter >=151; formstøpte SJG; laid year: 1945-1964
class 3	steel; laid year: 1858-1994
class4	SJK; laid year: 1965-1994
class 5	plastics; laid year: 1960-1994

For the survival data for the stock, the same survival functions were used as in the *Saneringsplan VAV 1996*. The values for the 100, 50 and 10 % survival functions are shown in table 3. (in Saneringsplan 1996, part 12, the values 90, 50 and 10% are used, however these are equivalent).

Tab.3 Survival data for the stock

	100%	50%	10%
class 1a	53/53	100/130	140/170
class 1b	73/78	120/150	160/190
class 2a.I	38/70	100/130	130/160
class 2a.II	32/38	60/90	90/120
class 2b.I	60/60	120/150	150/180
class 2b.II	42/45	80/110	100/130
class 3	80/88	110/140	140/170
class4	20/25	80/110	110/150
class 5	22/52	60/90	80/110

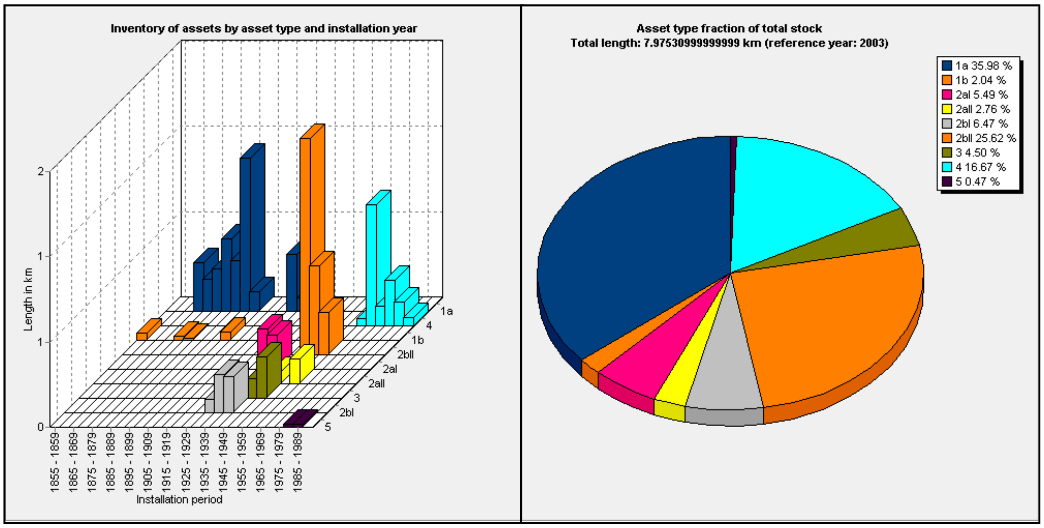


Fig.12 Current stock of network water mains

Kanew offers a number of graphical representations of ageing functions, residual service life and rehabilitation needs (figures 13 to 15). It is possible to include different rehabilitation strategies – figure 15 for example, considers that every pipe that reaches the end of its life is either replaced or renovated. In each class of pipes, 50% are replaced by a general material UT and 50% are renovated with a general material RE. Ageing functions for these two materials (RE and UT) were considered to be equal to the “best material”, in this case plastic.

Based on the results from *KANEW* the long term investment need is calculated for the Tøyen zone. Normally, *KANEW* results are presented at network level (i.e. for the whole city).

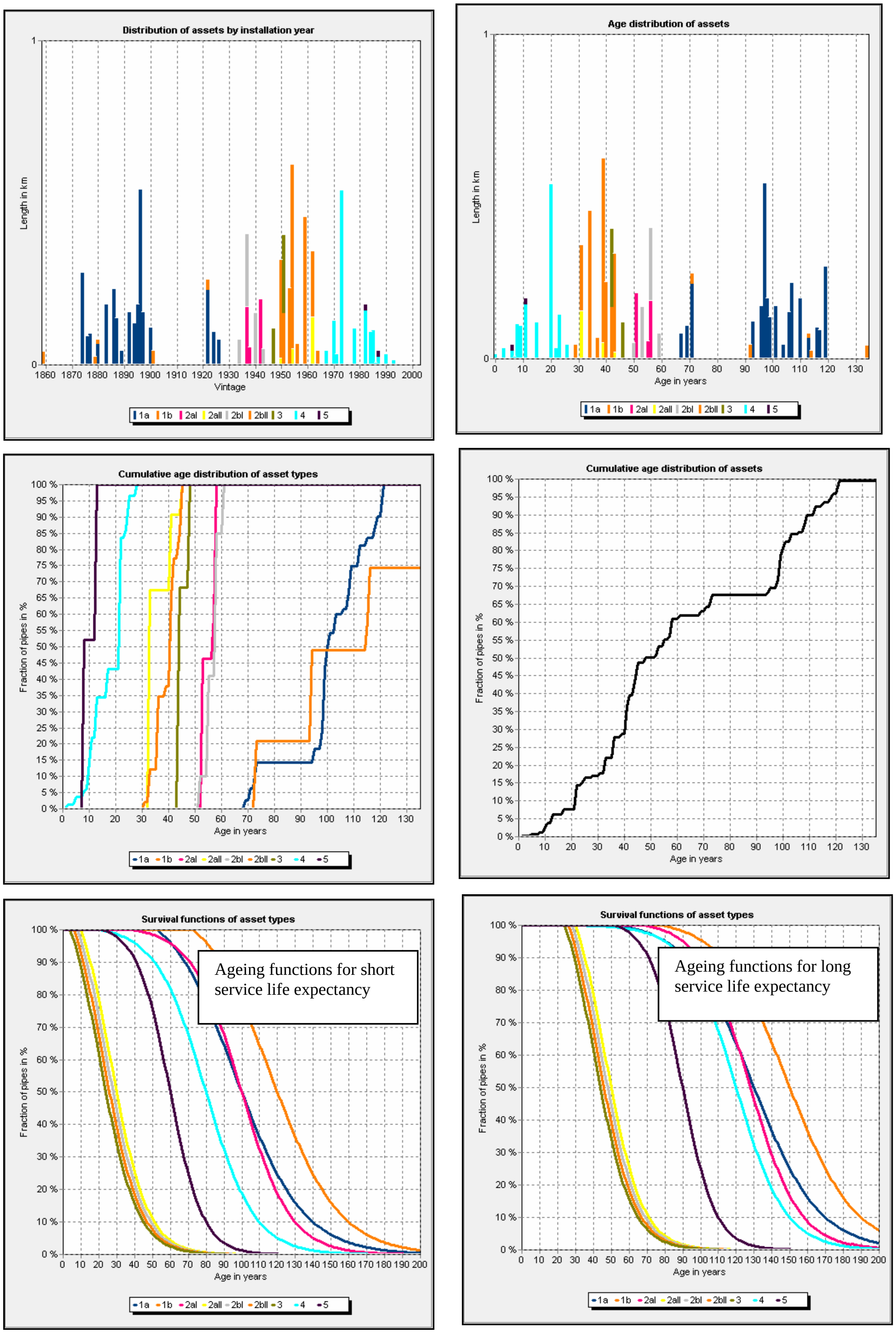


Fig. 13 Ageing functions and residual service life

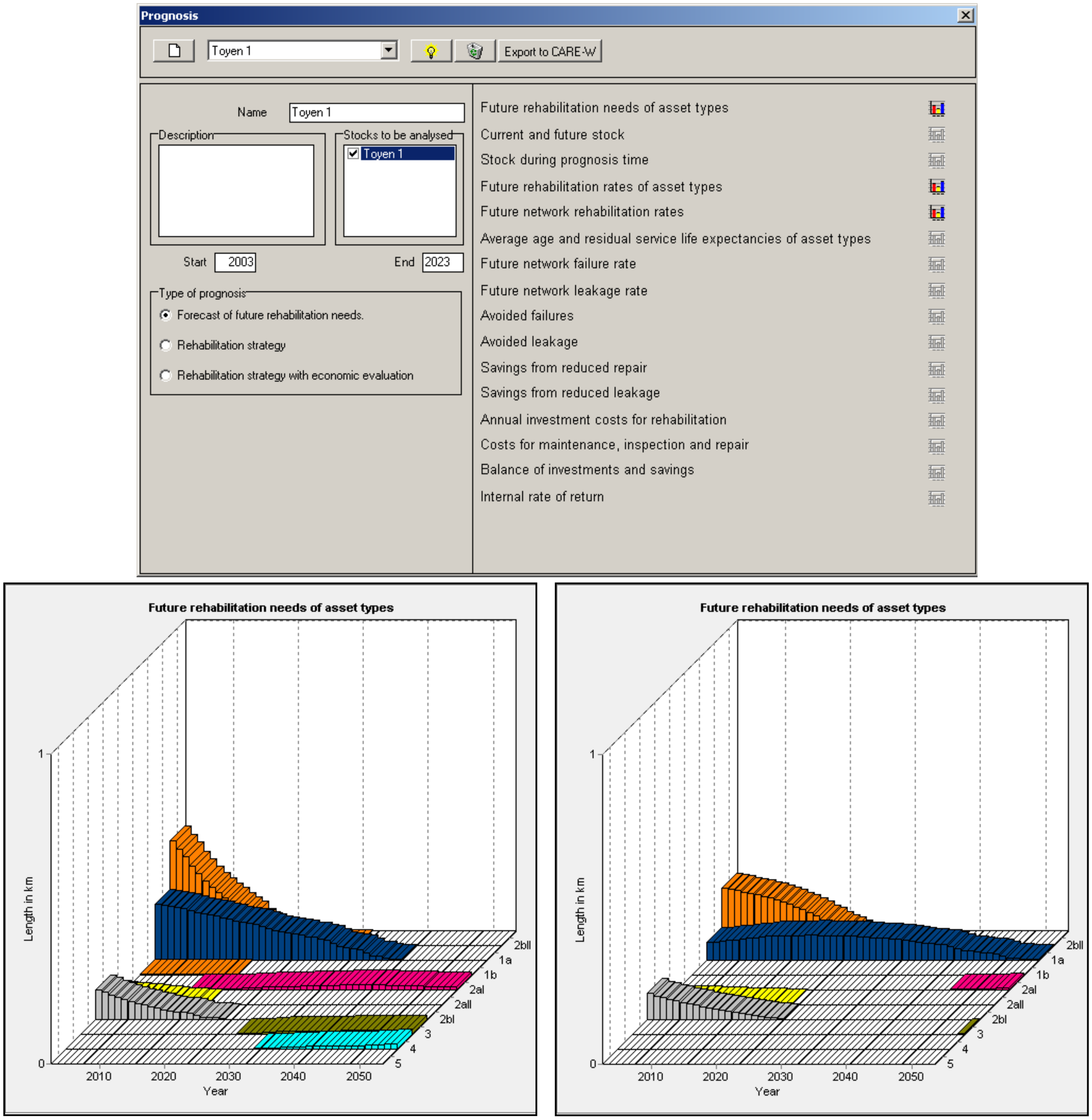


Fig. 14 Forecast of future rehabilitation needs

Figure 14 shows the rehabilitation needs for the different pipe groups for both a short and long service life expectancy.

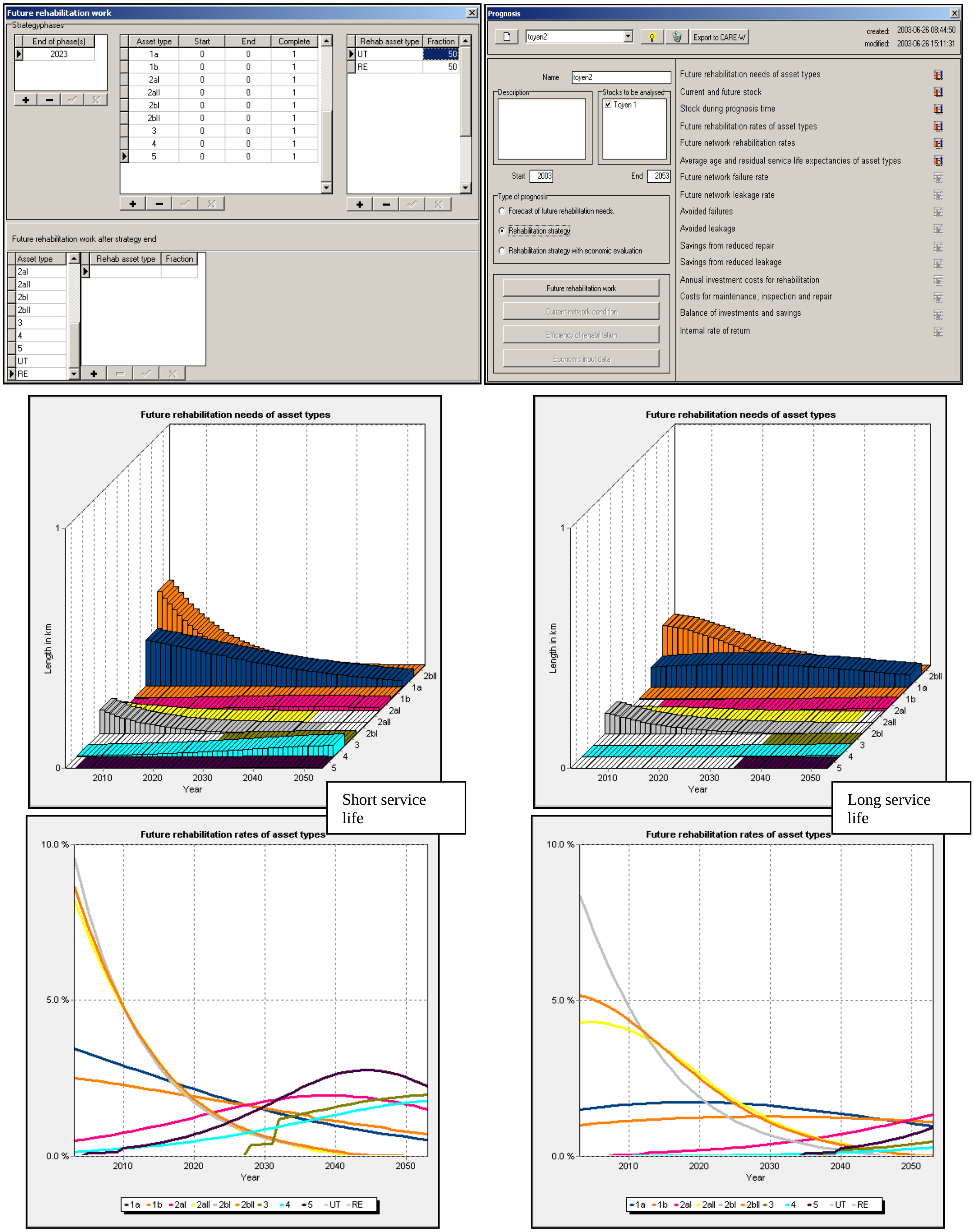


Fig. 15 Forecast of future rehabilitation needs with the implementation of rehabilitation strategy (without investment calculus)

CARE-W ARP: Annual rehabilitation Planner

ARP – Annual Rehab Planner

This multi-criterion tool combines results from the *CARE-W* tools with additional information from the utility. This outranking procedure enables analysis over the whole network, sectors or clusters in order to make a prioritized list of rehabilitation candidates for the annual rehabilitation investment programme.

The input data for *CARE-W ARP* consists of category codes used in calculating each of the criteria required, together with key attribute data, predicted break/failure rates and, if available, hydraulic criticality values (table 4). The categories are defined in “knowledge bases” in the program (figure 16). The criteria can then be calculated by simple formulae. In some cases, the codes refer to sensitivity or vulnerability factors. Even if all pipes in the zone are assumed to have the same factor, values should be entered, as the criterion may also depend on pressure and diameter, for example, which obviously differ.

Based on the available information in the GIS files, *CARE-W ARP* has been applied for Tøyen. The following aspect are taken into consideration:

- Annual repair costs
- Hydraulic criticality of pipes
- Predicted water interruption
- Traffic disruptions
- Damage/disruption to bridges
- Damage due to flooding after a break

In order to evaluate the criteria, there are two separate approaches. The first is to set absolute thresholds for certain criteria and all pipes failing a threshold would be listed as rehabilitation candidates. The alternative approach is the *Electre Tri* method, where weights can be assigned to each criteria and reference profiles used to group pipes into one of 6 categories (figures 17 and 18).

Tab. 4 CARE-W ARP input data

ID	User Reference (Pipe ID)
L	Length (m)
D	Diameter (nominal) (mm)
M	Material
NPS	Number of People Supplied (No. Of people connected to adjacent pipes between 2 nodes)
P	Average Working Pressure (MPa)
SC	Sensitive Customer
C-COS	Code of category used in calculating Criterion "Co-ordination score"
C-UCRp	Code of category used in calculating Criterion "Annual Repair Cost"
C-UCRh	Code of category used in calculating "Unit Cost of Rehabilitation"
C-RRT	Code of category used in calculating "Relevant Rehabilitation Techniques"
C-WLI	Code of category used in calculating Criterion "Water Losses Index"
C-WQD	Code of category used in calculating Criterion " Water Quality Deficiencies "
C-EDI	Code of category used in calculating Criteria "Predicted Water Interruption", "Critical Water Interruption" & "Frequency of Water Interruption"
C-SFH	Code of category used in calculating Criterion "Damages due to Flooding in Housing areas"
C-SFI	Code of category used in calculating Criterion "Damages due to Flooding in Industrial or commercial areas"
C-LS	Code of category used in calculating Criterion "Damages due to soil movement"
C-SR	Code of category used in calculating Criterion "Traffic Disruption"
C-SI	Code of category used in calculating Criterion "Damages and/or Disruption on other Infrastructures"
C-IFH	Code of category used in calculating Criterion " Damages due to Flooding in Housing areas "
C-VFH	Code of category used in calculating Criterion " Damages due to Flooding in Housing areas "
C-VFI	Code of category used in calculating Criterion " Damages due to Flooding in Industrial or commercial areas ""
Info1	Criterion calculated by an other tool (imported in CARE-W)
Info2	*As Info1*
Info3	*As Info1*
Info4	*As Info1*
Info5	*As Info1*
PBR	Predicted Break Rate, used to calculate criteria: "Predicted Water Interruption", "Critical Water Interruption" & "Frequency of Water Interruption", "Damages due to Flooding in Industrial or commercial areas" & "Damages and/or Disruption on other Infrastructures"
PFR	Predicted Failure Rate, used to calculate criteria: "Annual Repair Cost", "Damages due to soil movement" & "Traffic Disruption"
HCI	Hydraulic Criticality Index

Mandatory data
Optional data used in Tøyen Analysis
Optional data not used in Tøyen Analysis

