PETUS description of tool in use	
Name of the case	**Rehabilitation of water supply network in urban fields (CARE-W-ARP).**
Name of the tool	**CARE-W-ARP**
Country	France, Rhone Alpes region, Greater Lyon
City / region Total area (km2) Population Density (people/km2)	Greater Lyon (G.L.)- France: 1.2 million inhabitants / 500 km² Lausanne (L)- Switzerland Reggio Emilia (R.E)- Italy Brno (B)- Czechoslovak Oslo (O.) and Trondheim (T.)- Norway
Tool user's profile a. Organisation name (municipality, NGO, national or regional department, company, etc.) b. Field of activity c. Detailed contact/feedback (project website, e-mail, address, tel., fax)	a. Water Department of cities and private water companies. Private and Public operators. b. In charge of studies, constructions and management of water infrastructures. c. http://care-w.unife.it/
Reviewer, date	INSA-Lyon, France, last update Feb 2005

Short description of the case

CARE-W-ARP is a multi-criterion decision support tool that enables analysis of the whole water supply network to take place in order to produce a prioritised list of rehabilitation pipes for an annual rehabilitation investment programme. CARE-W-ARP was developed during the European Project CARE-W (Computer Aided Rehabilitation of Water Network, February 2001- January 2004) which was funded by the European Community.

CARE-W-ARP considers different aspects of existing deficiencies (failures, leakages, ageing etc) and potential improvements for ranking and selecting pipes. Two types of criteria have been defined: criteria assessing the consequences of the condition of each pipe like expected repair costs or expected impacts of water interruptions, and criteria assessing the opportunity of a rehabilitation project like rehabilitation costs or coordination with other utilities (gas, road works). In addition, information required for the calculation of these criteria is derived from four main sources: 1. Performance indicators (complains rates, valve density etc) 2. Hydraulic Reliability software, 3. Failure prediction tools, and 4. Utility databases. The utility database contains information on the pipe (diameters, length, material use, date of placing etc) and on the pipe environment (number of people supplied, presence of sensible clients etc). Therefore the outranking approach proposes to represent each pipe using a multi-criterion profile which is compared with two reference profiles without aggregating criteria. A multi-criterion profile is the graphic representation of several criteria that have been previously calculated (see figure 1).

The CARE-W-ARP software has been tested on several water supply networks of European cities for example Reggio Emilia (I), Greater Lyon (Fr), Lausanne (CH), with the collaboration of the water services. Different criteria can be used to compare pipes for rehabilitation on a case by case basis, although this will depend on the specific context of the city and data availability (see figure 2).
Several simulations may be run by modifying criteria weights, reference values and/or other parameters. These results can be compared in CARE-W-ARP using sensitivity or robustness analysis.

The use of CARE-W-ARP improves the relevance and justification of the rehabilitation plan and reduces the ageing impacts of the network (water losses, damages, water interruptions etc). It may also improve discussion and dialogues between municipal engineers of the water network and the elected representatives by the increase of transparency and communication.

Why was the case chosen?

The PETUS project analyses a range of practical tools which could be used to assess the sustainable dimensions of urban development projects. In order to build on our knowledge of these tools, to judge their potential utilisations and their relevance, two methods can be considered. The first one consists of highlighting a particular tool and observing its use in different projects. The second consists of outlining the different tools implemented in a particular project which incorporate sustainability aspects. This case study belongs to the first category in which the tool in practice is the entry point of the study.

Reference to the concept of sustainable development concept is not directly explicit here. Nevertheless, reports and documents read, supplemented by the discussions with the authors who produced the tools (researchers) and the tool users (the technical services of municipalities) show the construction of a new relevant issue related to practice. We could have chosen to present here one implementation of the CARE-W-ARP tool in a specific city. However, this is the common work between researchers and technical managers, the wish to work together through years and to share means, in relation with the urban water supply network, which insist on the sustainability reference. This case study is, in our opinion, representative of the process that should be encouraged in regard to sustainable practices.

This case study can be related with the PETUS key-problem of the "Water/sewage" section: Management and conception of urban water infrastructures.