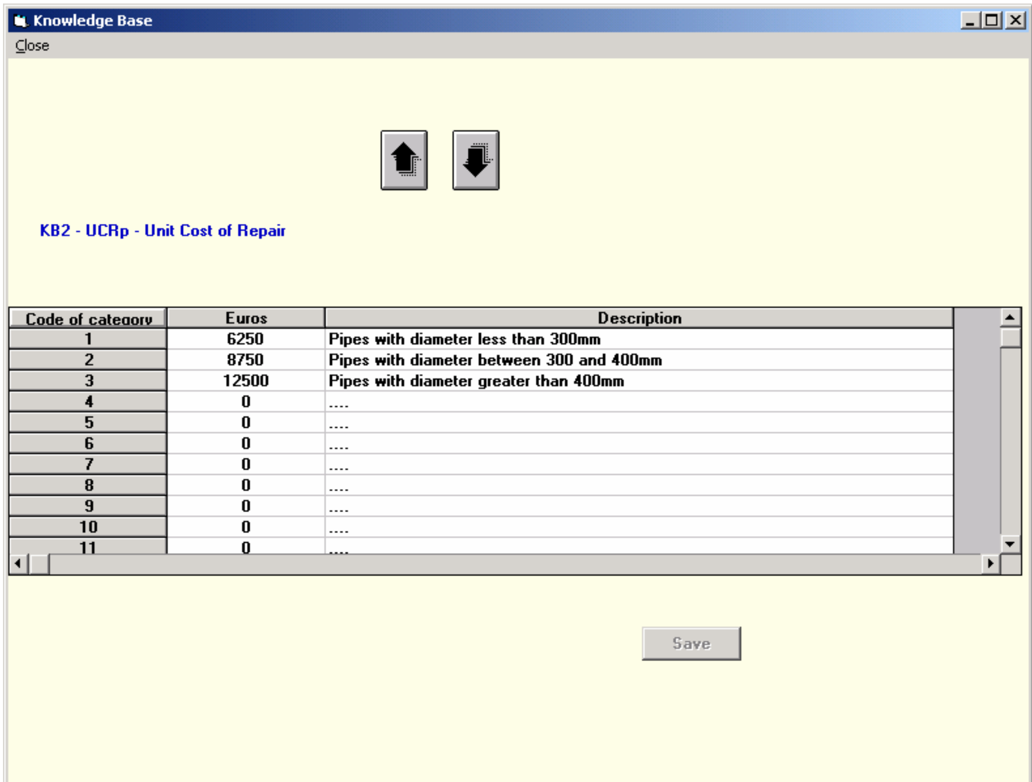


Fig. 16 Category code definition in knowledge bases

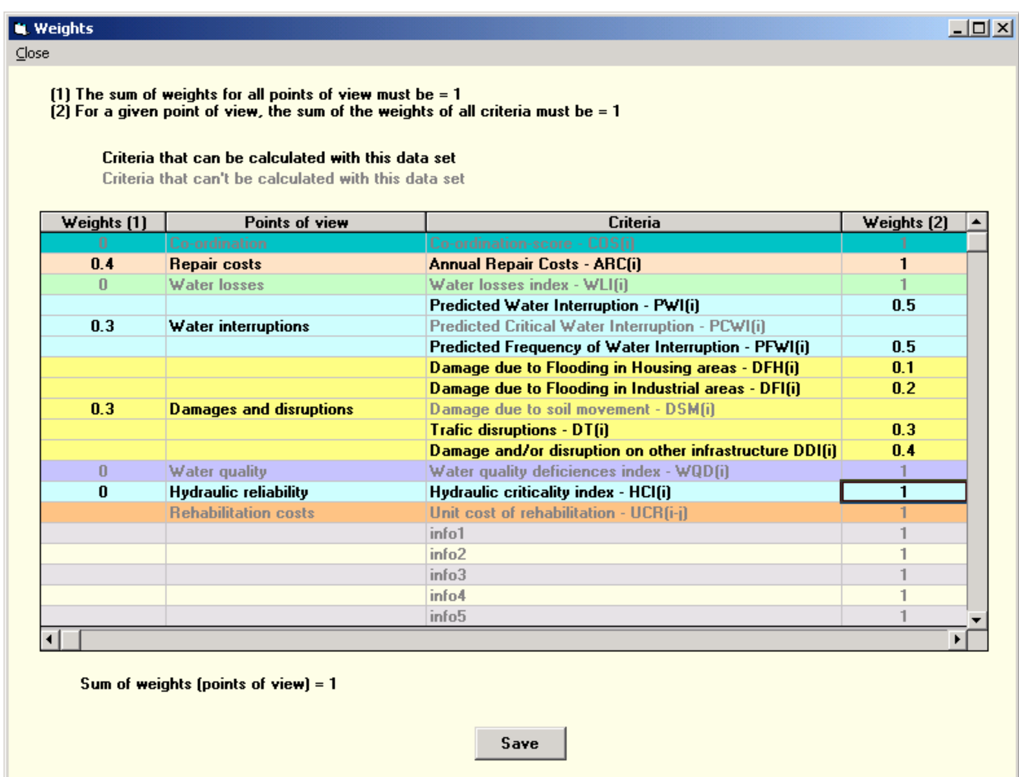


Fig. 17 Setting weights for the calculated criteria

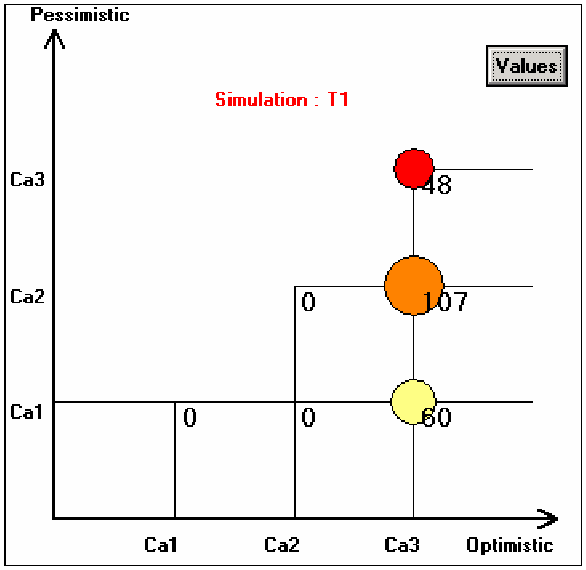


Fig. 18 Electre Tri results for Tøyen

The results show that 48 pipes are in the worst category (prime targets for rehabilitation). The exact ranking of these pipes can also be shown, and the results can be displayed geographically, back in the *CARE-W Rehab Manager* (figure 19).

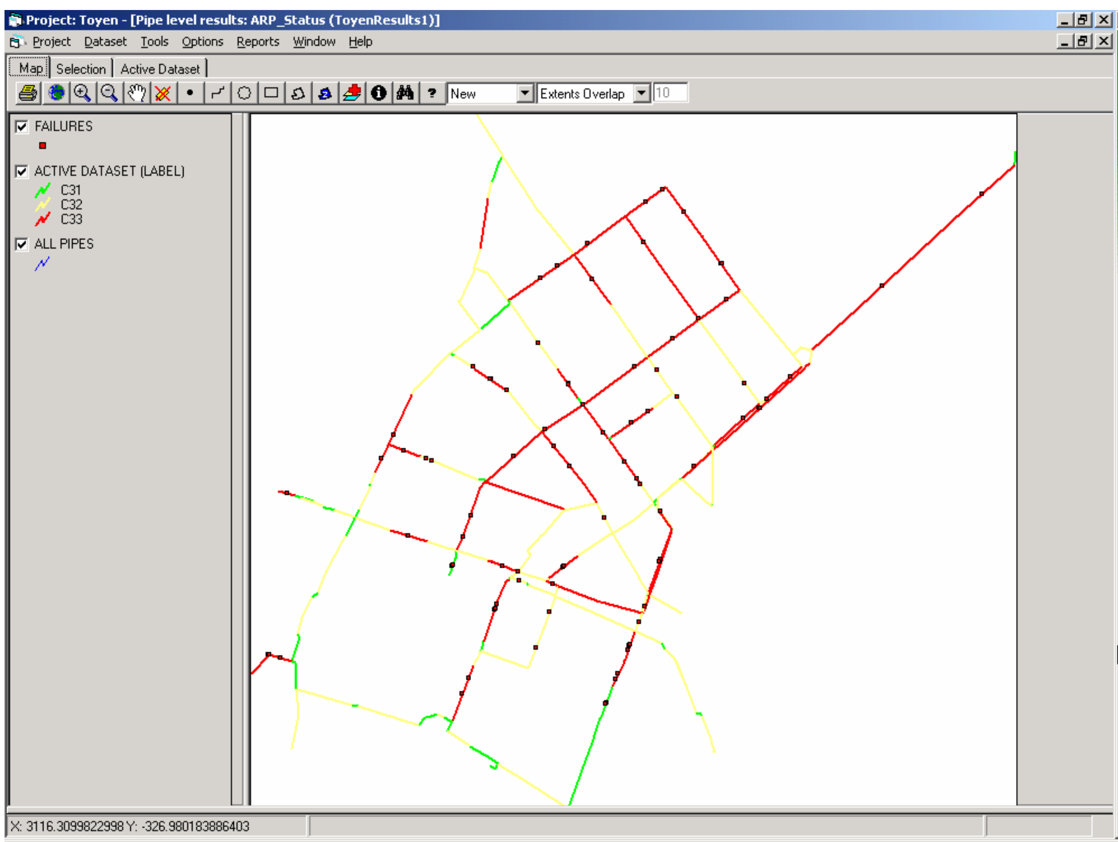


Fig. 19 Tøyen ARP results

Report on testing carried out in Reggio Emilia, Italy

CARE_W

APPLICATION
TO THE CASE OF THE AGAC MANAGEMENT OF THE URBAN NETWORK
OF THE CITY OF REGGIO EMILIA

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3.1 INTRODUCTION TO MODELS

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4.4 DARK LOOK AHEAD

CARE_W
APPLICATION
TO THE CASE OF THE AGAC MANAGEMENT OF THE URBAN NETWORK
OF THE CITY OF REGGIO EMILIA

Author: Marcello Schiatti, Engineer, DEWI S.r.l.
Former AGAC Network Services Head

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4.1 SCENARIO PRINCIPLE

The principle of writing/thinking Scenario for Reggio water network application case has been the look ahead on internal performance indicators and the setting of goals in the future. In doing this, the starting base has been the WP1 "Performance Indicators" which has been adopted within WP4 "Scenario writer". So that, for the coming years the scenario can be controlled, adopting a benchmarking internal process.

4.2 IMPACT MATRIX

The impact matrix contains the pre-defined key factors and their cross-references and consistencies. Through it, each factor inter relation has been stated and given its weight. The key factors have been modified to taylor with the case under study. They are 13 in total, whose 4 factors are in the original impact matrix.

The original factors are:

- W1 Population supplied
- W2 Total per capita consumption
- W4 Water losses reference to IWA PI A20
- E3 Running costs reference to IWA PI Fi2

The extended factors are:

- W3 EXT Customer for each meter
- W4 EXT Network length reference to IWA PI C6
- W5 EXT Leakage control as number of active districts
- W6 EXT Yearly number of pipe breaks
- W7 EXT Yearly number of service pipe breaks
- W8 EXT ARP tool extension as number of districts info collection
- E4 EXT Yearly Differential Income reference to IWA PI G30
- E5 EXT DI Development Investment reference to IWA PI G27
- E6 EXT RI Rehabilitation Investment reference to IWA PI G28

Impact Matrix A Interactions Between Paired key factors	(W1) Population supplied	(W2) Total per capita consumption	(W3 EXT) Customer per each meter	(W4 EXT) Network length	(W4) Water Losses (Hidden breaks)	(W5 EXT) Leakage Control Number of active districts	(W6 EXT) Yearly number of pipe breaks	(W7 EXT) Yearly number of service connection breaks	(W8 EXT) ARP tool extension Number of districts info collection	(E3) Running costs	(E4 EXT) Yearly Differential Income	(E5 EXT) Development Investment	(E6 EXT) Rehabilitation Investment
(W1) Population supplied													
(W2) Total per capita consumption	|												
(W3 EXT) Customer per each meter	0												
(W4 EXT) Network length	|	0	0										
(W4) Water Losses (Hidden breaks)	0	0	0	|									
(W5 EXT) Leakage Control Number of active districts	|	0	0	|	■								
(W6 EXT) Yearly number of pipe breaks	0	0	0	|	←	0							
(W7 EXT) Yearly number of service connection breaks	|	0	0	0	←	0	0						
(W8 EXT) ARP tool extension Number of districts info collection	0	0	0	0	→	↔	■	■→					
(E3) Running costs	0	0	0	0	|■	←	|■	|■	←				
(E4 EXT) Yearly Differential Income	|	0	|	0	0	0	0	0	0	0			
(E5 EXT) DI Development Investment	|	0	0	0	0	0	0	0	0	|	|		
(E6 EXT) RI Rehabilitation Investment	0	0	0	0	0	0	|	|	|	|■	|	|	

	Key factor to the left has a **strong influence on** key factor above
|	Key factor to the left is **strongly influenced by** key factor above
ʃ	Both key factors **interact strongly** with each other
→	Key factor to the left has **some influence on** key factor above
←	Key factor to the left is **somewhat influenced by** key factor above
↔	Both key factors **interact** with each other
0	There is **no interaction** between the two key factors
←	Key factor to the left has a **strong influence on** key factor above and is **somewhat influenced by** key factor above
→|	Key factor left has **some influence on** key factor above and is **strongly influenced by** key factor above

Note: marked key factors refer to dark scenario

4.3 BRIGHT LOOK AHEAD

The span of years has been:

- Available data 5 years from 1996 to 2000;
- Partly available data 2 years from 2001 to 2002;
- Scenario writes for 8 years from 2002 to 2009.

Scenario has considered:

- Development of inhabitants and water consumption;
- Actions to control the growth of the water consumption;
- Cash flow and economic availability related to capita and length of network;
- Investments for the network and related rehabilitation investments dedicated to network diagnosis and replacement;
- Rehabilitation actions for the category of asbestos cement pipes.

Scenario has assumed:

- No changes in water tariff;
- No inflation rate effect;
- Constant running costs.

4.3.1. Water demand (Plot 1)

An increase of inhabitants could be expected till 2007; then from years 2008-2009 the inhabitants do not increase; this change is the main factor for assessing the consistency of network management in Reggio. It is a challenge because the maximum capacity of the water underground table is estimated about 17.0 million cubic meters per year within affecting the present acquifers level. In spite of that the water abstracted volume per year could be critical because greater than the maximum capacity and this would have to be managed with programms of water conservation.
It is an opportunity because the increasing revenue will keep producing the economical resources to maintain the network at the present standard and possibly upgrade it.

On the side of water conservation, the current authorized water per capita per day is 280 l/ab/d. The value will have to be control to decrease it from 280 l/ab/d @2000-2001 to 260 l/ab/g @2008-2009. Water losses volume will have to be kept within 2.0 million cubic meters per year.

To control the water demand, which is composed by consumption and losses, the actions are to be in line with:

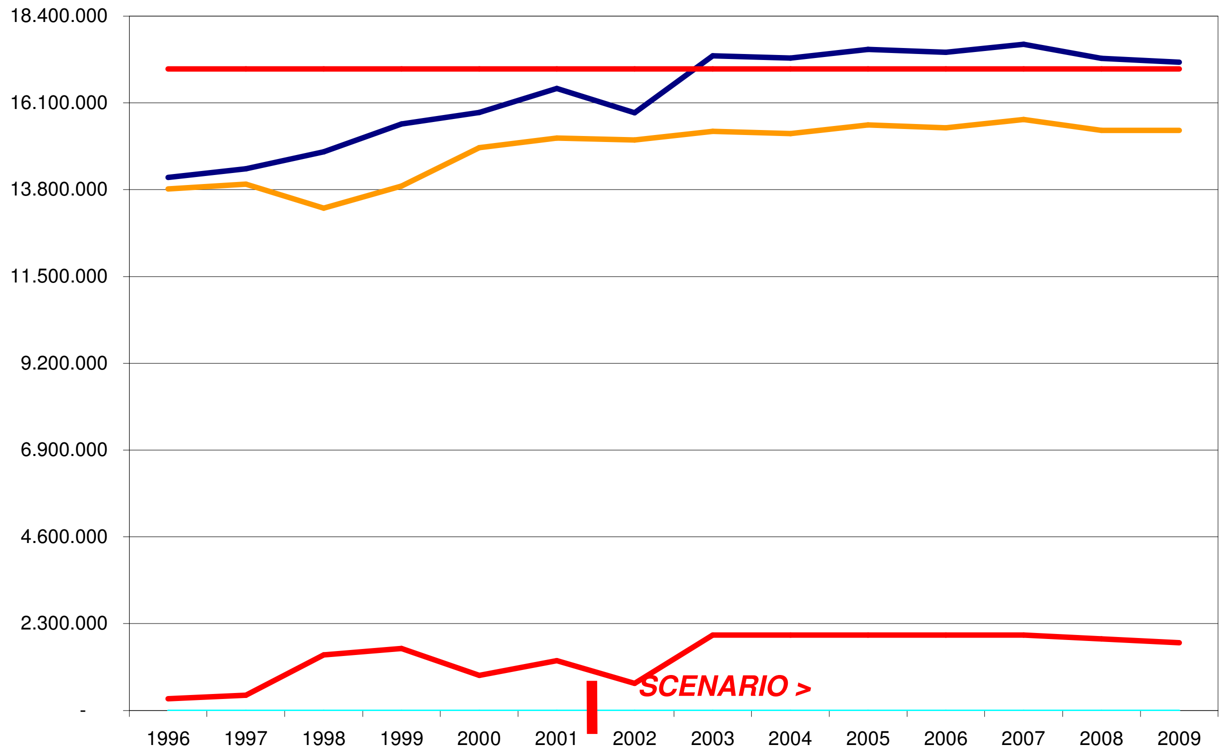
- Customer meter installation extension;
- Long term conservation program for:
  Residential indoor use
  Residential outdoor use
  Commercial use
- Financial incentives for low water use
- Youth education

Foto no. 4.1 - Conservation programm

- Active control system extension to cover the whole network and to have a water losses volume per year within 10-12% ;
- Active detection of water leaks;
- Hidden and not hidden leaks and breaks recording and classification.

The plot n.1 explains the volume water demand development in a trend/bright circumstance. The total volume is kept in balance with the natural resources, the water consumption is used with care despite the inhabitants increase and the water losses are kept under control with a trend towards a slight decrease.

Plot no. 1 – Inhabitants and water consumption



No.	Key factor	IWAPI	Description	Unit	Graph line
2	*W5*		Yearly water balance capacity	m3/year	
3		*A7*	Water abstracted	m3/year	
4		*A19*	Authorised consumption	m3/year	
5		*A20*	Water losses	m3/year	

Table no.1 – Key factors and IWA PIs for scenario graph no.1

4.3.2. *Actions for water conservation and water losses (Plot 2)*

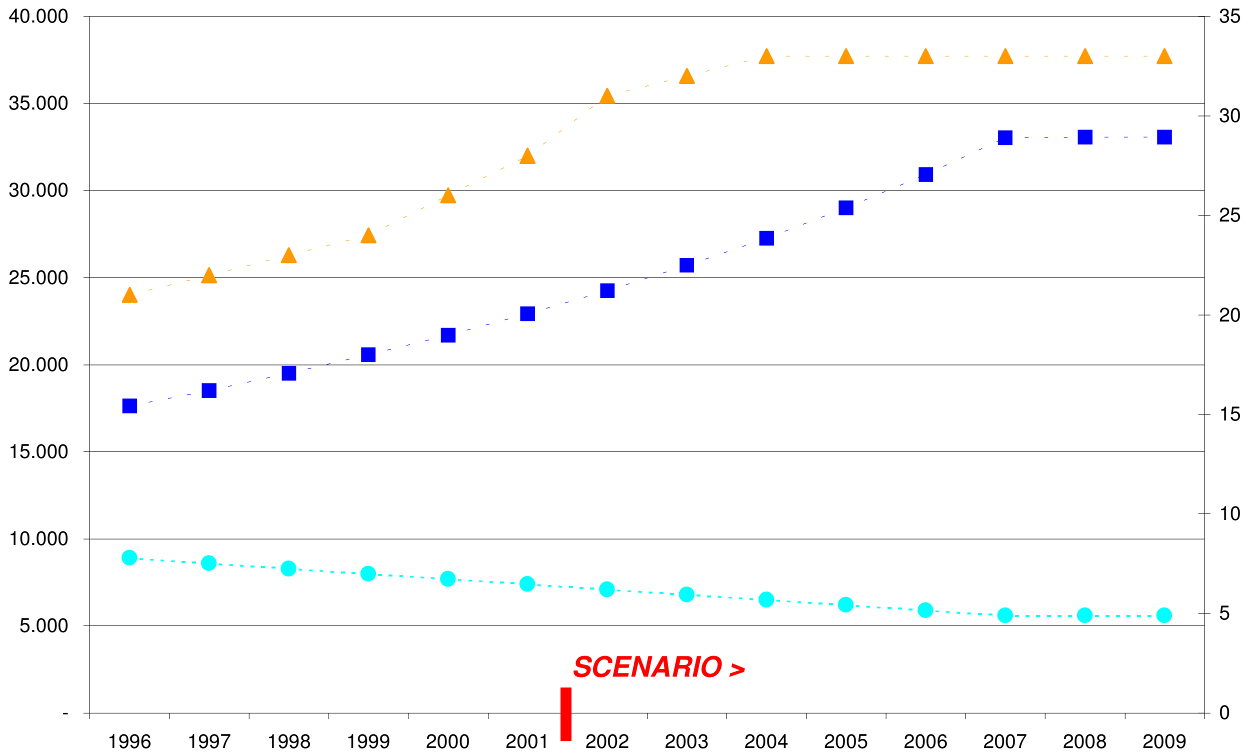
Foto no. 4.2 – Active districts

The following plot explores the development of the actions for water conservation and water losses. It is expected an increase in the number of active districts to control permanently the night flow and the leakage level of the whole town. The number of domestic meters which represents the 75% of the total stock of meters will increase, not only due to the new population living permanently in the town, but also for the water company policy to remove bulk meters for a building into a single meter for each flat. Per capita meter ratio is expected to decrease. The other actions to lower the consumption are in the field of information and educational programms.
In the plot no.2 it is expressed the ongoing implementation of districts to cover the whole urban area leakage control and the ongoing indoor domestic meter installations.

4.3.3. *Economical availability (Plot 3)*

It has been considered an increase in the total length of the network due to the growth of inhabitants and the new urbanisation needs. The length per inhabitant might vary from 4,7 m/capita @2001 to 4,4 m/capita @2009. The stock of pipes will increase from 696 km @2001 to 717 km @2009.
The percentage difference in the revenue water year by year might be positive till 2006 and negative during the years 2007-2009; the values should vary from +1,7% @2000-2001 to (-1,9%)@2008-2009.
The revenue per length of pipe might be steady with a slight decrease in the years 2007 – 2009; the values should vary from 14.4 euro/m @2001 to 13.7 euro/m.
From the above points, the water sales revenue should generate a relative steady specific per length cash flow till 2006. The network investments and the rehabilitation part of them should be steady, with a decrease in the period 2007 – 2009.

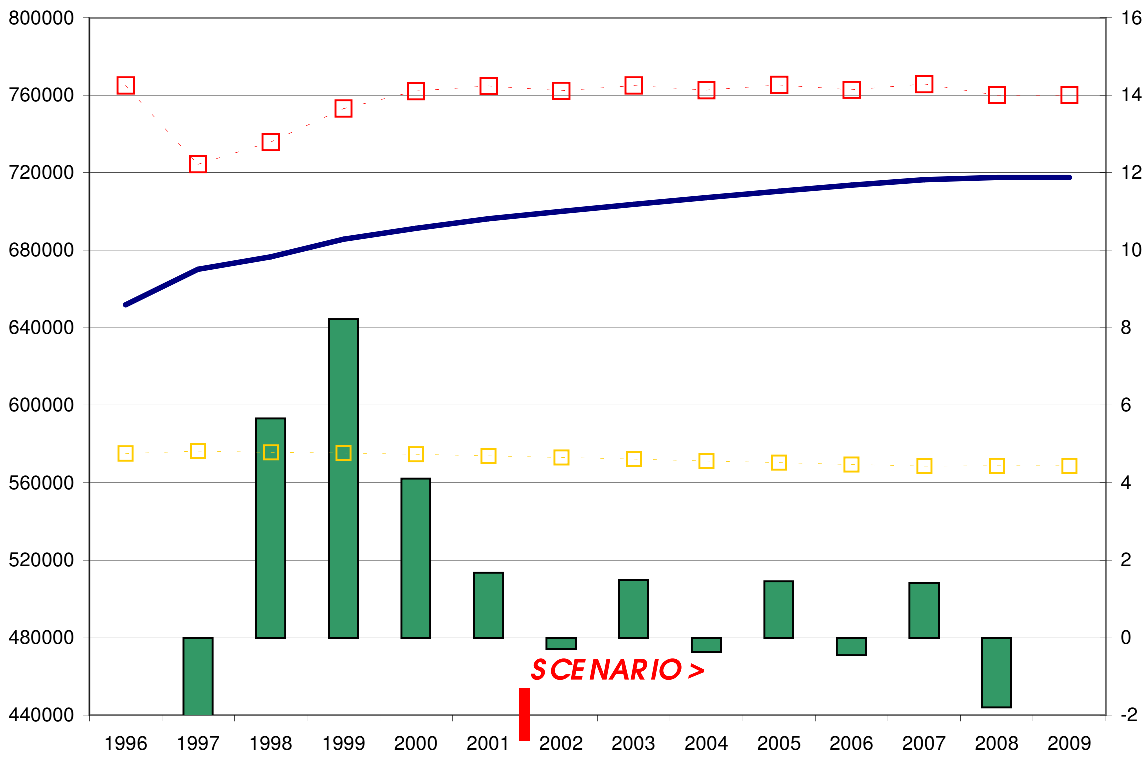
Plot no.2 – Water conservation and losses measurable actions



No.	Key factor	IWAPI	Description	Unit	Graph line
6			Domestic meters	No.of meters	
7			Population / Domestic user	Inhabs/meters	
8			Distretti realizzati	No. of districts	

Table no.2 – Key factors and IWAPIs for scenario graph no.2

Plot no.3 – Economical availability for network investements



No.	Key factor	IWAPI	Description	Unit	Graph line
9	W6	*C6*	Length of network	m	
10	W7		Length of network per capita	m / ab	
11		*G30*	Delta Water Sales Revenue	%	
12			Water Sales Revenue per length	Euro/(year x m)	

Table no.3 – Key factors and IWA PIs for scenario graph no.3

4.3.4. Rehabilitation investments (Plot 4)

The available network investments data are till 2000. Since then, they have been assumed constant per authorized cubic meter with a value of 0,15 euro/m3.

In the years 2008 2009 the decrease in the water sales could have an effect on them. From 2001 – 2002 the part of network rehabilitation investments and relative activities is of the same amount of network extension investments. The rehabilitation part might increase till a percentage of 74% of the total investments with a absolute available value of 1.7 million of euro per year

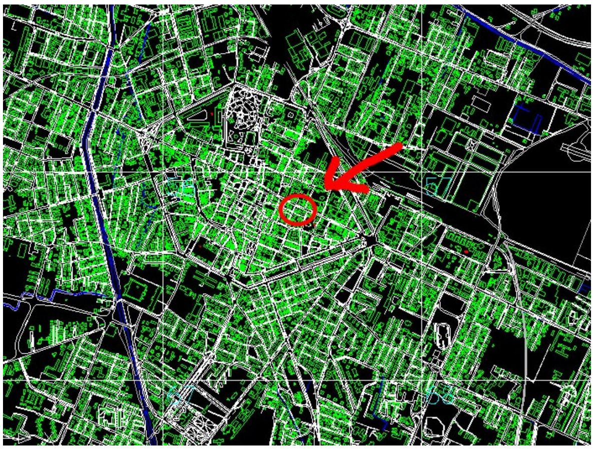


Foto. No. 4.3 – Pipe replacement program

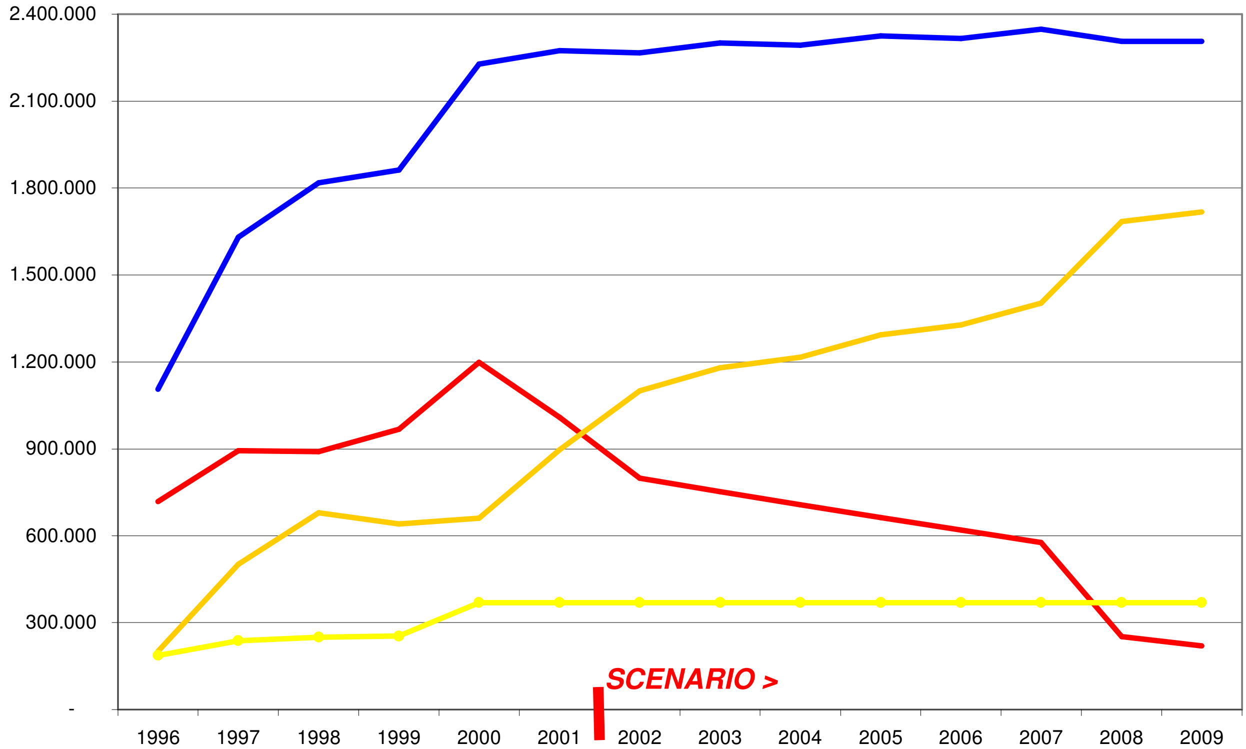
The service pipes rehabilitation investments might continue with a percentage of 16% of the total investments and an absolute value of 370.000 euro per year.

The plot n.4 highlights the growth in the availability of rehabilitation budget for pipes and a steady and slightly increasing need of investment in service pipe replacement.

4.3.5. Rehabilitation actions for asbestos cement pipes (Plot 5)

According to the tendency faced in the past years the asbestos cement pipes will decrease and with them the expected number of accidental breaks. In the past the ratio of replacement has been not steady but for the coming years the value might be of 0.8%. The tendency towards a reduction of this category is rather slow but constant. The number of breaks per year might be of 50 breaks per year, about a break per week for this category. In a long term scenario this value could be reduced with activities of investigations and selection of the most vulnerable pipes. The rehabilitation investments will improve the positive trend of the past years.

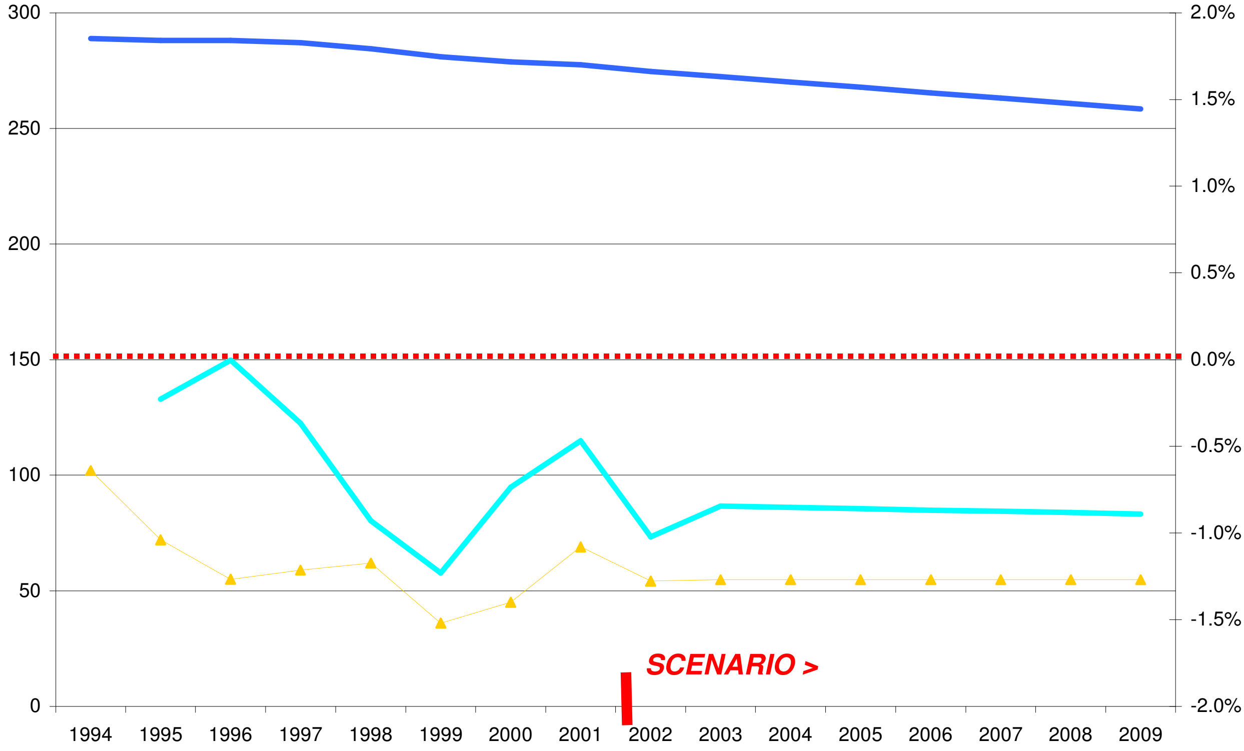
Plot no.4 – Network extension and rehabilitation investments



No.	Key factor	IWAPI	Description	Unit	Graph line
13		*G26*	Network investement	euro per year	
14		*G27*	New assets	euro per year	
		G28	Part for network rehab	euro per year	
15		*G28a*	Rehab pipes	euro per year	
16		*G28b*	Rehab service pipes	euro per year	

Table no.4 – Key factors and IWA PIs for scenario graph no.4

Plot no.5 – Asbestos cement length and rehabilitation investments



No.	Key factor	IWAPI	Description	Unit	Graph line
17			Asbestos length	m	
18			Delta Asbestos %	%	
19			Asbestsos breaks	n° per year	

Table no.5 – Key factors and IWAPIs for scenario graph no.5

4.4 DARK LOOK AHEAD

For a dark scenario look ahead, it has been assumed a population growth of the same values as in the trend scenario. The considered key factors are marked in the impact matrix (see impact matrix table). In principle, a negative scenario could occur because of:

- a progressive absence of management in the network leakage control and repair;
- a reduction of care in the operational data collection and processing, base for the ARP application.

In spite of that and considering the same authorized water as in the trend scenario, the effects are:

- increase in yearly water losses, pipe and service pipe breaks;
- increase in yearly water production;
- running costs expansion;
- reduction of rehabilitation investment for the running costs negative development;
- reduction of rehabilitation investment for the investment in new water sources of production.

4.4.1. Dark water demand (Plot n. 6)

The increase in water losses occurs during the 2004 towards. At the end of the period 2009 the amount of water losses increases of 2.0 million m^3:

- water abstracted (IWA PI A7) 18.9 million m^3 @ 2009;
- water losses (IWA PI A7) 3.8 million m^3 @ 2009.

Foto no 4.4 – Water shortage

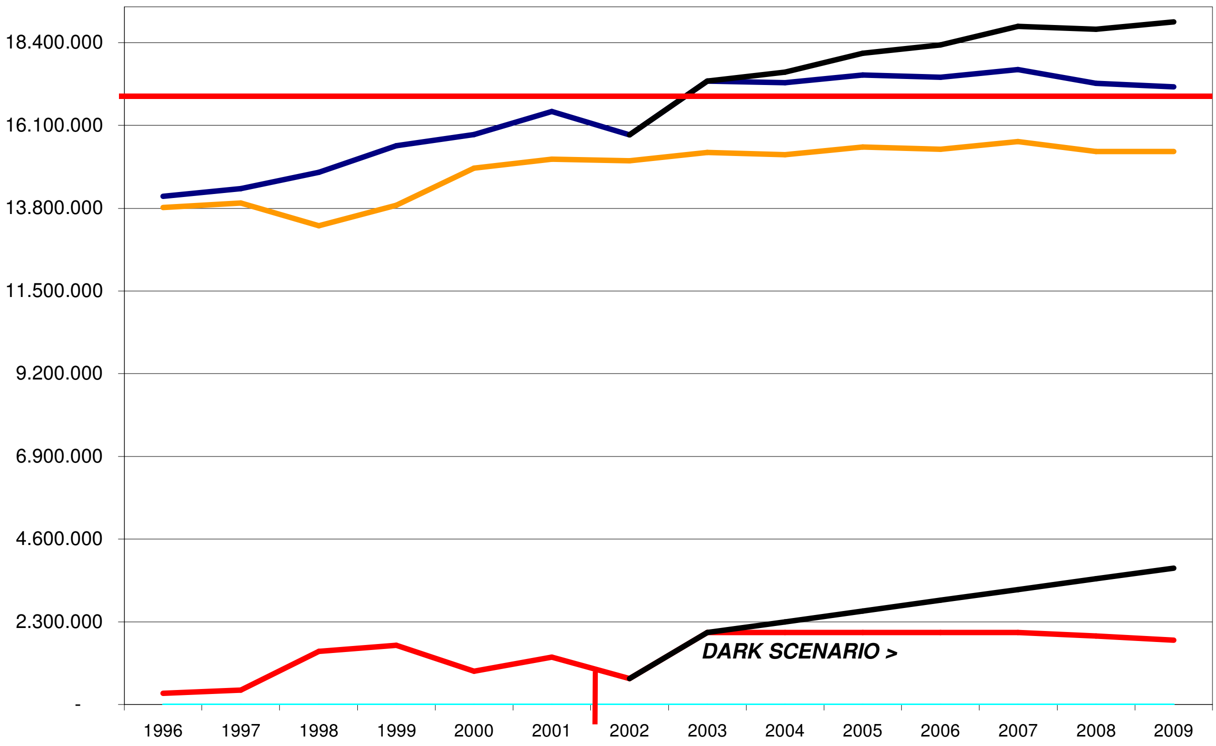
The marginal cost of water production is 0.115 euro/m^3. The operational costs increase up to 230.000 euro/year after 6 years. Not only, the abstracted water exceeds the maximum allowed amount of the ground water natural resources, causing a change in the depth of ground water level. This last aspect requires a specific study.

4.4.2. Dark rehabilitation investments (Plot n.7)

The break reduction depends on a sound and systematic database. Current and past repairs documentation can be used to have a whole network condition assessment and to focus on specific conditions which are worth to be rehabilitated. Day by day operations do not allow to consider ahead the network efficiency and the more effective annual rehabilitation works but they are indeed useful to determine the current situation. The repairs database must be kept updated and checked so that annual rehabilitation plan ARP can rely on it. It is not an easy task to point out the whole disadvantage of not adopting ARP network database implementation and maintenance. It can be expressed as an increase in breaks repairs during the coming years. The amount of steady increase can be up to 40 more pipe breaks till 2009 which is what has been reduced in the past years with investigations and active management plus 50 more service pipe breaks till 2009.

The running costs increase of 100.000 euro/year and of 230.000 euro/year with the water losses till 2009. The performance indicator Fi2, running costs indicator, has a delta increase + 0.021 euro/m^3. Conversely the performance indicators Fi18 goes down to 0.129 euro/m^3.

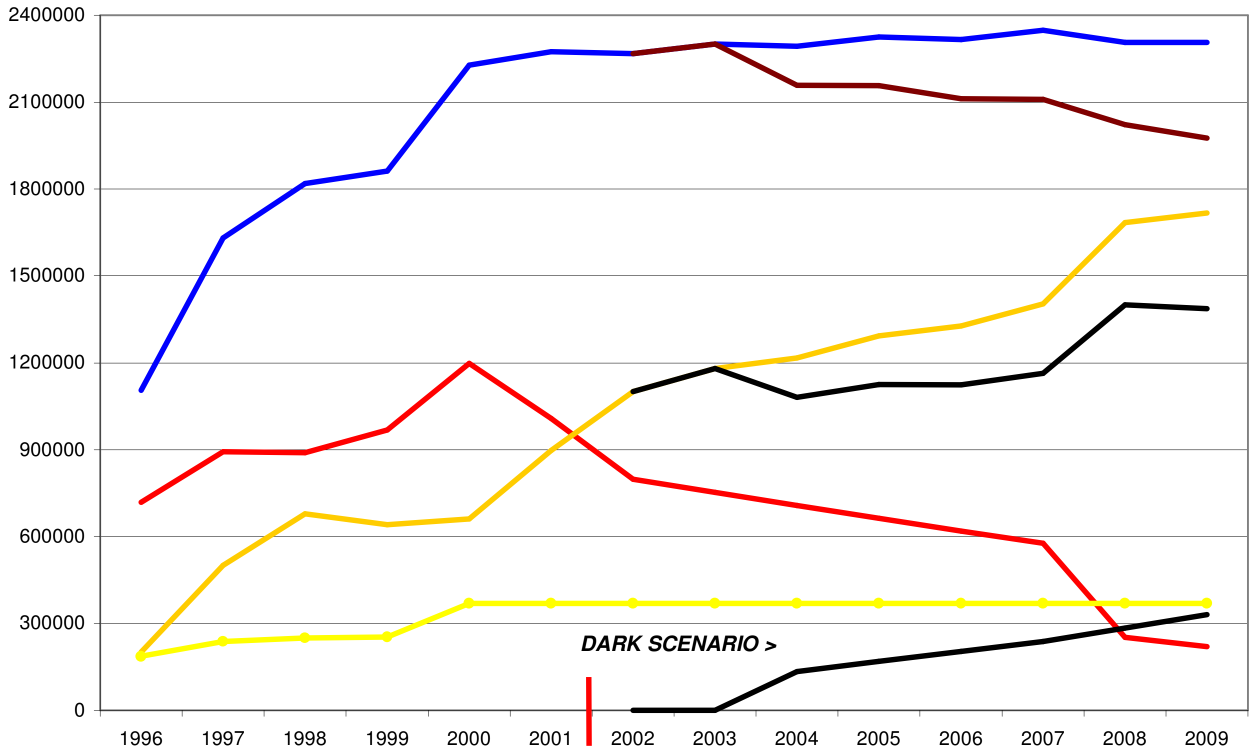
Plot no. 6 – Water consumption dark scenario



No.	Key factor	IWAPI	Description	Unit	Graph line
2	*W5*		Yearly water balance capacity	m3/year	
3		*A7*	Water abstracted	m3/year	
4		*A19*	Authorised consumption	m3/year	
5		*A20*	Water losses	m3/year	
		A20	DARK Water losses	m3/year	
		A7	DARK Yearly water balance capacity	m3/year	

Table no. 6– Key factors and IWAPIs for dark scenario graph no. 6

Plot no.7– Rehabilitation investments dark scenario



No.	Key factor	IWAPI	Description	Unit	Graph line
13		*G26*	Network investement	euro per year	
14		*G27*	New assets	euro per year	
15		*G28a*	Rehab pipes	euro per year	
16		*G28b*	Rehab service pipes	euro per year	
		delta Fi 2	DARK Delta running costs	euro per year	
13		*G26*	DARK Network investment	euro per year	
15		*G28a*	DARK Rehab pipes	euro per year	

Table no. 7– Key factors and IWAPIs for dark scenario graph no. 7

CARE_W APPLICATION TO THE CASE OF THE AGAC MANAGEMENT OF THE URBAN NETWORK OF THE CITY OF REGGIO EMILIA

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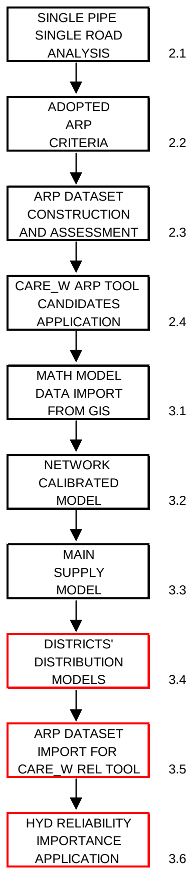
Former AGAC Network Services Head

AGAC participants: Gloria Delsoldato, Emiliano Sironi, Maurizio Cingi, Robert Bertozzi

3.1 MATH MODELS IMPLEMENTATION

To model the Reggio network it has been used the industry standard code Epanet, prepared by U.S. Environmental Protection Agency. The adopted approach is represented in the flow chart. The analysis from the ARP dataset construction has been the start point. Each road has a full description of the asset stock and the series of events which occured in the past to the pipes. With the ARP tool, according to the selection criteria, the rehabilitation list of pipes has been determined. ARP rehabilitation list considers the mechanical reliability of the pipes, the consequences of the breaks for the customers, either water customers or traffic customers as well as the importance of rehab the network in accordance with the other companies which manage different services within the urban area. Therefore the hydraulic importance of the pipe and the consequences of its failure for the water service must be added to ARP list to complete the assessment.