Sector	Waste	Energy	Water	Transport	Green/blue	Building & Land Use
			X			

Scale of project	Component	Building	Neighbourhood	City	Region
				X	

Status of project	Starting up	Ongoing	Finished	Start date	End date
			X (operational)	Feb 2001	Jan 2004

Key words **Water supply network, Proactive rehabilitation, Multi-Criteria-Analysis, multi-criterion profile,**	
Project a. Object (building, city park, wind farm, etc.) b. Type of activity (regeneration, renovation, new development, etc.) c. Type of product (plan, scheme, design project, etc.)	a. Object: Water supply network b. Type of activity: Rehabilitation c. Type of product: annual rehabilitation planning
Tool a. Character (according to WP3final0704.doc) b. Benchmarks (qualitative or quantitative) c. Availability (paid/ free)	a. Character: Calculation tool/assessment method: Multi-Criteria-Analysis b. Benchmarks: Yes (both qualitative and qualitative) c. Availability: paid. The tool will soon be marketed by Care com company.
Decision-making process	

a. Stage of the tool implementation (preliminary, midterm, etc.) b. Level (political, technical, etc.) c. Public participation	a. Stage of the tool implementation: Preliminary studies b. Level: Technical c. Public participation: no.
Other *(optional, if needed)*	

DETAILED INFORMATION

A. Detailed description of project and tool

1. Description of context

Water Department of cities, which are in charge of the management of the water supply network, are more and more aware about the fact that the state of health of their infrastructures is not good enough and even not known. Water supply infrastructures represent an important asset that has to be managed to the best way as possible because it represents a huge economical investment.

The overall goal of the tool implementation is to propose a proactive management of the water supply network. It means that water utilities predict failures or deficiencies of the pipe before it occurs. Therefore the curative management, which consists on rehabilitation of the pipe when the deficiency has occurred, can be reduced. Of course, if the global state of water supply network is good, proactive management will be more efficient and relevant that if the global state is bad. The use of CARE-W-ARP allows producing rehabilitation priorities related to impacts of breaks or internal condition of the pipe (corrosion for example).

2. Description of project

The entry point is a tool CARE-W-ARP. This **multi-criterion decision support tool** enables analysis over the whole water supply network, sectors or clusters of pipes in order to produce a **prioritised list of rehabilitation pipes for an annual rehabilitation investment programme.**

Care-W-ARP is a component of the European Project CARE-W (Computer Aided Rehabilitation of Water Network, February 2001- January 2004) funded by the European Community. This project deals with the public water supply networks and their problems of ageing such as structural failures, insufficiencies and leakages (affecting hydraulic reliability), deteriorating water quality and increasing maintenance costs that impact on urban environment. The ultimate goal of the project is to develop tools that provide the **most cost-efficient system of maintenance of water distribution networks**, with the aim to guarantee a security of water supply that meets **social**, **health**, **economic and environmental requirements**.

The CARE-W objective is to establish a rational framework for water network rehabilitation decision-making including methods and software that will enable municipal engineers to establish and maintain effective management of water supply networks, rehabilitating **the right pipe at the right time** by using the right rehabilitation technique at a minimum total cost, before failure occurs. This is a pro-active approach.

Within definitions of CARE-W objectives, it would be possible to find, even if it was not formulated with that purpose at the beginning of the project, the links with firstly the asset management of urban infrastructures and secondly with sustainable development dimensions.
To date some technical tools for assessing the state of the pipes or the need for rehabilitation have been

developed or are under development in several European Research Centres and Universities. But these tools do not take into account all aspects of rehabilitation decisions, and have only been applied to a limited number of water services. The tools need to be tested and validated on more water services and to be aggregated and linked with those performance indicators that are the decision criteria of rehabilitation.

The specific objectives of the project are to improve these tools and to make them usable in formulating a rehabilitation policy. The final product of the project will be a Decision Support System for rehabilitation including:

- a control panel of Performance Indicators (PI) for rehabilitation,
- technical and statistical tools assessing and forecasting some of the PIs,
- a procedure to support the construction of an **annual rehabilitation program** (**ARP**),
- a procedure to define the best strategy for planning rehabilitation investments (long term: 10 to 20 years)
- a software, called "prototype" that will allow the use of the above products with the existing data of the respective water utility.

3. Description of tool

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**. A multi-criterion profile is the graphic representation of several criteria relating to one pipe that have been previously calculated (see figure 1).