This has been done with a mathematical and calibrated model. The math model must have a size to be easier understandable in its results. Hence it has been split the Reggio model in two steps. Then, because the aim was to assess the criticality of the distribution pipes, it has been applied Relnet tool to figure out the hydraulic criticality index of the pipes in the ARP list. Relnet tool is an advanced tool developed from Brno University and included in the CARE_W suite of tools.

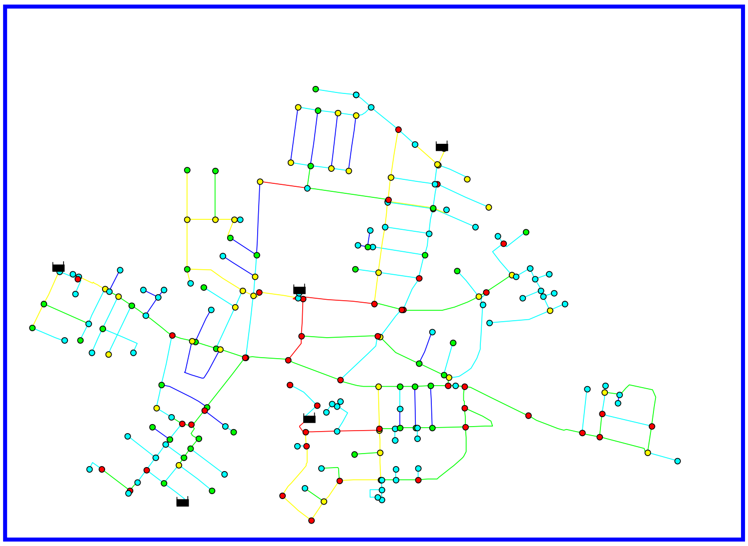


Fig. no.1 – Model construction

Two main interface codes have been used to introduce data from different archives into the Epanet code.

Input data

Epanet code needs the following input data:

- pipe features,
- node features,
- boundary conditions.

The pipe features have been acquired automatically through a first internal code from the GIS archives. Not only that but also the geographic coordinates have been imported. Hence the length of pipe has been worked out.

The second internal code has been used for the node consumption. The code, which has been applied also during the dataset construcution of ARP tool application, works out from the customer information system CIS, the value of the user consumption of each street through a process of data withdrawal by road. During the procedure, the main customers are analysed as well as customers with a not domestic profile. The boundary conditions are processed with the data delivered from a specific office, namely Gestione impianti acqua.

Data processing and analysis

The nominal diameter is converted into internal diameter; the roughness is defined from the pipe material and then, during the calibration phase, it has been modified to be the model heads in accordance with the heads collected during the field survey.

The consumption has been split between the two nodes of the pipe with the assumption that the consumption is uniformeously distributed along the branches within the road. The customer with a specific consumption has been located to the nearest node. The pattern consumption is defined through the sample of typical consumers of a specific category.

Field survey

Firstly each district boundary has been verified to have a valid survey without any unknown inflow. Then the field survey has been undertaken. To calibrate the model the measurements are collected to the inflow to the districts and to the pressure inside the districts in a selection of significant positions. A levelling activity took the ground level position of the points. The field survey has been taken for a period of a week, given a wide sample of hydraulic measurements.

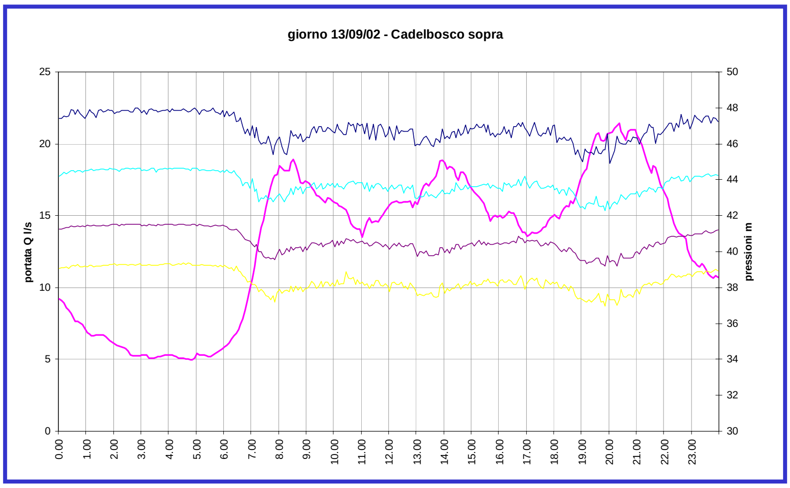


Fig. no 2 – Hydraulic measurement field survey

Model calibration

The hydraulic measurements are taken for model calibration. For the network analysis a flow selection considered three conditions which are maximum, average and minimum network demand. The head at the field survey nodes is obtained from the sum of the level and the pressure at the selected time of the day. The discordance was a very good exercise to understand the network behaviour and its anomalies. Therefore it was necessary to modify the network or to take further measurements on field. It can be said that calibration activity is the core of the math model. Through it the network has been understood and it gave the confidence to apply the model for the next step of Relnet application. Data to assess were pressures at nodes, the head losses into the pipes, the flow paths.

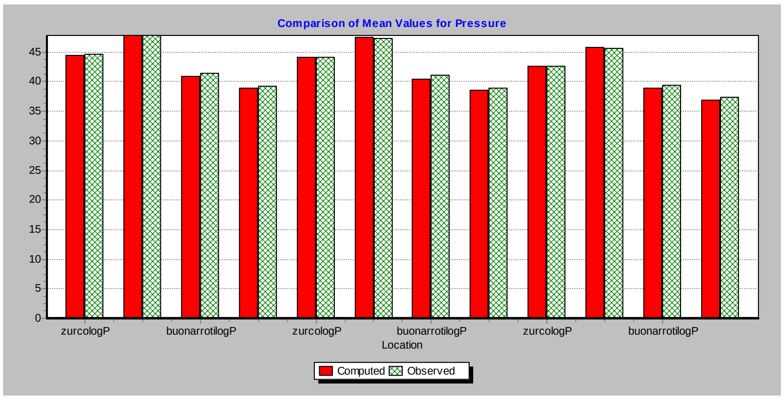


Fig.no 3 – Field survey measurements and model values

3.2 MODELS ACTIVITIES

Main urban supply model

Model construction has been done automatically by importing the GIS data into Epanet. This process has avoided any errors due to the input process. From the structure of the network it was natural to split the model construction in two parts:

- the main urban supply model
- the districts models

The structure starts with the well field outside the town. The water is convoyed, with two main supply pipes, into the main plant, namely via Gorizia with two ground tanks (9,5 Ml liters capacity at 55 meters above sea). One group of pumps (and one emergency group) supplies water directly into the water distribution system and into the small water tower (1,0 Ml liters). The water tower determines the maximum piezometric level, 101 meters above sea, and balances the pump production and the water demand. In the eastern part of the town it has been built a relative recent plant, Reggio Est. The plant is located on the large ring pipe of the town, it is supply during the night by Gorizia plant and during the day it supplies water into the town at the same piezometric level i.e. 101 meters above sea.

The main network convoys water from a water tower to the other. From the main line, except few cases, each district receives water for the customers. Each inlet to a district has its own flow meter. The measurements are available and are the boundary conditions for the main supply model. The pressures in the network have been taken with a field survey.

The model with the EPANET code, fig.no.4, has been built to reproduce the conditions of the main supply network during three significant demand conditions.

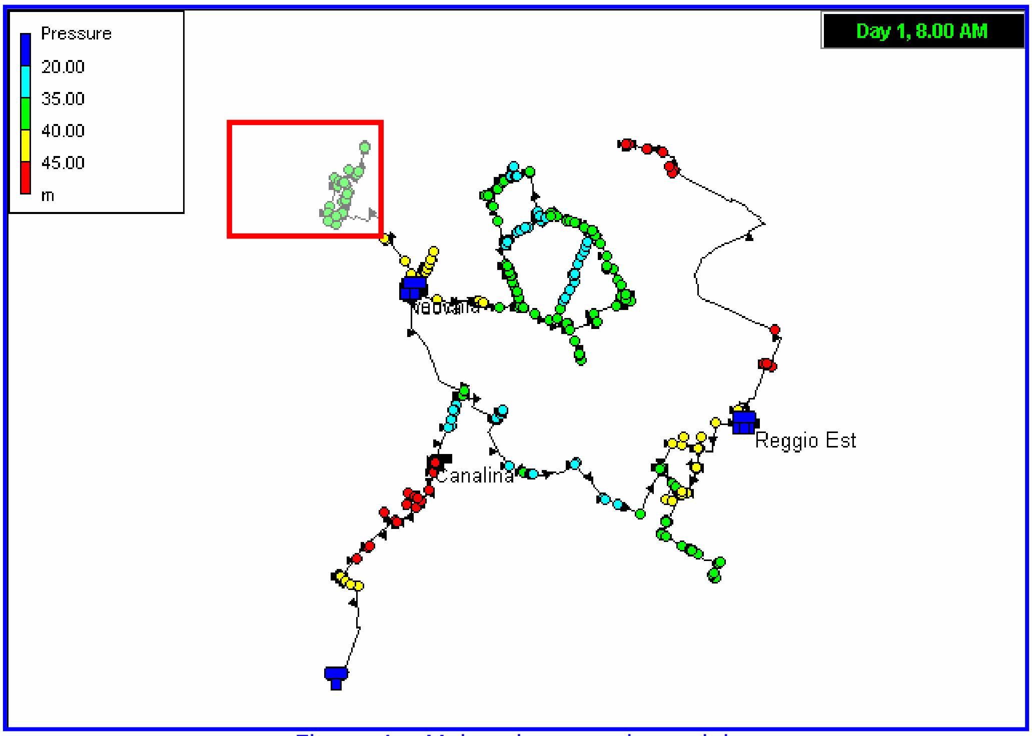


Fig.no.4 – Main urban supply model

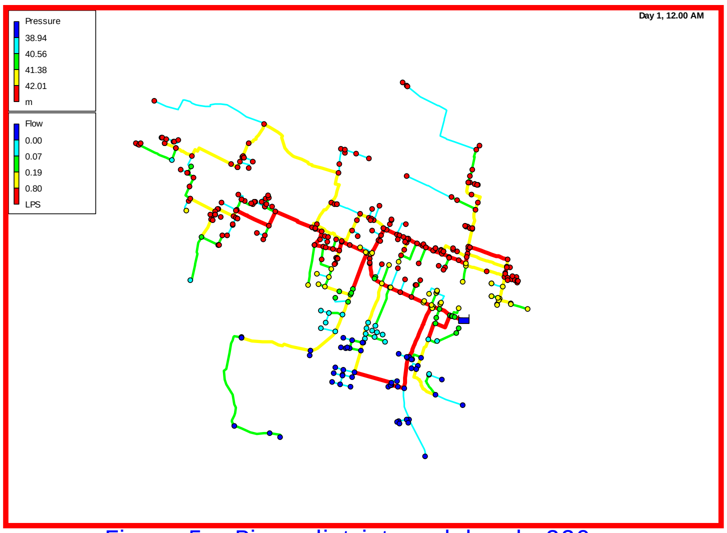


Fig.no.5 – Pieve district model code 220

The model analysis describes how, during the different period of the day, the network pressure changes quite consistently. This condition occurs in the nodes between the two water towers and it describes the current operational mode of Reggio est water tower. The plant has been built with a ground water tank and a small tank at the top of the tower as much similar to Gorizia plant. The final configuration will have an indipendent well field which it will fill Reggio Est ground tank. Then the town will have two water production systems, completely indipendent. Meanwhile Reggio Est is fed through Gorizia during the night period. During the night the external ring pressures reduce due to the batch process to fill the tank. Once the tank is full, the external ring operates in the typical condition with the total head of the two water towers.

Districts models

The head and pressure results of the main urban supply model in the different conditions have been used as boundary conditions for the model of each districts. The districts pipe structure, as in the main model, has been imported automatically from the GIS system. Typically the model construction is done selecting part of the pipes to give a better interpretation of the model results rather than to keep all the pipes. For the CARE_W application it has been necessary to use all the components in order to assess the hydralic criticality of the ARP list of pipes. The boundary pressure conditions of each district have been classified in the following graphs:

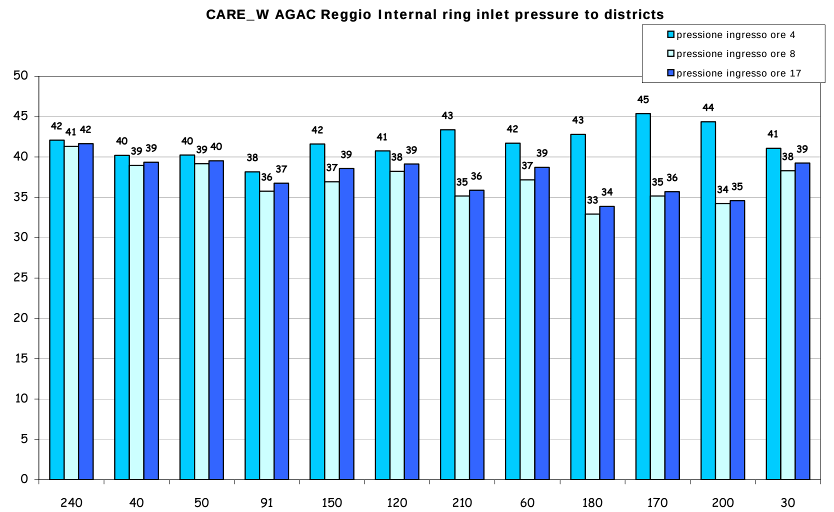


Fig. no.6 – External districts maximum, average and minimum pressure

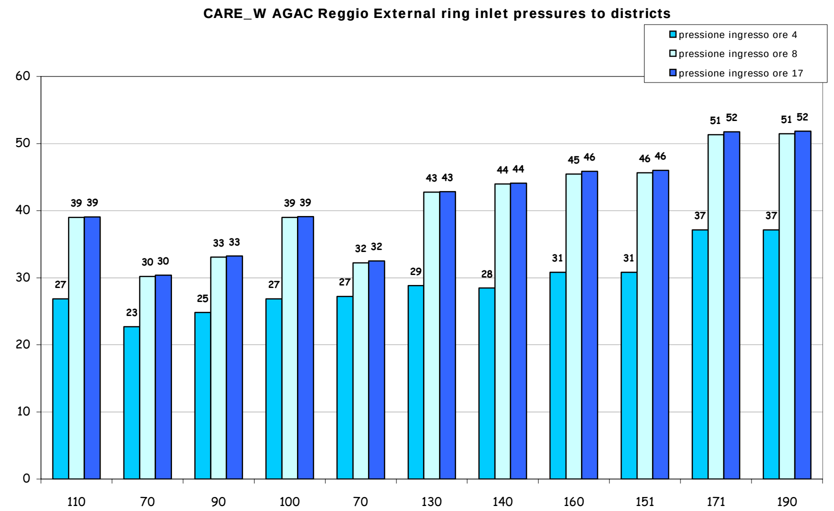
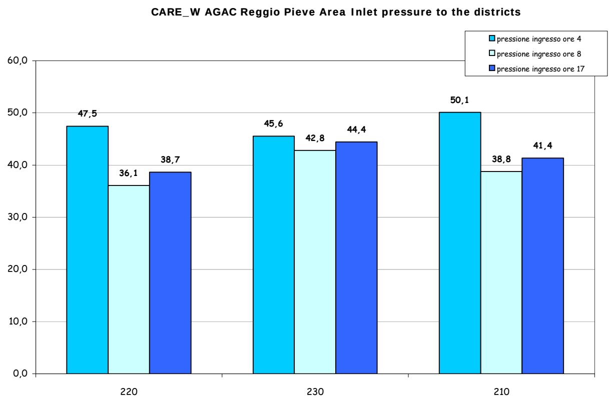


Fig. no.7 – Internal districts maximum, average and minimum pressure



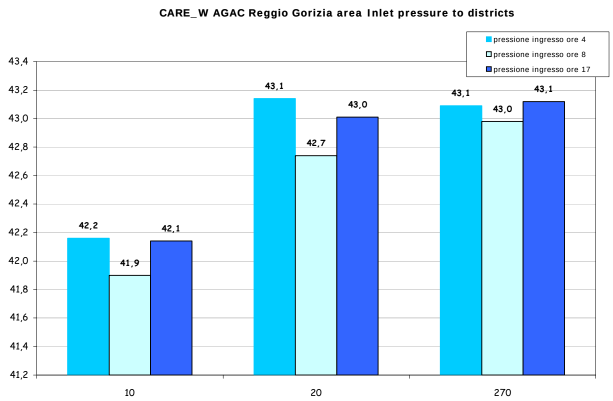


Fig. no.8 and Fig. no.9 – Pieve and Gorizia districts maximum, average and minimum pressure

3.3 REHAB CANDIDATES AND HYDRAULIC CRITICAL INDEX

Relnet conditions

Two aspects have to be analyze and evaluated when there is an event of a pipe failure:

- effect to the network operational pressure; a reduction or an interruption of the service.
- effect to the water tanks and their capacities.

The aim of the application has been the first effect. The selected pipes have been those who have had the highest number of failures (MTTF lower) and with the worst consequences on water customers and traffic.

Relnet model considers the actual conditions of head, pressure and flow (H_{actual}, h_{actual}, Q_{actual}) in the network and its nodes. Then the hydraulic criticality index for the selected pipe is worked out. The failure pipe is not available for the network. The model calculates the new conditions of pressure ($h_{new\ condition}$). Relnet considers two pressure thresholds and three pressure bands:

- below $h_{minimum}$ the demand at nodes is not satisfied;
- between $h_{minimum}$ and $h_{required}$ the demand at nodes is reduced;
- above $h_{required}$ the demand is satisfied.

More the hydraulic criticality index is higher, more is important the pipe with potential failure. So a pipe hydraulic criticality index with value of 0 represents a pipe not at all critical, while with a value of 1 represents a pipe so important that the failure creates an operational collapse of the network.

Relnet tests

For the case of Reggio the minimum pressure has been defined equal to 15 metres in the peak of the day, with reference to an house of three levels and a pressure above the critical tap of 6 meters. The required pressure has been defined equal to 25 meters.

Table no.1 considers a list of pipes extracted from the ARP dataset, for some of them the corresponding leakage control district and the reference to the math model. The math model has been prepared for nine of them (see Epanet file name).

Reggio Emilia network, January 2004

Street	Num	D (mm)	Material	L(m)	District	District name	Epanet file
Andreoli Don Giuseppe *	1	63	PE	110	30	Teatri	30-cs1-i-teatr.inp
Camurri Quarto *	1	200	FIB	560	220	Pieve	220-pieve glo.inp
Colsanto *	1	60	FIB	210	20	Gorizia	20-via-gorizia.inp
Cugini A. *	5	200	FIB	690	OFF		Reggio maestra.inp
Folloni Selvino *	1	150	FIB	600	OFF		Reggio maestra.inp
Giotto da Bondone *	3	63	PE	70	280	Coviolo	280-coviolo.inp
Gozzano G. *	2	150	FIB	180	250	Canalina	250-canalina.inp
Gramsci A. *	1	200	FIB	1810	190	Mancasale	190 mancasale.inp
Medaglie d'Oro della Resistenza *	1	100	FIB	170	120	Ex Polveriera	120-ex -polveriera.inp
Premuda *	1	250	GH	760	270	Premuda Francia	-
Ramazzini B. *	1	80	GH	750	172	Reggiane Ramazzini	-
Risorgimento (Viale) *	7	150	FIB	390	120	Ex Polveriera	120-ex -polveriera.inp
Roma *	1	80	GH	150	60	Fontanesi Tricolore	60-cs3-piazzafontanesi.inp
Samoggia N. *	1	300	FIB	1530	170	San Prospero	-
Tassoni A. *	2	200	FIB	700	80	Canali	80-canalina-fogliano.inp
Verdi Giuseppe *	1	80	FIB	560	20	Gorizia	20-via-gorizia.inp

Tab. no.1 - Candidates for Relnet

Then it has been selected the GIS pipe code, the maximum and minimum flow, demanded from the specific district, Table no.2.

Reggio Emilia network, January 2004
Min pressure 15 m Required pressure 25 m

Street	Num	D (mm)	Material	L(m)	District	Max	Min	GIS > Math code	HCI
Andreoli Don Giuseppe *	1	63	PE	110	30	28.8	8.1	6388	0
Camurri Quarto *	1	200	FIB	560	220	30.9	11.3	3634	0.67
Colsanto *	1	60	FIB	210	20	22.2	6.5	5761	0
Cugini A. *	5	200	FIB	690	OFF				
Folloni Selvino *	1	150	FIB	600	OFF				
Giotto da Bondone *	3	63	PE	70	280	-	-	768	0
Gozzano G. *	2	150	FIB	180	250	25.6	5.1	1043	0.18
Gramsci A. *	1	200	FIB	1810	190	-	20.0	9990-9993	0.83 -0.75
Medaglie d'Oro della Resistenza *	1	100	FIB	170	120	31.5	7.0	4804	0.04
Premuda *	1	250	GH	760	270	-	-	-	-
Ramazzini B. *	1	80	GH	750	172	-	12.0	-	-
Risorgimento (Viale) *	7	150	FIB	390	120	31.5	7.0	5150	0
Roma *	1	80	GH	150	60	26.1	7.4	6666	0
Samoggia N. *	1	300	FIB	1530	170	-	6.0	-	-
Tassoni A. *	2	200	FIB	700	80	30.0	10.4	941	0.08
Verdi Giuseppe *	1	80	FIB	560	20	22.2	6.5	5658	0

Tab. no.2 – HCI of ARP candidates

3.4 REMARKS

The adopted approach for Reggio network has not had the aim to analyse the global reliability index of each model but to assess the hydraulic criticality of the pipes which were candidates for the rehabilitation according to ARP tool. Epanet plus Relnet tools have been seen as an useful integration of the ARP tool to assess the operational condition in the new event of a failure at the previous repaired pipe.

From the tests it resulted that:

- not all the pipes which are ARP candidates are critical in hydraulic terms (HCI=0).
- among the other candidates, table no.3, the worst critical case is Gramsci because of the highest HCI and the high demand area. This pipe has the highest priority according to the past events, the adopted criteria and C33 category, the hydraulic calculations done.

Reggio January 2004 ARP + Epanet + Relnet

ARP pipe Id	Priority level	COS	ARC	WLI	PWI	PCWI	PFWI	DT	PFR	Long Name	Fail No 1994-2001	L(m)	Fail Rate 1994-2001 Fail /100m/year	HCI
1188	C33	0	152	0.5	241	0.48	8.75	0.052	0.069	Gramsci A._1	10	1810	0.069	0.83 -0.75
2410	C33	0	393	0.2	1221	0.63	8.75	0.045	0.179	Tassoni A._2	10	700	0.179	0.08
413	C33	0	295	0.3	110	0.47	5.25	0.033	0.134	Camurri Quarto_1	6	560	0.134	0.67

Tab. no.3 – ARP category and HCI of highest priority candidates

Some candidates have been already rehabilitated. Among them, actions have been taken for Roma, which is critical but not for its hydraulic importance, and Tassoni. About Tassoni, HCI index reflects the upgrade hydraulic configuration to reduce the criticality of this pipe. For this pipe, further rehabilitation actions should be considered.

From the tool applications AGAC has:

- improved the whole knowledge of its network;
- proceeded by priority in a proactive way according to the most critical rehabilitation works for Reggio urban area;
- assessed the action to be taken in case of emergency;
- develop the diagnose method and tools for its rehabilitation needs.

Further more, the CARE_W integrated approach has improved the skill of the whole organization to work by priority in a much wider perspective.

CARE_W
APPLICATION
TO THE CASE OF THE AGAC MANAGEMENT OF THE URBAN NETWORK
OF THE CITY OF REGGIO EMILIA

Author: Marcello Schiatti, Engineer, DEWI S.r.l.
Former AGAC Network Services Head

AGAC participants: Gloria Delsoldato, Emiliano Sironi, Barbara Barani, Paolo Torre, Raul Borciani, Maurizio Cingi, Robert Bertozzi

2.1 ANNUAL REHABILITATION PLAN

The ARP tool is based on the concept of past reliability and future criticality of a defined category of pipes. Such approach requires a well-established database, and it is represented in figure 2.1.

As for the reliability criteria, it is necessary to reconstruct the condition of the components, then the different breaks that have occurred. As for the criticality criteria, it is necessary to define the consequences of the pipe breaks on the system, in the broader sense of the word (waterworks consumers, businesses, traffic).

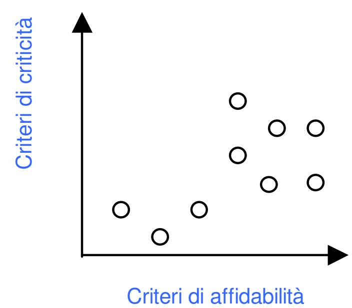


Fig. 2.1 – ARP Tool

The definition of both the hosts of criteria is given through a sequence of rules. Such rules are applied to the cases under examination in order to set the priority of every single case. The result leads to a bi-dimensional classification of pipes/streets, see figure 2.2, with a bottom-up rehabilitation importance hierarchy. Hence, according to the set criteria, C33 is more important than category C32, then C22 is similar to category C31, then C21 is more important than C11.

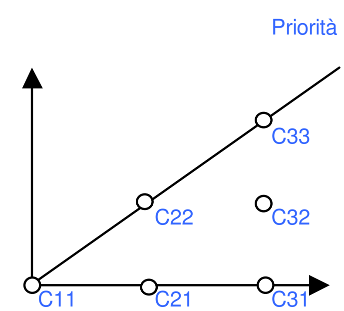


Fig. 2.2 – ARP Categories

This document describes the method followed in the collection of the data for the application of the support instrument for the choice of the pipes to be rehabilitated year after year, called ARP, annual rehabilitation plan.

2.2 CRITERIA

The use of Performance Indicators does not allow to diagnose which parts require rehabilitation, when interventions should be made and what kind of rehabilitation should be done. In order to answer to these questions, several measures and pieces of information must be collected, which shall be useful to decide the candidate parts for rehabilitation, starting from single, well-described cases. The objective of this work was therefore to collect such information, to automatically define the feasibility of the procedure, to obtain the candidate parts for rehabilitation for 2002, to perform the necessary observations on the candidate parts thus obtained.

Since the waterworks network under examination is around 700 km long, and its components are interconnected, the operation of a component has a hydraulic influence on those surrounding it. This part of the study, i.e. the hydraulic exam of the potential consequences of every single break, has been dealt with in a second stage (see chapter 3: Hydraulic reliability and service level of packet WP2). The primary task was to organize the knowledge on single cases and then, once the candidate parts have been known, they have been verified with the Epanet + Relnet model. In our application case, we built the database until 2001, basing it on *components*, *asset stocks*, *network*, *urban environment*, as reported in figure 2.3:

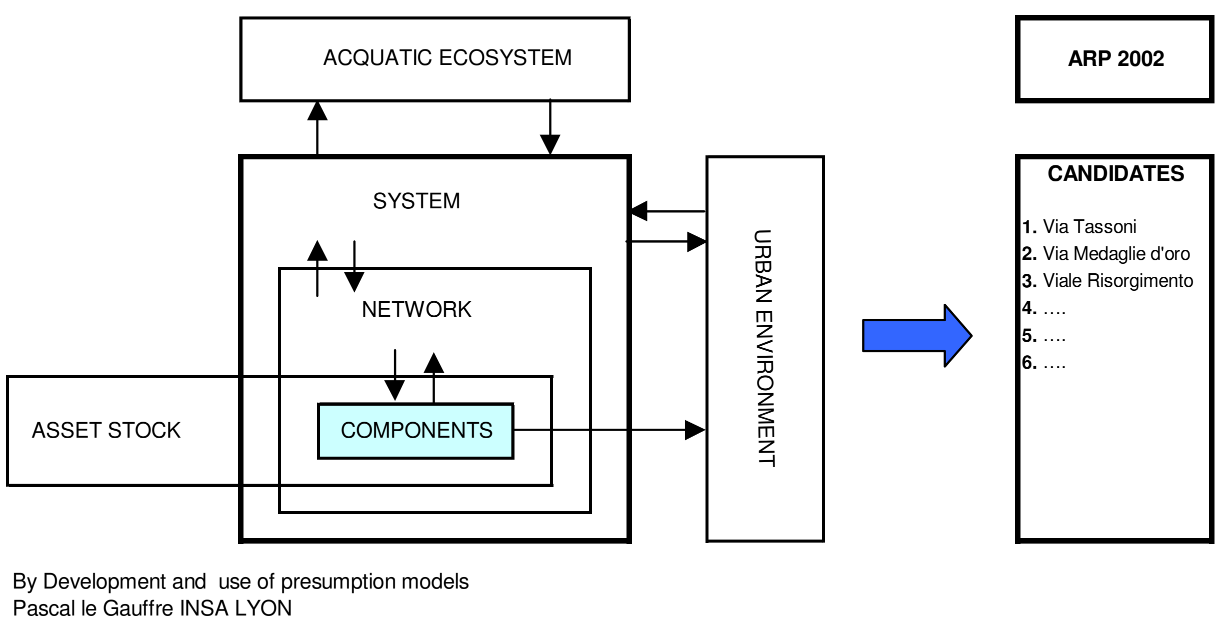


Fig 2.3 ARP yearly analysis till year 2001 - Candidates 2002

The database components are the parts of the street with the same kind of pipe. So, for example, each street can have more components, as shown in the following table:

Street	Num	D (mm)	Material	L(m)	Dist
Allegri (Viale)	1	90	PVC	135	30
Allegri (Viale)	2	80	FIB	45	30
Allegri (Viale)	3	32	PE	50	30
Allegri (Viale)	4	80	GH	60	30
Allegri (Viale)	5	63	PE	55	30
Allegri (Viale)	6	90	PE	45	30
Amendola G.	1	200	FIB	910	160
Amendola G.	2	200	ACC	10	160
Amendola G.	3	110	PVC	1100	160
Amendola G.	4	90	PVC	126	160
Amendola G.	5	90	PE	35	160
Ampere A.M.	1	160	PVC	96	180
Ampere A.M.	2	80	FIB	70	180
Teggi	1	160	PE	2770	10
Teggi	2	63	PE	1290	10
Teggi	3	110	PE	840	10
Teggi	4	160	PE	780	330
Teggi	5	75	PVC	120	10
Teggi	6	40	PE	100	10
Teggi	7	32	PE	50	OFF
Teggi	8	40	PE	50	330
Teggi	9	90	PE	40	10
Teggi	10	50	PE	30	330
Valle D' Aosta	1	90	PE	170	OFF
Valle D' Aosta	2	160	FIB	420	OFF
Valle D' Aosta	3	160	PE	450	OFF

Table No. 2.1 - Example of component constructions

Even if the cartographic system is up-to-date (see the article Diagnosis of urban water supply and wastewater infrastructure – *M Schiatti Acquire cartographic data as basis to reinforce management and rehabilitation of water infrastructure* Proceedings from COST C3 end of action workshop Brussels, 18 and 19 May 2000), the street parts are not linked to the street name, therefore the list was made manually and it required an examination of all the existing cartographic documents, for an extension reported in table 2.2:

REGGIO E. TOWN Case Study

ROADS	COMPONENTS	EXTENSION
Q.ty	Q.ty	Length Km
1258	2825	651,2

Tab 2.2 – ARP Database Extension

for a total of around 1400 streets and an extension of 700 km. For each part the breaks occurred have been reconstructed. In this case as well, the break reconstruction work was done manually and independently from the cartographic database, even if, with the recent creation of a new GIS system, it shall be considered an integral part of the same.

The analysis of the break data was carried on with the examination of the break registrations and, among these, of those referring to the pipes, and overlooking the intake breaks which cause small inefficiencies, that are part of a normal management situation. The data which could be retrieved from the call centre recordings were divided in successive subsets, according to the four criteria below:

1. at a first level, information has been divided into network water breaks, intake water breaks, private property water breaks (outside our jurisdiction) and unknown water breaks;
1. at a second level, a verification was made in order to assess for which breaks a repair paper had been written that contained the fundamental data for a successive classification;
2. at a third level, with a further subdivision, it was confirmed how many network breaks were such, and not intake breaks;
3. at a fourth level, the final subdivision was made: breaks caused by other operators and breaks without a cause. **It is this final part that expresses the reliability degree of a waterworks network.**

The breakdown into single categories was done in compliance with the Bayesian diagram reported in Figure 2.4:

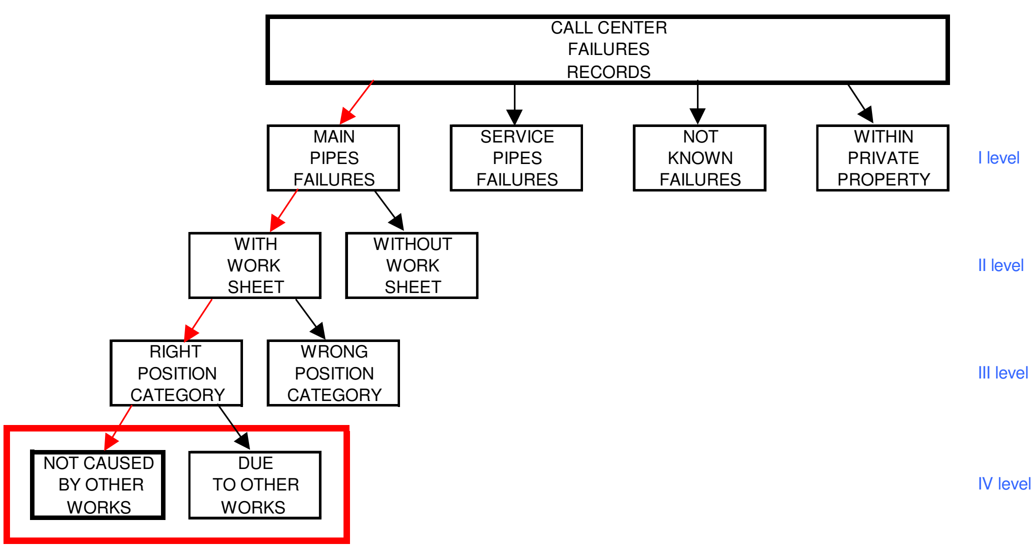


Figure 2.4 – Diagram of classification of the break database

For the 1998 case, the analysis showed the data dispersion reported in table 2.3. There is an initial condition of uncertainty; of the 139 calls for assistance, 137 present a recording with information, while 2 are unknown (1.4%). At the first level, the network break recordings have a percentage α=53.9%; the percentage of these which presents the repair paper is β=98.6%; by analyzing the papers, the interventions made on the network and not on the intake were χ=92.7%; of these, the interventions not due to third parties were δ=92.9%.

1998 BREAKS DATA DIAGONAL DISPERSION		
BREAKS CALLS	139	
BREAKS RECORDS	137	
NOT KNOWN BREAKS	2	
I level		
	Percentage	Other
MAIN PIPES FAILURES	0,538	0,462
II level		
	Percentage	Other
WITH WORK SHEET	0,986	0,014
III level		
	Percentage	Other
RIGHT POSITION	0,927	0,073
IV level		
	Percentage	Other
NOT CAUSED	0,929	0,071

Table 2.3 – Data failure dispersion

Observing the data on the red diagonal thus obtained, we can observe the reduced data dispersion in Figure 2.4, i.e. that part of the recordings which is fundamental in order to understand the water supply network reliability. At the end of this analysis, in the case of the year under examination, it can be stated that 118 interventions were made which are without doubt the manager's responsibility, since they have not been caused by other reasons and they have occurred on the supply network. Summing up, the database was integrated with the breaks, positioned in the examined parts for an amount of:

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	ARP DATA BASE
1994	12	5	14	5	17	12	26	19	17	7	17	15	166	134
1995	7	8	6	9	4	9	12	9	9	10	10	6	99	97
1996	7	6	5	1	7	3	9	21	9	4	10	4	86	74
1997	6	4	8	6	4	2	7	16	19	10	6	2	90	81
1998	12	7	15	8	8	3	15	15	11	11	5	8	118	109
1999	1	1	4	8	8	8	6	9	7	7	3	6	68	56
2000	5	1	0	7	4	11	10	11	12	10	9	3	83	74
2001	11	13	5	5	8	13	12	17	22	10	9	11	136	103
TOTAL	61	45	57	49	60	61	97	117	106	69	69	55	846	728

Table 2.4 – Years examined, seasonality and network breaks

Beyond the data on breaks, which are the basis for applying the ARP tool reliability criteria, the flow measurements proper of the active leak control system have been associated to them. In this case, the minimum night flows have an area reference, and not a single street and component reference; it was therefore necessary to associate to the code of each district the number of components and streets it contains; see table 2.5:

Street	Num	D (mm)	Material	L(m)	Dist	2000(m3/km/h)
Asioli B.	1	110	PE	130	70	1,53
Balletti A.	1	80	FIB	160	70	1,53
Campanella T.	1	80	FIB	420	70	1,53
Caro A.	1	80	FIB	80	70	1,53
Croce Benedetto	2	80	FIB	500	70	1,53
Croce Benedetto	4	90	PE	60	70	1,53
Gambetti Socrate	1	63	PE	100	70	1,53
Girona	1	80	FIB	110	70	1,53
Lepanto (Piazza)	1	175	FIB	140	70	1,53
Lepanto (Piazza)	2	90	FIB	40	70	1,53
Lepanto (Piazza)	3	200	PE	90	70	1,53
Magati C.	1	200	FIB	280	70	1,53
Magati C.	2	125	FIB	20	70	1,53
Motta R.	1	110	PE	50	70	1,53
Motta R.	2	90	PE	60	70	1,53
Passo Buole	2	225	PVC	110	70	1,53
Passo Buole	9	225	PVC	60	70	1,53
Pindemonte I.	1	80	FIB	400	70	1,53
Pindemonte I.	2	90	PE	40	70	1,53
Quarnaro (Piazza)	1	200	FIB	100	70	1,53
Quarnaro (Piazza)	2	90	PE	40	70	1,53
Risorgimento (Viale)	1	200	FIB	500	70	1,53
Risorgimento (Viale)	2	90	PE	40	70	1,53
Risorgimento (Viale)	3	90	PVC	50	70	1,53
Risorgimento (Viale)	4	100	FIB	10	70	1,53
Risorgimento (Viale)	5	110	PE	10	70	1,53
Rousseau G.G.	1	80	FIB	70	70	1,53
Tassoni A.	1	150	FIB	750	70	1,53
Tassoni A.	3	80	FIB	90	70	1,53
Tassoni A.	5	60	FIB	130	70	1,53
Telesio B.	1	80	FIB	530	70	1,53
Umberto Primo (Viale)	1	175	FIB	390	70	1,53
Umberto Primo (Viale)	2	90	PE	160	70	1,53
Umberto Primo (Viale)	3	100	ACC	570	70	1,53
Urceo A. detto Codro	1	100	FIB	330	70	1,53
Urceo A. detto Codro	2	80	FIB	130	70	1,53
Voltaire	1	80	FIB	410	70	1,53

Tab.2.5 – Active district code 70, measured night flow minimum and related components

Carrying on in the database construction, the criticality of the pipe break on a single part had to be assessed. The first step was associating the street to its water consumption. The elaboration was performed automatically, and was then useful for the Epanet + Relnet hydraulic models. The consumptions of the users' database of the last year under examination, 2001, were therefore assigned to the examined streets, obtaining the degree of importance of the street from this point of view. **Particular users** and **sensitive users** were also taken into account in characterizing the streets. Sensitive users were reconstructed starting from their position on the territory. Hospitals, flying squad centres and centres for the elderly are included in this category. They have been represented on the official cartography with a proper symbol.

Particular users use water for their economic production activity, therefore, if there is a break, they have not only a serious inconvenience, but also, potentially, a direct damage due to the lack of water. Among these, the following have been spotted: dentists, kindergartens, hotels, beauty centres. In this case the identification was obtained through a research on the Yellow Pages database, since there is no distinction among the commercial users in the company database.