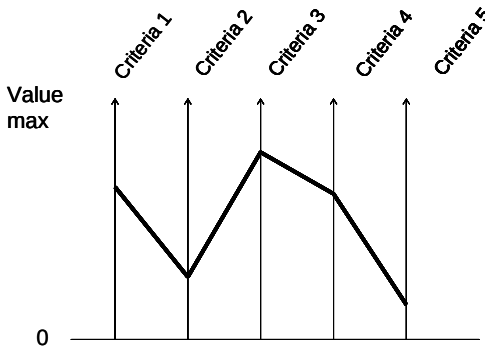

Figure 1: example of multi-criterion profile

The decision problem for the water utility company is **how to spend a given annual budget** for rehabilitation (potentially derived from a rehabilitation strategy) on the most efficient projects. Usually, the costs of all potential rehabilitation projects in the network that would be desirable for different reasons exceed the available annual budget. In order to rank and select pipes for the annual rehabilitation plan, different aspects of existing deficiencies and potential improvements in the water supply system must be considered and analysed. The set of criteria describing the different aspects must be coherent and should cover the various interests. Thus, the aim of a model for decision support is the selection of the most efficient rehabilitation projects by considering the different aspects **according to the preferences of the decision maker**. Furthermore, the result of the decision process should be **transparent and communicable.**

① Water infrastructures renewal

Over recent years, the question of water infrastructure renewal has taken on more and more importance due to increasing of the network size, maintenance costs. Several studies, in providing the age pyramid of all the pipes that constitute water distribution network, try to assess the renewal needs and its impact on water price. The different scenarios proposed by these studies for the rehabilitation interventions programme is based on the pipe lifetime. Nevertheless, this criterion (pipe lifetime) is often not enough to

develop such programme because:

- **Problems do not come necessarily from the oldest pipe**. Different stresses (soil nature, traffic etc) effect on pipe ageing. Thus, it depends on pipe environment.
- **The most damaged pipe is not automatically the most critical one**. It depends on the consequences of the deficiency, e.g the impacts on environment (water interruptions, traffic disruptions etc).

② Multi-criterion assessment for prioritisation

In order to assess and compare potential candidates for rehabilitation, two types of criteria have been defined by CARE-W-ARP partners (Figure 2):

- **Criteria assessing the consequences of the condition of each pipe** of an asset stock: expected repair costs, expected impacts of water interruptions, contribution to water losses or water quality problems, possible damage or disruption to the urban environment due to bursts or repairs, etc.
- **Criteria assessing the opportunity of a rehabilitation project**: rehabilitation cost, co-ordination with rehabilitation programmes of other utilities (gas, roadworks, etc.).

Short name	Long name
ARC	Annual Repair Costs
WLI	Water Losses Index
PWI	Predicted Water Interruptions
PCWI	Predicted Critical Water Interruptions
PFWI	Predicted Frequency of Water Interruptions
HCI	Hydraulic Criticality Index
DFH	Damages due to Flooding in Housing areas
DFI	Damages due to Flooding in Industrial or Commercial areas
DSM	Damages due to soil movements
DT	Traffic Disruptions
DDI	Damage and/or Disruption on other Infrastructure
WQD	contribution to Water Quality Deficiencies
AUCR	Annual Unit Cost of Rehabilitation
COS	Co-ordination Score

Figure 2: Criteria definition (source: Le Gauffre et al. 2003)

Information required for the calculation of these criteria is derived from four main sources (Figure 3):

- Performance indicators
- Hydraulic Reliability software
- Failure prediction tools to supply predicated burst rates per pipe (Theory of probability).
- Utility Databases (information on the pipe environment, surface type, population supplied and so on). These data are obtained from water utilities or other utilities (roads & traffic, urban planning, etc.).