REGGIO E. TOWN Case Study

ROADS	SENSITIVE USERS	CRITICAL USERS
Q.ty	Q.ty	Q.ty
1258	14	342

Table 2.6 – Streets examined and particular users

The recordings of low pressure and water with negative features were useful to further characterize the street and its service level. The position and number of each of these two report types was therefore also included. Passing on to the urban environment, the rehabilitation interventions performed in the past have been analyzed, together with the street types on which they were performed. The performed interventions archives date back to 1994, and they show the interventions done for substitutions on the water network, but also for gas pipes and sewers. It must be observed that the interventions on sewers are competence of the municipality.

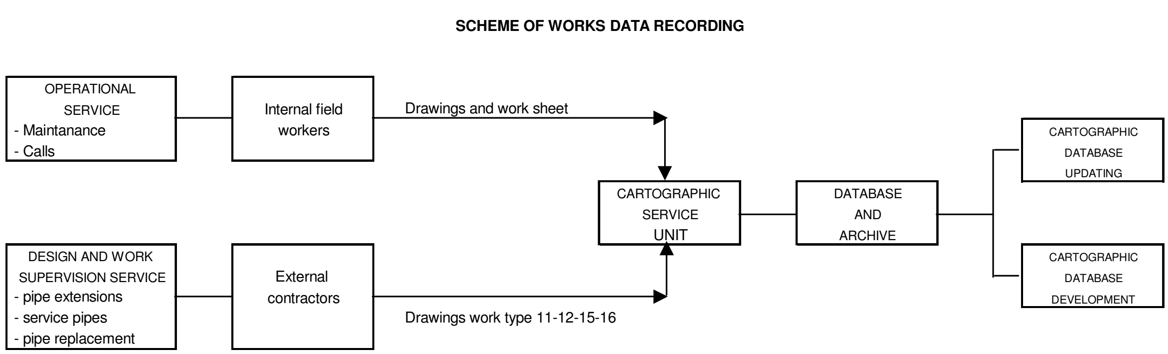


Fig. 2.5 – Flow chart of works recording

Single streets were therefore classified according to the year in which the last intervention had been made, and then divided in two classes, i.e. interventions performed in the last five years (1997 – 2001) and interventions performed earlier. Equally, the interventions performed for other services were divided in the same way, in order to classify past inconvenience suffered by the users.

A further knowledge base was built reporting the road works performed by the municipality; among these there are street asphalting, creation of new cycle lanes and of roundabouts. The reconstruction of this information was troublesome, and it was only possible for the last year under examination, 2001, since said road works, with a budget assessed at around 1 million euros per year, are not performed in compliance with a preventive programme.

Successively, each street was evaluated according to a classification which gives importance to the traffic intensity and the type of service of the street. The classification included, by order of importance, the streets for public utilities such as hospitals and care centres, then the streets leading in and out of the city, then the streets giving access to the services of the old town and finally all the other streets.

AGAC Reggio case 09 June 2003

STREET CATEGORY FACTOR		
C_SR	**Index ε [0,1]**	**description**
4	1	High
3	0,75	Critical
1	0,5	Central offices
0	0,25	Others

Table 2.6 – Classification of the urban streets

Taking into account the average times for the different break cases in the past, it was also possible to obtain a typical time for break time:

AGAC Reggio case 09 June 2003

EXPECTED DURATION OF INTERRUPTION		
C_EDI	**within hours**	**Description**
1	4	<= 110 FIB
2	7	<=200 FIB
3	10	>200 FIB
4	3	<= 110 other material
5	6	<=200 other material
6	8	>200 other material

Table 2.7 – Maximum typical intervention duration

Hence, it is possible to have a first indication of the global time of service absence or of potential inconvenience due to the breaks during a year. The single case and the inconvenience influence area must in any case be studied with a calibrated mathematical model.

Finally, the construction of the database for the application of the ARP tool for supporting the selection of the rehabilitation interventions was completed with the evaluation of the rehabilitation and repair costs for the year 2002.

MIN MAX REPLACEMENT COSTS • /ml (2002)

		without service pipes		with service pipes	
	Type of road	**Min diameter (DN 63)**	**Max diameter max (DN 200)**	**Min diameter (DN 63)**	**Max diameter (DN 200)**
rural	Terreno Nat.	• 22,50	• 62,50	• 77,50	• 117,50
	Macadam	• 32,00	• 72,00	• 87,00	• 127,00
central	Asfalto+Tappeto	• 91,00	• 131,00	• 201,00	• 241,00
	Asf+Tapp+magro	• 101,00	• 141,00	• 211,00	• 251,00

Table 2.8 – Rehabilitation unit costs

AGAC Reggio case 09 June 2003

C_UCRp	**UNIT COST OF REPAIR •**	**description**
1	1100	Diam [0-63] mm
2	1100	Diam]63-90] mm
3	1100	Diam]90-110] mm
4	2200	Diam]110-160] mm
5	2200	Diam]160-200] mm
6	3200	Diam]200-300] mm

Table 2.8 – Repair unit costs

The rehabilitation costs have been formulated taking into account:

1. an average substitution cost of a user connection equal to 110 euros, including digging and repristination on a private property;
2. for urban areas, a connection every 10 metres;
3. for rural areas, a connection every 20 metres;

2.3 CANDIDATES

The host of data was constructed with the evaluation and the participation of INSA from Lyon.

After the completion of the construction a **pre-selection of the candidates** to rehabilitation was performed.

Such pre-selection was performed taking into account a single criterion, the breaks in the last years, and writing a list with the streets with more cases. The candidates' pre-selection is reported below, together with the street pipes. Each of these candidates was later re-examined by INSA with the ARP tools for defining the selection of the rehabilitation candidates according to the given weights, i.e. in compliance with the greater importance attributed to the criteria used. The pre-selection was useful to go on with the hydraulic evaluation of the single cases:

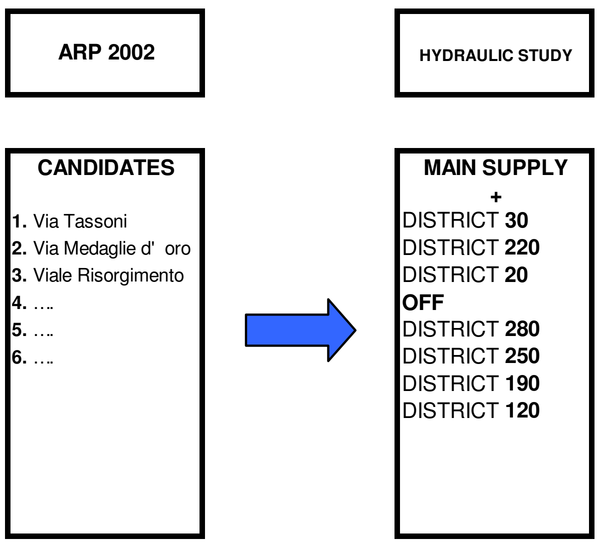


Fig. 2.6. – Hydraulic study of the pre-selected cases

The models of the districts including the candidate pipes were built and calibrated, and the degree of hydraulic relevance which the pipe break has on the service level was measured (Performance Indicator Ph13 – Hydraulic Criticality Index).

Street	Num	D (mm)	Material	L(m)	Dist	2000(m3/km/h)	Total Failures
Andreoli Don Giuseppe *	1	63	PE	110	30	2,79	6
Camurri Quarto *	1	200	FIB	560	220	0,85	6
Camurri Quarto	2	110	PE	279	220	0,85	0
Colsanto *	1	60	FIB	210	20	0,85	7
Cugini A.	1	90	PVC	190	140	0,94	0
Cugini A.	2	63	PE	100	OFF		0
Cugini A.	3	110	PVC	370	140	0,94	0
Cugini A.	4	175	FIB	110	OFF		0
Cugini A. *	5	200	FIB	690	OFF		5
Cugini A.	6	250	FIB	600	OFF		0
Cugini A.	7	110	PE	741	140	0,94	0
Folloni Selvino *	1	150	FIB	600	OFF		6
Folloni Selvino	2	110	PE	175	OFF		0
Giotto da Bondone	1	110	PVC	230	280	0,36	0
Giotto da Bondone	2	90	PVC	70	280	0,36	0
Giotto da Bondone *	3	63	PE	70	280	0,36	3
Gozzano G.	1	125	FIB	380	250	0,70	3
Gozzano G. *	2	150	FIB	180	250	0,70	7
Gramsci A. *	1	200	FIB	1810	190	1,41	10
Gramsci A.	2	125	FIB	790	OFF		0
Gramsci A.	3	40	PE	750	OFF		0
Gramsci A.	4	160	PVC	430	190	1,41	0
Gramsci A.	5	160	PE	200	190	1,41	1
Gramsci A.	6	65	ACC	120	190	1,41	0
Gramsci A.	7	140	PE	80	190	1,41	0
Gramsci A.	8	90	PE	80	190	1,41	0
Gramsci A.	9	80	FIB	60	190	1,41	0
Gramsci A.	10	200	FIB	170	171	1,86	0
Gramsci A.	11	160	PVC	180	171	1,86	0
Medaglie d'Oro della Resistenza *	1	100	FIB	170	120	1,48	3
Medaglie d'Oro della Resistenza	2	80	FIB	90	120	1,48	0
Medaglie d'Oro della Resistenza	3	110	PE	70	120	1,48	0
Medaglie d'Oro della Resistenza	4	110	PE	70	90	0,39	0
Medaglie d'Oro della Resistenza	5	100	FIB	110	90	0,39	0
Medaglie d'Oro della Resistenza	6	50	FIB	30	90	0,39	0
Medaglie d'Oro della Resistenza	7	110	PVC	10	90	0,39	0
Premuda *	1	250	GH	760	270	1,88	4
Premuda	2	150	FIB	470	270	1,88	0
Premuda	3	100	FIB	170	270	1,88	0
Premuda	4	160	PE	90	270	1,88	0
Premuda	5	80	FIB	80	270	1,88	1
Ramazzini B. *	1	80	GH	750	171	1,86	3
Ramazzini B.	2	150	FIB	350	171	1,86	2
Ramazzini B.	3	80	FIB	60	171	1,86	0
Ramazzini B.	4	110	PE	253	171	1,86	0
Ramazzini B.	5	90	PE	46	171	1,86	0
Risorgimento (Viale)	1	200	FIB	500	70	1,53	1
Risorgimento (Viale)	2	90	PE	40	70	1,53	0
Risorgimento (Viale)	3	90	PVC	50	70	1,53	0
Risorgimento (Viale)	4	100	FIB	10	70	1,53	0
Risorgimento (Viale)	5	110	PE	10	70	1,53	0
Risorgimento (Viale)	6	200	FIB	270	50	2,53	0
Risorgimento (Viale) *	7	150	FIB	390	120	1,48	4
Risorgimento (Viale)	8	50	GH	310	120	1,48	0
Risorgimento (Viale)	9	110	PVC	70	120	1,48	0
Risorgimento (Viale)	10	63	PE	50	120	1,48	0
Roma *	1	80	GH	150	60	3,07	6
Roma	2	160	PE	270	60	3,07	0
Roma	3	90	PE	50	60	3,07	0
Roma	4	160	GH	16	60	3,07	0
Samoggia N. *	1	300	FIB	1530	170	1,82	7
Samoggia N.	2	200	FIB	250	170	1,82	0
Samoggia N.	3	90	PE	130	170	1,82	1
Samoggia N.	4	63	PE	120	170	1,82	0
Samoggia N.	5	90	PVC	90	170	1,82	0
Samoggia N.	6	40	PE	80	170	1,82	0
Samoggia N.	7	32	PVC	60	170	1,82	0
Samoggia N.	8	300	ACC	50	170	1,82	1
Samoggia N.	9	300	FIB	270	170	1,82	0
Tassoni A.	1	150	FIB	750	70	1,53	0
Tassoni A. *	2	200	FIB	700	80	0,50	10
Tassoni A.	3	80	FIB	90	70	1,53	0
Tassoni A.	4	90	PE	100	80	0,50	5
Tassoni A.	5	60	FIB	130	70	1,53	0
Tassoni A.	6	90	PVC	100	80	0,50	0
Tassoni A.	7	63	PE	220	80	0,50	1
Tassoni A.	8	250	PVC	140	80	0,50	0
Tassoni A.	9	110	PE	60	80	0,50	0
Tassoni A.	10	225	PVC	70	80	0,50	0
Tassoni A.	11	110	PE	440	320	not measured	0

NB: Via Verdi, pipe 80 FIB must be added

Table 2.10 – Pre-selection of rehabilitation candidates – Parts with asterisk

2.4 REMARKS

The pre-selection consents the following remarks:

a. ARP is a tool which moves from a collection of data which provide an evaluation of the parts to rehabilitate, examining historical series, the consequences of breaks and not their causes; the selected candidates can successively be examined on a case-by-case basis, in order to assess the features of a part which has been repaired several times, so as to better evaluate the cause and the chance of the circumstance taking place again.
b. The candidates' cost was assessed at 1,500 thousand euros, which is above the value of the yearly budget. Therefore, some interventions shall have to be taken into account in the successive ARP.
c. All the candidates are in the urban area. The cost takes therefore into account this condition and, for the pipes within the districts, also the reconstruction of the connections, one every 10 metres. On a case-by-case basis, it is possible to assess the real cost, taking into account also to pipe depth, the real number of connections, the presence in the excavated area of other earthed services.
d. There are two typologies of candidates: candidates within and outside the districts. The out-of-district parts have a large diameter, and they constitute relevant pipes for the transportation of water.
e. Among the out-of-district candidates, one suffers from several breaks due to the pressure variations originated by a re-circulation pump. In this case, it is not a problem of bad laying or material deterioration, but of criticality of the pump-pipe group.
f. Among the parts within the districts, one district has two parts in which the pipes have broken again and again. The service level in that district is more critical than in others.
g. In our case, given the laying conditions, the type of streets and the pipe depth, there is no case justifying a no-dig intervention. Such procedure could be considered for the pipe of via Samoggia, which crosses a street with intense traffic and several earthed services.

2.5 BENEFITS

The creation of the ARP database allowed to highlight the following:

A. priority interventions in a longer period of time and with a correlation between a higher number of criteria. Earlier on, past years' situation could hardly be taken into account.

B. the importance of the control on interventions and of the coordination with other structures operating at the local level, which in this case are the gas supply and sewers management company and the municipality for street reconstruction, which can be enlarged to the other companies operating at the local level.

C. the state of cost of the smallest parts of the network, the districts, since through the database it is possible to perform the classification not only street by street, but also according to the pipes/streets within the district; it is therefore possible to draw up a yearly ARP planning on priority streets, but also on priority streets and districts.

D. the commitment required for network management both during a year and during a season, thus allowing to improve the allocation of the necessary resources.

E. the most important factors to prepare the rehabilitation agreements. These agreements are becoming widespread between the Authorities which own the plants and the management companies. In this case, both the collection of data and their evaluation can be included in the technical specifications for the allotment of the rehabilitation agreement and, together with the Performance Indicators, they can be an instrument of evaluation of the interventions in time.

The construction was also useful for defining an automatic system of construction of the ARP database year after year. With reference to this, it must be remarked that the main IT system used was the cartographic one, which shall have to be integrated in the following parts:

1. Creation of a link between the street identifier and the pipe part (CI Context Information). The type of data integration, once the program setup has been done, needs no further control and can be performed in a completely automatic way. An identical link must be done with the district identifier.
2. Creation of the link with interventions on pipe breaks (PI Operational Performance Indicators). This type of link shall be done in two parts: the automatic listing of

the streets in which repair operations have taken place; a second part, subject to verification, which attributes the intervention to the defined set (see Bayesian diagram, Figure 2.4).

3. Rough evaluation of the expense for the repair operation performed (UI Utility Information).
4. Street characterization (CI Context Information) through an examination of critical and sensitive users on the basis of the information collected, or through the automatic billing programme.
5. Dating, by year and month, of the interventions performed in the street by other units, in order to be able to retrace the real conditions of the street in the past. It shall be useful to take into account both the repair and substitution operations performed on gas pipes and sewers.

The development of the database can be further extended to the cases of intake break, which have less importance because they produce less inconvenience and can be repaired in less time.

This application case highlights the importance of implementing among town management actors a well-structured info **coordination** of past, current and future rehabilitation work, oriented towards the inconvenience caused and causable to citizens and users or, to use the language of Performance Indicators, more careful to Context Indicators.

CARE_W

APPLICATION
TO THE CASE OF THE AGAC MANAGEMENT OF THE URBAN NETWORK OF THE CITY OF REGGIO EMILIA

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CARE_W

All over the world, the issue of water preservation and usage and the problem of the ageing of the water supply network are considered the challenge for the years to come. In the last century, the global water extraction has become 7 times higher and the consumption for industrial usage 30 times higher. The ageing problems appear in the form of structural leaks and breaks which lead to shortages in the continuity of the water supply and of the hygienic conditions. Waste is impressive, and it is assessed at around 40% of the urban consumption.

These conditions occur in many water supply systems, the **economically active** management of which is a difficult objective to reach, due to the critical situation, the management and technical difficulties implied by the solutions and the image they offer. Furthermore, in the last years the security, environmental and service standards have become higher, inducing a stronger commitment by the operators of the sector.

The many difficulties of an efficient management can also be realized by remembering that the urban waterworks infrastructures are one among the several earthed networks of any city, that they have a widespread distribution to every single road and that the interferences with other city infrastructures are inevitable.

Therefore, in order to improve the water supply service, a wider improvement of the city services and environment is fundamental.

Networks must first be controlled, then rehabilitated with programmed actions that can improve the service for the short term and preserve its conditions for the future.

Summing up, if management is carried out correctly, providing a reliable water supply service that respects social, health, economic and environmental needs is a feasible achievement.

European cities spend approximately a total amount of 5,000 million euro per year on the rehabilitation of water supply networks. In Italy there is a strong requirement for investments on the waterworks service. A recent study by the *Committee for the supervision on the use of water resources* assessed said requirement at 16.5 euro per year for every citizen; this means, by way of example, that a city with 150,000 inhabitants has a 2.5 million euro requirement per year.

This amount, which is expected to grow in the years to come, gives an idea of the upgrading commitment needed in the water supply sector, but it is not enough. Well-established rehabilitation criteria are needed. The European project CARE_W, which contributes to the objectives of the Key Action "Sustainable Management and Quality of Water" aims at setting the modalities of a rational and modern management of the water supply service. Some of the most important European institutes of applied research in the field of water supply system management have taken part in this project.

1.1 PERFORMANCE INDICATORS

For some time now the Performance Indicators PI have been used in the management of many sectors, above all industrial, but also services, which need to understand in perspective the trend of their activities. Performance Indicators deal with management by measuring in time a host of indicators for the different components of a company: **who**, that is the human resources involved, **what**, that is the working process, **how**, that is the quality of the supply process, **how much**, that is the economic aspects. The features of the products or services sold are analyzed on the basis of a number of indicators, among which product reliability, distribution and assistance network, depreciation in time of the service offered. The application of these indicators to the field of water supply service management, in which the rules of competition and service level are catching on, is much more recent.

This is why in Italy, until few years ago, the situation appeared heterogeneous and not regulated. The excessive fragmentation of managements, the impossibility to reach economies of scale, the choices in tariff policies which aimed at favouring the social aspects: all these factors often determined the absence of a correct entrepreneurial approach and, as a consequence, of the necessary service standards that could grant in an optimum way all the stages of the drinking water supply cycle.

The objective that all the operators of the sector had to set and to reach as soon as possible was the definition of a real **water supply system**. The reform was started with law 36/94, known as Galli law, and it included five new elements:

- the institution of optimal territorial management domains;
- the consolidated management of the complete water supply cycle, that is to say an integrated water supply service;
- the stipulation of a clear and precise programme agreement between the local authorities and the service manager;
- the adoption of adequate tariff regulations;
- the institution of adequate control bodies.

The growth of new water supply managements is now under way. Within the new domains integrated local managements have arisen between existing subjects and new managing subjects, but many difficulties have occurred, and they can be summed up as follows:

- **lack of knowledge of the actual situation;**
- **chronic service shortcomings;**
- **difficulty in the planning of activities;**
- **difficulty in defining priorities.**

In these conditions, the definition of investment plans is often based on broad analyses and on the following simplified diagnoses. The uncertainty margin of the plan, which is the basis on which service amelioration is built, is therefore very high. All this considered, a verification approach is necessary that measures the actual situation and, in time, highlights the correct orientation of investments and management costs. A relevant part of the investments is for network analysis and rehabilitation.

Furthermore, rehabilitation plans are often justified by the idea that only a systematic rehabilitation of the whole network consents an improvement of the same. This approach calls for two remarks. It would require very long periods of time, in comparison with the typical terms of agreements, and a substantial outlay; furthermore, experience shows that there are many cases of networks which, in time, required no intervention. It is therefore necessary to measure the actual efficiency status of networks, the only condition for a priority-based approach.

Summing up, Performance Indicators are the means through which the state and the management of the network are measured, using a thoroughly defined formal language of variables and indicators, i.e. the language of Performance Indicators.

In order to rehabilitate urban networks, the LNEC (National Laboratory of Civil Engineering) in Lisbon developed a number of Performance Indicators, taken from the world plan AWWA IWA PI, and called them "**Control Panel of Performance Indicators for Rehabilitation**".

Before going on, the following concepts need to be reminded:

- Performance Indicators (PI) are the relation between values of the same or different nature, expressing the performance of a management company from a standpoint which is relevant for rehabilitation;
- Utility information (UI) is the complex of data directly connected to the activities of the management company (the organization and the physical system) and under its control. It is used both for the evaluation of the selected PI and for the CARE_W decision-making process;
- Context information (CI) is the host of data which cannot be directly influenced by the management company (i.e., they are outside the organization and its physical system) but which is critical to determine the rehabilitation or necessary for the CARE_W decision-making process (e.g., soil type, rain, ..).

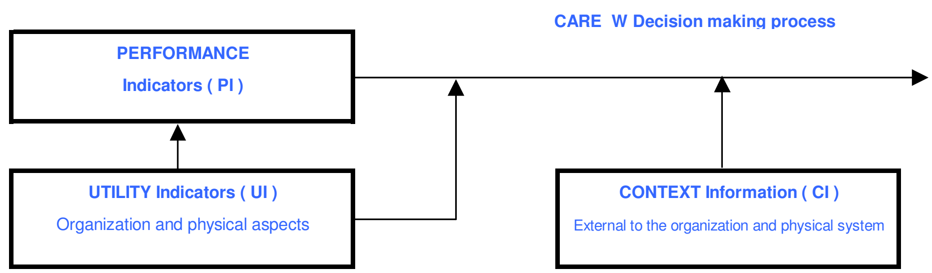

Fig. No. 1 - PI/UI/CI Scheme

The application case of the CARE_W project to the management of the waterworks distribution network of the city of Reggio Emilia, managed by AGAC, is reported in the present document.

The application is structured into the four CARE_W working packages:

WP1 application of a control panel of performance indicators for rehabilitation;

WP3 application of a decision support system for annual rehabilitation programmes;

WP2 application of technical tools for assessing the network hydraulics;

WP4 application of long-term strategic planning and investments.

During the application, where possible, the official quantities of the language of performance indicators have been used.

1.2 APPLICATION CASE OF REGGIO EMILIA

At the beginning of the Nineties the ascertained leaks in the Reggio Emilia network were very high, being evaluated at 0.527 l/s/km. At the time, every year, the final balances of the activities showed a relevant number of repaired leaks. In 1993, for example, 685 million lire (354 thousand euro) had been spent for 539 repairs. Previous experiences of systematic research on water supply leaks had not given the expected results. After a thorough technical, security and economic analysis it was therefore decided to invest on an active control system on leaks, rather than keep working systematically. The average expected result was reducing network leaks by around 1,200,000 m^3/year in two years' time, and them preserve this trend in the following years.

The control system on leaks has been used and extended since, and today it has become a well-established means to analyze network conditions and to define priority-based interventions. This way, the management was able to:

- reduce the volumes collected;
- increase the attention on all the cases of network breaks;
- sensitize the personnel and the customers to the issue of water preservation.

The current objective is that of optimizing the programme and the results of the rehabilitation budget, around 1.0 million euro, with the following measures:

- retrieving and analyzing the available data;
- evaluating the network status with the PI;
- setting up a comparison with the other European end users.

1.3 UTILITY INDICATORS

The water supply system of Reggio Emilia provides water to a resident population of 146,000 inhabitants, a population which has been steadily growing in the last years. The water extracted exceeds 15 million cube metres per year, great part of which is allotted to the city, while the water used is 12 million cube metres. The consumption per inhabitant is 242 litres per day.

The first waterworks in Reggio Emilia were built in the XIX century. The system brought water to the town from two well areas through a grey cast iron pipe and distributed it in the city centre through a ring network. Until the first half of last century (1890 – 1960), grey cast iron pipes were used. Some examples of these pipes are still in place today. At the beginning of the Sixties pipes in asbestos-cement were used extensively; the maximum length reached was equal to 45% of the total network extension. In 1980 this material was put out of the market, and this marked the end of a period. After 1980 a new material, PVC, was introduced, and it has been used until 1992. Currently, polyethylene is used for distribution pipes, ductile cast iron for supply ones. The total extension of the pipes exceeds 700 kilometres.

The main water supply resource for Reggio Emilia is the water-bearing stratum of the Enza torrent. The water is extracted from the wells (0.5 g/l mineralization, with prevalence of calcium bicarbonate and magnesium, absence of ammonia, low quantities of nitrates, 21 mg/l, hardness 40 F). Water is disinfected and iron and manganese are removed from it.

From the wells, the water flows in two main pipes towards the most important plant, called Gorizia. Gorizia was built in the western area of the city, and it has two 9.5 million litre grounded tanks at the quota of 55 metres above sea level, and a 1.0 million litre elevated tank which determines the maximum piezometric quota of 101 metres above sea level. The tank balances pump production with the water required by the customers. The ground quotas decrease from south to north. The area to the north of the Emilia street is 32 metres above sea level and requires no further elevation. The area to the south of the Emilia street has two pumping stations which provide water to the water supply network of the municipality of Albinea.

A new tank has been built in the eastern area of the city, and it has been called Reggio Est. The plant is placed in the vicinities of the wider ring of the city, it is served by via Gorizia during the night time and during daytime it provides water to the city with a very similar quota to that of the first tank. This is an intermediate situation, while in the final situation water will be supplied to Reggio Est from a new well area. Summing up, the current supply comes from a single water-bearing area, in the future the areas will be two, and this will represent an advantage for the system security.

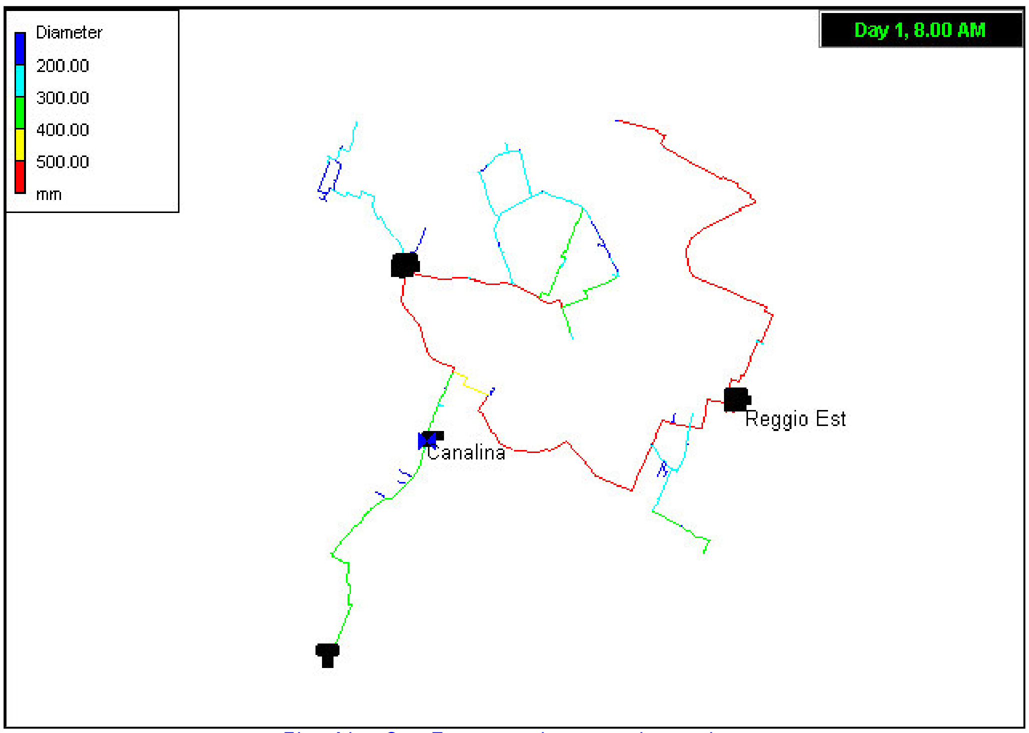

Fig. No. 2 – Town water supply system

As previously explained, a decision was made to invest on a leak monitoring system rather than keep a systematic approach on the whole network. The original realization method by the British WRC was adapted to the peculiarities of this case in the following way:

a. Transport pipes have been taken into account separately from the districts (pipes with a diameter above 300 mm or specific transport pipes). The districts are therefore fed by the connection between the main pipe and the transport pipe;
b. The main transport pipe is arranged on a ring (see Fig. No. 2). The purpose of the ring is that of balancing and stabilizing the pressure conditions in the districts when there are strong variations in water demand;

c. The internal ring is fed by two transport pipes ; this allows one of them to be temporarily out of commission without a too-sharp pressure variation in the districts;
d. The districts have been designed using a calibrated mathematical model and evaluating the pressure and rate of flow trends following closings;
e. The condition of minimum pressure in the nodes of the model during the condition of maximum demand is above 30 metres; there is an exception for those nodes in which the starting pressure is lower; a second inlet has been considered for these cases, or they have not been organized in districts;
f. The district has been designed in order to create an insulated area with no exit towards a different district;
g. Notwithstanding what was mentioned above, the district has been designed to be fed by a single feeding instrument.
h. Each districts supplies water to 1,000 to 3,000 household; the differences within this span are justified by altimetric and hydraulic conditions.

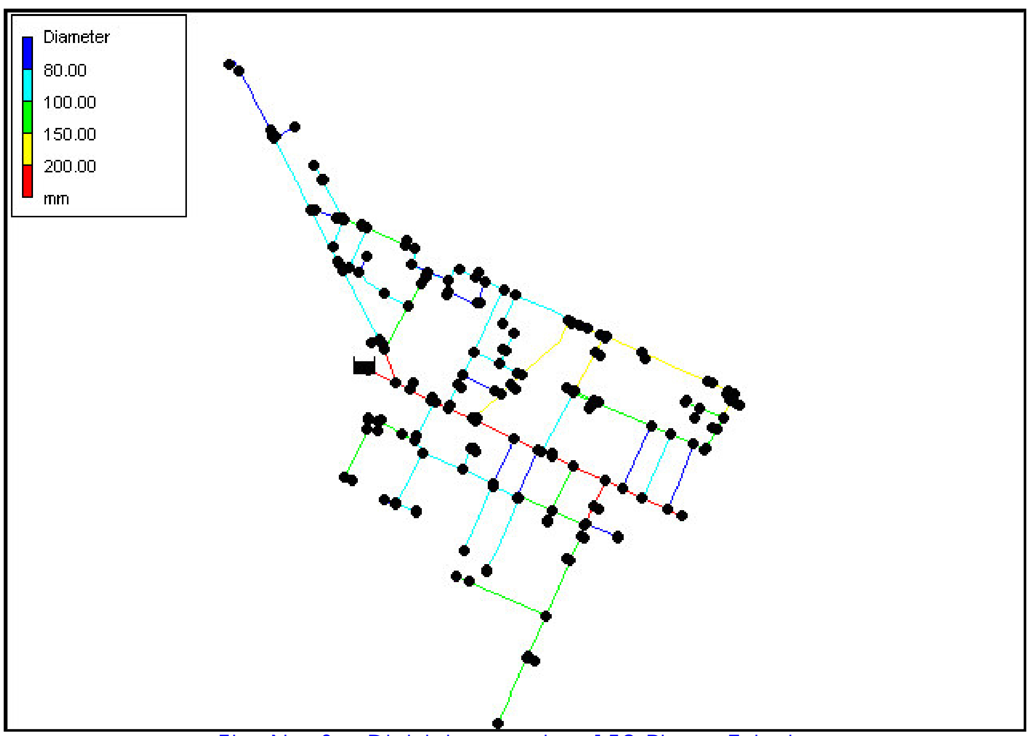

Fig. No. 3 – District example - 150 Piazza Tricolore

1.4 PI CONSTRUCTION MODE

1.4.1 Introduction

The realization of an active leak control system required around two years' work, from 1993 to 1995, and it allowed not only to reduce the leaks in a large part of the city, but also to have for the first time a decision-making system against leaks based on performance indicators. Indeed, the night consumption for each district is constantly measured and the specific consumption values per kilometre of network supplied are obtained.

District		Flow meter		Flow analisys				
n°	Name	n°	address	Min l/s	max l/s	PI: ratio	Lenght *km*	PI: spec min m³/h* km
020	Via Gorizia	02	via Gorizia	6.52	22.2	29%	11.39	2.06
		03	viale Timavo					
030	CS1 I Teatri	04	via Del Portone	8.10	28.82	28%	9.41	3.10
040	CS2 Comune	05	p.zza Fiume	3.22	13.09	25%	5.12	2.26
050	Gattaglio	06	via Beretti	6.06	28.38	21%	9.98	2.19
060	CS3 Fontanesi Tric.	20	p.zza Tricolore 2	7.40	26.09	28%	8.69	3.07
		07	via Baruffo-via Guazzatoio					
100	Rosta Togliatti	11	via Cugini	5.01	19.87	25%	7.84	2.30
120	Ex Polveriera	14	via Cialdini	6.99	31.51	22%	10.93	2.30
150	Piazza Tricolore	19	p.zza Tricolore1	13.87	38.76	36%	8.69	5.74
170	Mancasale 1	21	p.zza Duca degli Abruzzi	12.00	*via Adua*		11.85	3.65
	Mancasale 2	22	via Gramsci	20.00	*zona ind.*		24.73	2.91
210	Meridiana	26	via Costituzione	14.48	60.62	24%	15.69	3.32
		27	via Ferrari					
200	Villaggio Crostolo	25	via Manfredi	11.76	33.53	35%	21.44	1.97
220	Pieve	28	via Zambonini	11.29	30.86	37%	25.42	1.60
080	Canali	09	via Tassoni 2	10.37	29.97	35%	27.59	1.35
		39	via Ardigò					
240	Ponte S.Claudio	30	via Zanichelli	6.51	27.74	23%	12.26	1.91
250	Canalina	31	via Canalina 1	5.13	25.59	20%	16.42	1.12
230	Regina Pacis	29	via Puccini	1.93	14.62	13%	6.37	1.09
160	S. Maurizio	18	via Amendola 2	8.29	35.78	23%	38.95	0.77
010	Orologio	01	via Gorizia	5.08	27.27	19%	20.18	0.91
151	Emilia Ospizio	17	via Amendola 1	0.04	0.32	13%	9.97	0.01
070	Ospedale	08	via Tassoni 1	4.04	39.76	10%	7.55	1.93
		33	via Bismantova 1					
090	Croce Pappagnocca	10	via Croce	0.75	14.63	5%	13.92	0.19
091	Pappagnocca 2	13	via Martiri di Cervarolo	0.00	91.28	0%	1.11	0.00
110	Buco del Signore	12	via Cugini 2	1.19	16.3	7%	11.48	0.37
130	Papa Giovanni	15	via Garagnani	0.18	19.73	1%	6.44	0.10
140	Bazzarola	16	via Einstein	0.70	9.09	8%	9.97	0.25
	Mancasale 3	24	via Cisalpina	6.00	*via Strinati*		27.12	0.80

Tab. No. 1 – First established Performance Indicators system

The table highlights the leak control and the performance indicators adopted.

It must be noticed that this important result of the project was not immediately understood, because it was less noticeable than the recovery made with the several leak detection and fixing interventions (99 leaks were found).

After the setting at work of the leak control system, in 1998 a survey on network breaks and on the number of replacements on the network was carried out, and this represented the second stage of introduction of the performance indicators system. Previously, breaks and network replacements had not been connected to each other, because they had been dealt with by two different services. The result was a second system of performance indicators, contained in the following table (see Table No. 2). The annual breaks of each material composing the network are highlighted, together with the network extension and the global incidence, that is to say the importance of the breaks compared to the network extension. Comparing the data of different years, it is possible to evaluate the consistency change for the different materials, in particular for asbestos-cement.

	2001					
	n° breaks	Length	D Length%	Tasso rot/an/10km	Length	Tasso/Tasso medio
FIB	70	277,54	-0,5	2,52	40%	1,72
GH	4	22,50	-2,3	1,78	3%	1,21
PE	18	205,95	3,4	0,87	30%	0,60
PVC	10	150,11	0,0	0,67	22%	0,45
Ignoto	0	40,14	0,0	0,00	6%	0,00
RETE	102	696,25	0,7	1,47	100%	1

	2000					
	n° breaks	Length	D Length%	Tasso rot/an/10km	Length	Tasso/Tasso medio
FIB	51	278,85	-0,7	1,83	40%	1,52
GH	4	23,03	-0,1	1,74	3%	1,45
PE	18	199,25	4,3	0,90	29%	0,75
PVC	4	150,14	-0,1	0,27	22%	0,22
Ignoto	6	40,14	-0,8	1,49	6%	1,25
RETE	83	691,41	0,8	1,20	100%	1

	1999					
	n° breaks	Length	D Length%	Tasso rot/an/10km	Length	Tasso/Tasso medio
FIB	42	280,92	-1,2	1,50	41%	1,51
GH	5	23,05	-2,6	2,17	3%	2,19
PE	16	191,05	8,1	0,84	28%	0,84
PVC	5	150,23	-0,8	0,33	22%	0,34
Ignoto	0	40,45	-0,1	0,00	6%	0,00
RETE	68	685,70	1,3	0,99	100%	1

	1998					
	n° breaks	Length	D Length%	Tasso rot/an/10km	Length	Tasso/Tasso medio
FIB	59	284,42	-0,9	2,07	42%	1,19
GH	8	23,66	-7,8	3,38	3%	1,94
PE	36	176,74	6,2	2,04	26%	1,17
PVC	9	151,36	0,5	0,59	22%	0,34
Ignoto	6	40,48	0,0	1,48	6%	0,85
RETE	118	676,66	1,0	1,74	100%	1

	1997					
	n° breaks	Length	D Length%	Tasso rot/an/10km	Length	Tasso/Tasso medio
FIB	61	287,09	-0,4	2,12	43%	1,58
GH	10	25,65	-7,7	3,90	4%	2,90
PE	7	166,35	14,2	0,42	25%	0,31
PVC	5	150,59	1,1	0,33	22%	0,25
Ignoto	7	40,48	-1,9	1,73	6%	1,29
RETE	90	670,16	2,8	1,34	100%	1

	1996					
	n° breaks	Length	D Length%	Tasso rot/an/10km	Length	Tasso/Tasso medio
FIB	58	288,15	0,0	2,01	44%	1,53
GH	8	27,79	0,0	2,88	4%	2,18
PE	5	145,64	1,9	0,34	22%	0,26
PVC	7	148,99	0,6	0,47	23%	0,36
Ignoto	8	41,28	0,0	1,94	6%	1,47
RETE	86	651,86	0,6	1,32	100%	1

	1995					
	n° breaks	Length	D Length%	Tasso rot/an/10km	Length	Tasso/Tasso medio
FIB	72	288,16	-0,2	2,50	44%	1,64
GH	11	27,80	-10,6	3,96	4%	2,59
PE	3	142,96	4,5	0,21	22%	0,14
PVC	8	148,04	5,0	0,54	23%	0,35
Ignoto	5	41,28	-0,9	1,21	6%	0,79
RETE	99	648,23	1,4	1,53	100%	1

	1994					
	n° breaks	Length		Tasso rot/an/10km	Length	Tasso/Tasso medio
FIB	108	288,82		3,74	45%	1,44
GH	33	31,08		10,62	5%	4,09
PE	1	136,85		0,07	21%	0,03
PVC	19	141,05		1,35	22%	0,52
Ignoto	5	41,67		1,20	7%	0,46
RETE	166	639,47		2,60	100%	1

Tab. No. 2 – Second Performance Indicators system

1.4.2 IWA Performance Indicators

In the year 2000 the use of the IWA performance indicators system was made official and the European CARE_W project was kicked off. It is the third development stage. The application is done for the city, intended as urban and suburban territory and the adjacent country. The total surface is of 20,225 ha. The waterworks of Roncocesi and of Masone are excluded, while the urban territory of Rivalta is considered part of the city.

Performance Indicators tackle service management with an integrated approach. It was therefore necessary to collect a large amount of necessary data. In order to allow to the groups of people involved to understand the reason of the data collection, many internal meetings were organized in order to explain the definitions of the performance indicators.

The first stage of the data collection, concerning the network conditions, was performed starting from the cartographic and leak searching services. This service, due to updating needs, requires the retrieval of information on network modifications performed by other services.

It was therefore possible to take advantage of the following:

- consumption and leak trends in the districts;
- projects of mains extension and replacement;
- works of service connection replacement;
- services for the detection of hidden leaks.

Each activity was later reconsidered and analyzed during the implementation of the WP3 - ARP Annual Rehabilitation Plan working package, which has been described in chapter 2. The data for the formulation of performance indicators were analyzed together with two work groups, the azure and yellow groups, in order to assess their precision and reliability degree.

The indicators on the waterworks performance have been inferred from those provided to the regional authorities. In this case, a third group, the green group, participated, fixing the different volumes used year after year by the whole system.