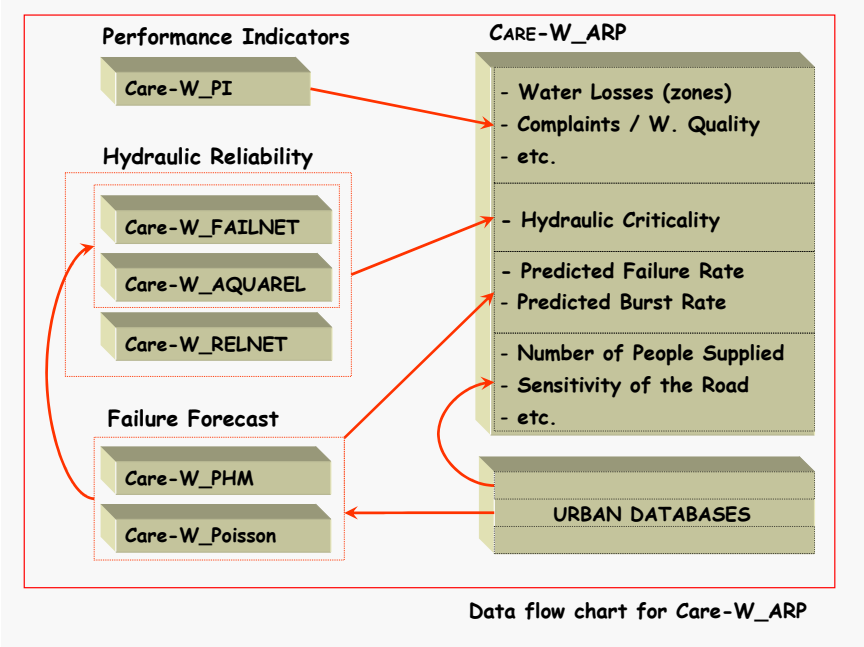

Figure 3: Data sources and data flow for CARE-W-ARP (source: Le Gauffre et al. 2003)

③ Multi-criterion tool proposed

The procedure of CARE-W-ARP uses the **multi-criterion method ELECTRE TRI**. Each pipe is represented by a multi-criterion profile (see figure 1). The outranking approach of the ELECTRE TRI method allows the prioritisation of candidate pipes by comparing each profile with **reference profiles**. The project authors have chosen to define 2 reference profiles for the delimitation of **3 categories** (**C3**: highest priority level, category including the less acceptable pipes (high risk), **C1:** lowest priority level (low risk) and **C2**: in-between category – figure 4).

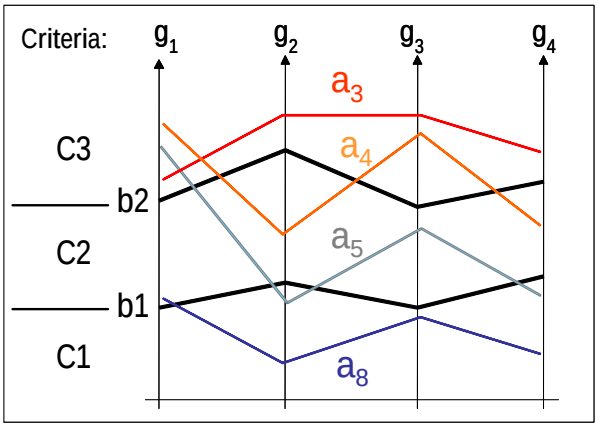

Figure 4: Two reference profiles (b1 and b2) are defined for the "delimitation" of three categories. In this example, each pipe a_i is assessed according to 4 criteria g_i representing performance deficiencies. (source: Le Gauffre et al. 2003)

For the assignment of a pipe to a category (C3, C2 or C1), the pipe profile is compared successively to the 2 reference profiles. Two procedures can be used: an "optimistic" one and a "pessimistic" one. They use the same information but different rules to assign candidates.
This double procedure allows knowing if the candidate is comparable (C33, C22, C11) or not (C32, C31, C21) to the reference profile. The cases where a pipe can not clearly be assigned to one of the categories of priority by both the optimistic and the pessimistic assignment procedures are due to the incomparability with at least one of the reference profiles (figure 5).

To make it clear, C33 means that both optimistic and pessimistic procedures allocate the pipe to the category C3. It is the case for the multi criterion profile of the pipe a_3 in the figure 4. C32 means that the

optimistic procedure allocates the pipe to the category C3 and the pessimistic to the category C2. For example, see multi criterion profile of the pipe a_4 in the figure 4.

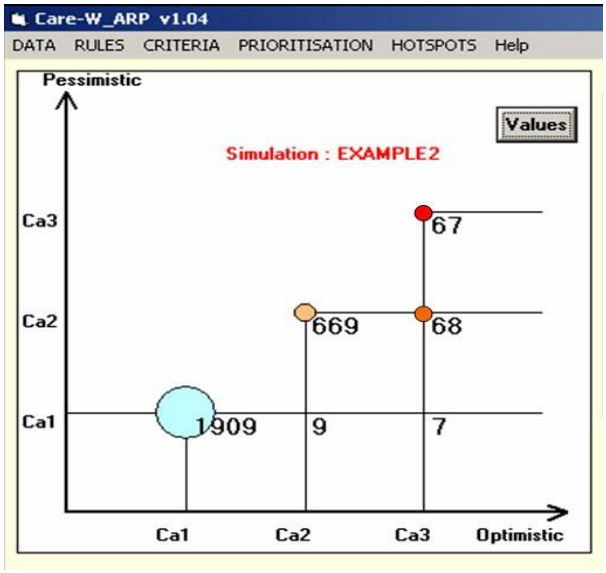

Figure 5: This figure represents an example of ELECTRE TRI simulation. It indicates the number of pipes assigns in each categories C33, C32, C32, C22, C21, and C11 (source: Le Gauffre et al. 2003)