Finally, a fourth group, the blue group, took part in gathering the data concerning the economic aspects. In this case the management costs have been excluded from the existing economic calculation, in order to attribute only to the water supply service the costs actually related to the city management.

Overall, 18 people took part in collecting the PI.
The PI concerned a 5-year time span, the period from 1996 to 2000, collecting 51 variables from which the rehabilitation performance indicators listed below have been drawn.

WR1 takes into account, at a global level, the ratio between lost water and extracted and imported water. This indication is contained in the Italian norms as well. In formulating this indicator, the importance of the unbilled metered consumption and of the unbilled unmetered consumption must be taken into account.

$$\mathbf{WR1} = A24/(A4+A5+A8) \times 100 \qquad \%.$$

The performance indicator **Fi21** was taken into account, which describes the company's total revenue divided by the global volume of authorized water A19.

$$\mathbf{Fi21} = G30/(A19-A9) \qquad Euro/m^3$$

The performance indicator **Fi2**, describing the unit running costs, was then taken into account. It is given by the ratio between the year running costs and the authorized used water.

$$\mathbf{Fi2} = G2/A19 \qquad Euro/m^3$$

and **Fi18**, expressing the year cost of investments on the network, comprising both new pipes and equipment and controls.

$$\mathbf{Fi18} = G26/A19 \qquad Euro/m^3$$

In this case as well, the PI is pegged to the authorized used water.

1.4.3. Rehab Performance Indicators

There are three performance indicators describing the rehabilitation strategy adopted. **Op5** expresses the number of leaks detected and fixed with the research of hidden leaks, divided by the total network length:

Op5 = D9/C6 x 100 (No./100 km/year)

Op15 is the network length rehabilitated during the year, divided by 100 times the total length of the pipes. The length of the rehabilitated network was obtained taking into account the cartographic documentation and the certificates of the single projects.

Op15 = D18/C6 x 100 (% /year)

Op19 is the number of connections substituted every year, divided by 100 times the total number of connections. The number of connection has been obtained year after year from the number of new customers, considering that the ratio between connections and customers is equal to four. For a connection to be considered substituted, more than half of its length has to be substituted:

Op19 = D22/C32 x 100 (% /year)

1.4.4. Rehab Impact Performance Indicators

Finally, the performance indicators measuring the impact of the interventions made on the rehabilitation strategy have been analyzed. In this case as well there are three of them.

Op22 is the lost volume per connection in a one-year span:

Op22 = A20/C32 (m^3/connection/year)

Op26 is the number of breaks in the supply network during a year divided by 100 times the total network length:

Op26 = D25/C6 x 100 (No./100 km/year)

Op27 is the number of breaks in the connections during a year divided by 1000 times the number of connections:

Op27 = D26/C32 x 1000 (No./1000 km/year)

The annexed tables contain the elaborations made with the tool LNEC PItool020.
The file name is PIRE for CARE.zip. The years taken into account are 1996 through 2000.

1.5 OBSERVATION ON PERFORMANCE INDICATORS

During the period 1996-2000 the following data emerged:

a. **population:** it has a gradual growth of 1.4-1.8 percent and it has gone from 137,000 to 146,000 inhabitants in the last 5 years;
b. **active customers:** i.e. excluding default customers without meter, have a progressive growth of 4.3 – 4.9% , passing from 24,200 to 28,900 customers in the last 5 years;
c. **resident population/customers:** decreasing value, around 2.0; the value appears more evident taking into account the new consumers for domestic use only;
d. **extracted water:** it is progressively growing, passing from 282 litres per inhabitant a day to 297 litres per inhabitant per day; the quantity seems to have become stable in the last two years;
e. **resource "natural" availability:** the water-bearing layer is not overexploited; but if the growth in the water extracted is taken into account, the trend is towards a heavier exploitation of the layer; an indicative value of the capacity of the layer has been set at 16,500,000 cube metres per year;
f. **billed water:** after a drop it has gone back to values close to 240 litres per inhabitant a day;
g. **network breaks:** in the year 2000 there were 230 of them, a number corresponding to the non-programmed interruptions; the value is stable along the years (excluding one year, 1998) and it has an incidence of 3.3 breaks every 10 kilometres of managed network;
h. **non-programmed interruptions:** corresponding to the number of breaks in the network, they are all carried out in a 3 hour average time; therefore breaks imply a 690 hour maximum service reduction or interruption;
i. **importance of the interruption:** impossible, in the WP3 working package an evaluation method for the classification of "water interruptions" has been set up;
j. **warranted breaks:** a relevant quota, around 64% , while the unwarranted breaks are decreasing ; the number of breaks in asbestos-cement pipes is relevant;
k. **overall service connections breaks:** in the year 2000 they are equal to 889, and they are strongly increasing;

l. **difference between extracted and authorized volumes, plus water not measured by mistake:** stable in the last three years, and equal to49 litres per inhabitant a day;

m. **detected hidden leaks:** they are constantly growing ; in the year 2000 34 leaks have been detected between network and connections, to which corresponded a recovered volume of 10 litres per day per inhabitant;

n. **inadequate pressures:** they are decreasing, and the value for the year 2000 is 64; a more exhaustive enquiry should be done on the features of these indications;

o. **rehabilitation:** a 10-metre length per connection has been considered; in the year 2000 rehabilitation was performed on 5.6 kilometres of the network; the result equals 0.8% of the existing stock; the trend along the years, though, is decreasing;

p. **rehabilitation:** rehabilitation includes an increase of the interventions on services pipes, with a percentage of replacement increasing by 3.10% on the service connection stock; main pipes rehabilitation is decreasing;

q. **new realizations:** a 10-metre length per connection has been considered; in the year 2000 the new realizations have been performed on10.3 km of the network; the trend in the last years is stable;

r. **investments:** for new realizations given by new networks and new connections; the trend of the specific value of the investments is increasing with the years; **Fi18** has a value included between 0.12-0.14 Euro/m^3 with a B4 degree. It must be considered that the street reconstruction costs are partly on the municipality.

s. **Management:** the running cost per inhabitant in the year 2000 equals 21.0 Euro ; the value is not increasing; the Fi2 running cost is 0.19 – 0.21 Euro/m^3; the values above take into account administrative, IT and motor vehicle costs, but they are divided into water and gas supply; D6 degree. Fi2 appears to be undervalued.

t. **Mean consideration per inhabitant:** equal to 65 Euro per inhabitant, with reference to 1999. The value has increased in the years 1997, 1998, 1999.

u. **Unit running costs and Unit investment costs:** they amount to 0.35 Euro/m^3 in the year 2000, with a D6 degree depending from management costs.

1.6 PERFORMANCE INDICATORS ASSESSMENT

In order to assess the data collected from 1996 to 2000 and expressed with the language of performance indicators, the following logical approach, represented in figure No. 4, has been followed.

The following elements have been taken into account:

- tariff variation;
- the quantity of water actually used;
- the running costs;
- the revenue in relation with the extension of the network to be managed;
- the variation in the interventions on the network;
- the effect on the network status indicators, i.e. actual leaks; overall breaks due to the reliability of the network;
- the effect on a revenue increase is always expressed in specific terms, i.e. in relation with the extension of the network to be managed.

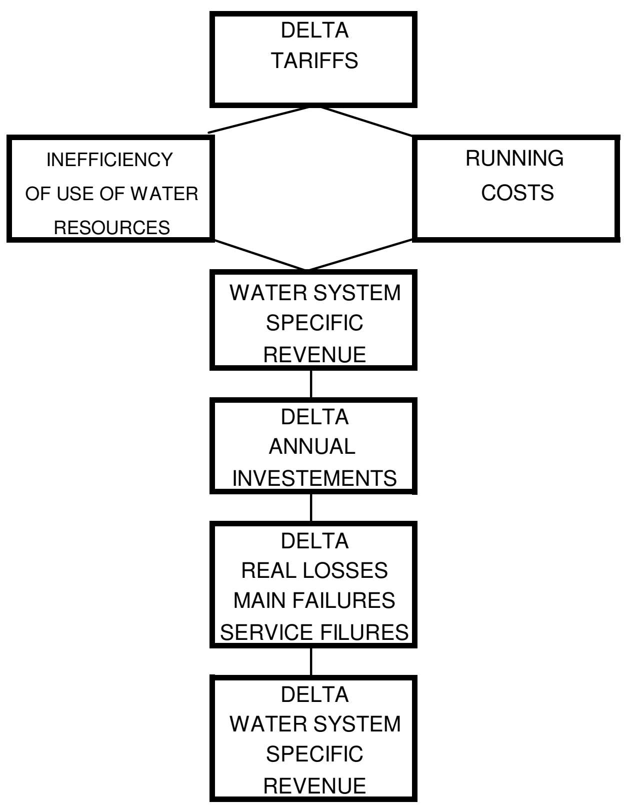

Fig. No. 4 - Path for performance indicators assessment

In the assessment of the performance indicators single values have been compared to those obtained in other case studies.

Tariffs: During the period under exam tariffs have not changed. The last variation dates back to 1993, a year which saw a relevant increase of the tariff following the revision of water leaks of the whole city water supply system.

Network efficiency: it can be stated that, during the years under exam, it has definitely improved, and the year overall value is below 10%. Nevertheless, a margin of subjectivity in the evaluation of unbilled metered and unmetered consumption must be considered. Subjectivity is in the consumption of technical type; it must also be considered that in the case of Reggio Emilia all consumptions are metered (there is no default consumption). In the other cases, the indicators expressed were between 14% and 28%.

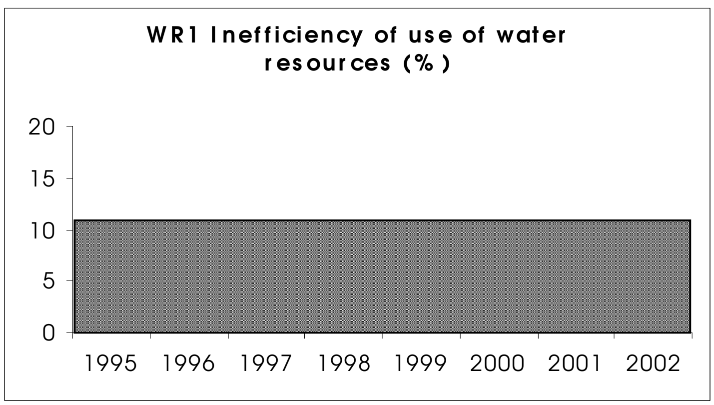

Fig. No. 5 – Surface status of network efficiency (see Tab. No. 1)

Management running costs: they have remained the same. They include all the personnel and energy costs. Nevertheless, some doubts remain on the entity of these costs that appear to be undervalued. The trend of the running costs Fi2 has been between 0.21 and 0.23 Euro/m^3. In 50% of the other cases under scrutiny the value is between 0.23 and 0.55 Euro/m^3. This value is therefore very low. One reason could be the further cost represented by the general expenses linked to the service and division between water and gas supply services.

Rehabilitation funding: since the 1993-1994 active leakage control project, the tariff allowed to implement all the necessary investments as self-financing. The economic budget for rehabilitation has been growing to the constant values of the last years, equal to 1.0 million euro:

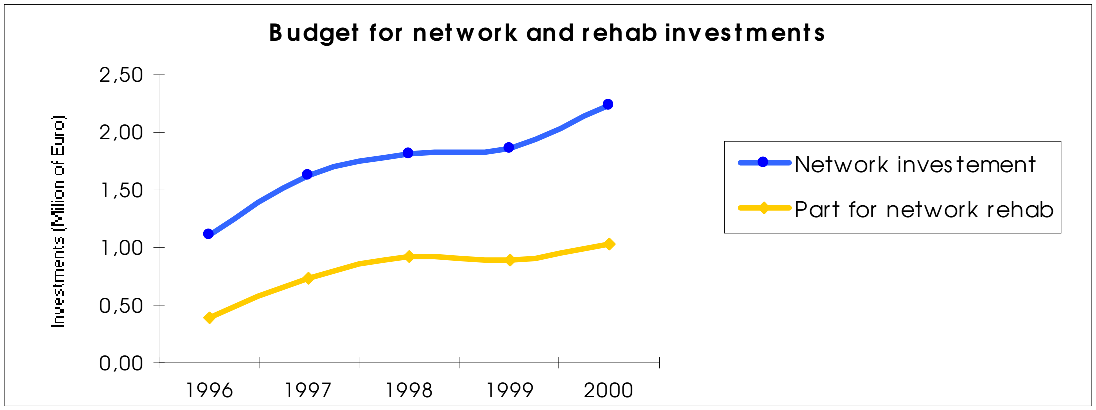

Fig. No. 6 – Investments for the town water network

Compared with the other cases, the sum of the running costs and investment costs of Reggio Emilia equals the minimum value in a span between 0.4 and 1.25 Euro/m^3.

Network rehabilitation: the network rehabilitation has been implemented according to three intervention guidelines, i.e. localized active leaks, replacement of service connections, replacement of distribution mains pipes. See the trend of the performance indicators in the graph attached:

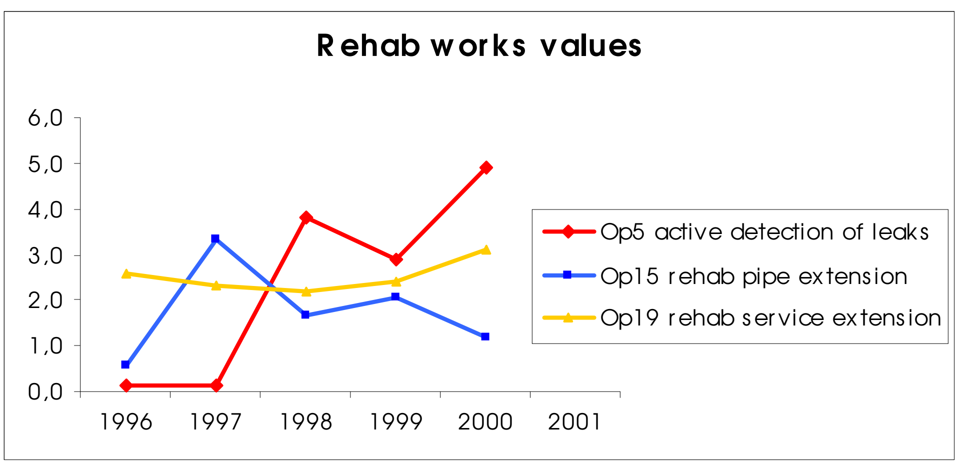

Fig. No. 7 – Performed rehabilitation

The active research activities on leaks are increasing. The research activities have been implemented by using the districts and constantly monitoring the night values of the network. Districts have increased as well. The activities on hidden leaks, performed with internal and external resources, represent a relevant part of the rehabilitation. Furthermore, rehabilitation is characterized by a constant care for the

reconstruction of service connections, an activity which has been growing. On the contrary, the substitution of pipes subject to repeated breaks is decreasing.
If compared with the results obtained in the other cases, the leaks detected with the Op5 active research are less than those detected in other cities. One possible explanation is that the extension of the network which undergoes research is limited, since it is subject to constant monitoring, therefore the activities are targeted to the necessary areas, and only the most significant cases from the quantitative point of view are detected. In short, it can be said that the Reggio Emilia indicator does not provide the efficiency degree of the network, but the efficiency degree of the research, which is high if compared to the other cases. The reconstruction percentage of the Op15 networks is currently lower than those detected in other cities, while the replacement percentage of the Op19 service connections is higher, indicating the constant higher commitment required for this kind of interventions.

Rehabilitation impact: The rehabilitation activities have led to a significant decrease of the Op22 indicator, which measures the quantity of lost water weighting on every single service pipes and therefore, indirectly, on the expense sustained by every single customer. The network breaks have remained stable, with a slight decrease. In this case it is all about understanding whether there are intervention which can significantly reduce the Op26 performance indicator (see Chapter 2). Finally the service connection breaks have kept increasing, despite the many substitutions.

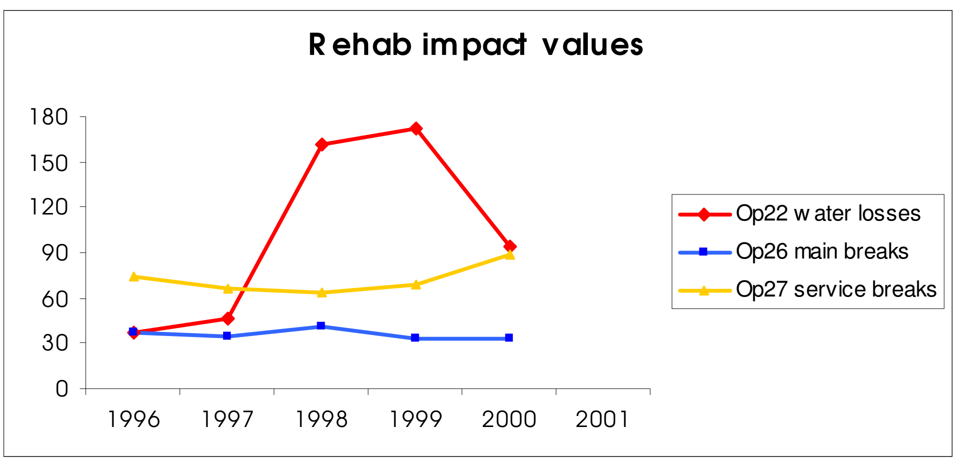

Fig. No. 8 – Values for assessing the rehab impact

Compared with the other case studies, the loss indicators have strong variations, with moderate minimum values and high maximum values, while network breaks are on the average of the cases analyzed and service breaks are definitely above average.

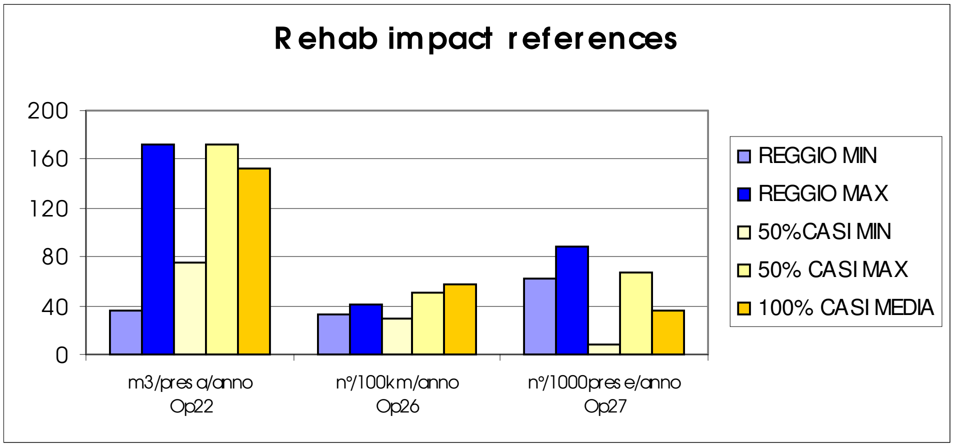

Fig. No. 9 – Reference values of rehab impact

Specific efficiency: with constant tariff, in these years the absolute economic efficiency of the waterworks has constantly grown due to a higher quantity of billed water volumes. In order to obtain a specific rehabilitation indicator, the economic efficiency trend by network kilometre was analyzed. Every network kilometre has had an economic efficiency which grew with time. The same billed volume was compared with the authorized water volume, i.e. with the total amount of water which had been necessary to provide the customers with the service. In this case, more water sold corresponded to more water used (unbilled metered and unmetered water), each water volume has had a constant economic efficiency in time.

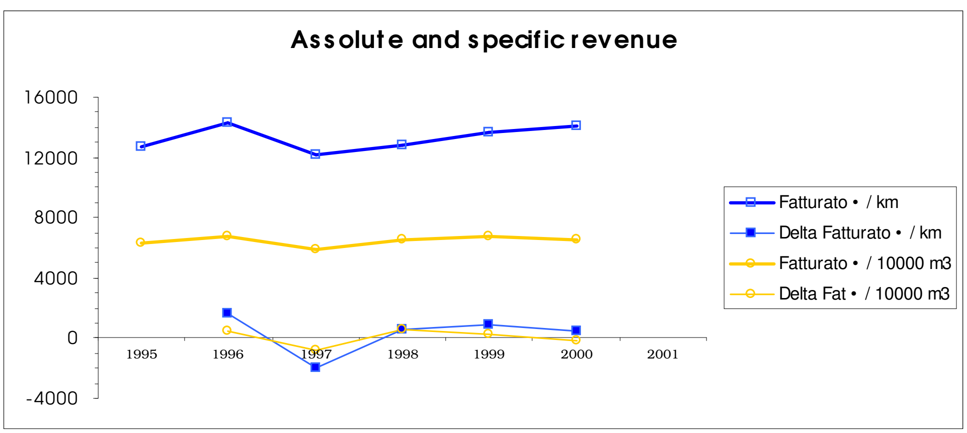

Fig. No. 10 – Economic sustainability

Evaluating the difference in efficiency from one year to another, a decrease in the efficiency of each kilometre can be observed for the last years. However, the value has preserved the plus. In the case of efficiency variation of each water volume, the decrease has a minus sign.

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