The figure 5 indicates that 67 pipes have been allocated to the category C33, 669 to the category C22, 1909 to the category C11, 68 to the category C32, 9 to the category C21 and 7 to the category C31.

This ranking, obtained from a simulation with ELECTRE TRI can be illustrated on a network representation. For each category, one colour can be affected. You can choose to represent the 6 categories or just 2 of them (for example, the 2 with the highest priority level – figure 6).

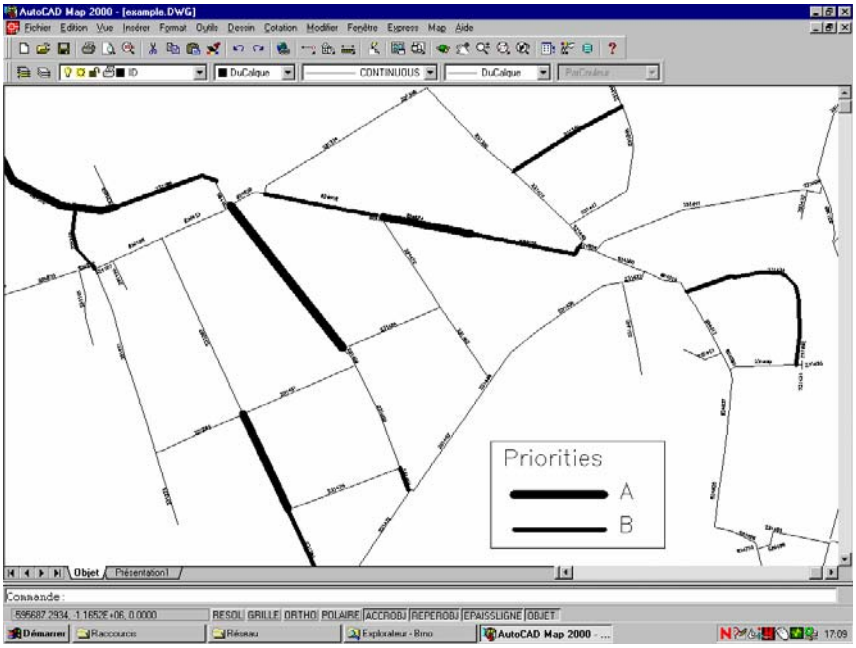

Figure 6: Mapping of prioritised pipes in the network for rehabilitation (source: Le Gauffre et al. 2003)

④ Testing of the CARE-W-ARP software

The CARE-W-ARP has been tested on 6 water supply networks of European cities (Greater Lyon (Fr), Lausanne (CH), Reggio Emilia (I), Brno (Cz), Oslo and Trondheim (Norway)) with the collaboration of the water services. This testing period occurred during 2003.

The end-user must select a well defined geographical area of its water distribution system for this activity, which can be:

- One entire network: this is the standard option.
- One sector of a network: if lack of data or limited availability of the end-user does not allow using the entire network, this option is an alternative; however, it is necessary that data is disaggregated enough to be adequately referred to the selected physical sector.

On a case by case basis, which depends on specific context of the city and data availability, **different criteria can be used** (example in figure 7) to compare pipes for rehabilitation.

	Water service:	R.E.	L.	O.	G. L.	B	T.
	Length studied (km):	632	800	8	1100	272	21
	Number of pipes:	2729	8000	215	19800	2000	279
	Status (oct. 2003):	done	done	done	→	→	→
	Criteria						
COS	Co-ordination score	✓			✓	✓	✓
ARC	Annual Repair Costs	✓	✓	✓	✓	✓	✓
WLI	Water Losses Index	✓					
PWI	Predicted Water Interruptions	✓		✓	✓	✓	✓
PCWI	Predicted Critical Water Inter.	✓			✓	✓	
PFWI	Predicted Freq. of Water Inter.	✓	✓	✓	✓	✓	✓
DFH	Flooding in Housing areas		✓		✓	✓	✓
DFI	… in Indust. or Comm. areas						
DSM	Damage due to Soil Movement				✓		
DT	Traffic Disruptions	✓	✓	✓	✓	✓	✓
DDI	Damage on other Infrastructure			✓			✓
WQD	Water Quality Deficiencies index	✓			✓		
HCI	Hydraulic Criticality Index		(✓)	✓		✓	✓
	Additional (user-defined) criteria	✓	✓,✓				✓

Figure 7: Criteria used in each experiment (source: Le Gauffre et al. 2003)

Several simulations may be run by **modifying weights of criteria, reference values and/or other parameters**. These results can be compared in CARE-W_ARP using sensitivity or robustness analysis.

There are 2 levels of testing. The first one is done on a water supply network of a city with the decision maker's preferences and gives the selection of the most efficient rehabilitation projects (ranked by category). The second one is undertaken by researchers who make sensitivity and robustness analyses in order to improve the ARP tool and also to be able to help and to give advice to end users on the different weights, thresholds, precisions used etc.
The second level of testing (done by researchers) has not been implemented in all cities involved, and will depend on the relevance and quantity of available data and of "end-users" demand.

⑤ Improvements gained by using the tools:

Environmental dimension
The tools reduce water loss, and thus the water management at the city level.

Social dimension
The use of this tool reduces the inconveniences and discomforts suffered by the water supply network users when there is problem such as pipes breaks etc.
This tool also allows political choices to be taken into consideration such as rehabilitation of a particular district of the city, etc.

Economic dimension
The management of how to spend a given annual budget for rehabilitation on the most efficient projects is improved without forgetting how to take into consideration the other dimensions (social and environmental).

B. Tool implementation

1. Argumentation for choosing the tool:

The most important particularities of CARE-W-ARP for producing an annual rehabilitation program in comparison with other tools are:

- The formulation of relevant criteria assessing deficiencies and impacts on the pipe environment (see figure 2). The new approach consists in taking into account the impacts of deficiencies and not only the breaks rate or the pipe lifetime as it is often practically done. Thinking about impacts allows enhancing the global vision of deficiencies. Here is taken into account the environment of the pipe which is the soil, roads above, clients supplied etc and not the network only.
- The possibility to compare pipes without aggregating criteria (and as criteria represent impacts, without aggregating impacts). The non aggregation of criteria is not something new about multi criteria analysis. However CARE-W-ARP represents an application of such method on water supply network.
- The will to keep criteria that are not costs. Traditional tools for producing rehabilitation plans often translate different criteria in costs to allow the comparison and also the ranking of pipes. CARE-W-ARP advocates pipes comparison according to criteria expressed in their own unit and not necessary costs.
- The distinction of short and long term approach. Traditional tools often calculate the optimum date for the rehabilitation works of a pipe. CARE-W-ARP proposes a procedure to define the best strategy for planning rehabilitation investments in a long term approach.

2. Barriers for the tool implementation

The barriers for CARE-W-ARP implementation are firstly the lack of data available. Without a real policy of data collection for the network, this tool is not relevant and can cause inaccurate results. Secondly the whole implementation of the tool is time consuming. However it is possible to implement just a part of the tool and of the ranking criteria according to the user needs (see figure 7).

C. Influence of the tool on the decision-making process

1. Description of the decision-making process/procedures

The CARE-W-ARP implementation belongs to the early stage of the decision making process. The results of the tool use indicate for one year the water network rehabilitation works to do. The choices done during the decision making process are essentially technical. However political choices have also an influence. For example political weights exist through the choice of taking more or less influence of criteria during the ranking procedure. For instance, if the local councillors decide that traffic disruption is not a priority in comparison with flooding criteria, the technicians who are in charge of the annual rehabilitation planning can take into account such preferences in choosing different weights for criteria. The political influence does not interact directly with the tool implementation but indirectly because it belongs to the technicians to take final conclusions. That's why the benefits of the tool implementation encourage opening a dialogue between technical and political levels: technicians should be well informed of the political orientations.

2. Tool in decision-making process

The tool CARE-W-ARP is a multi-criterion decision support. It guides the decision maker to a decision according to his own preferences and is also guided by the environmental, social and economic criteria. The decision maker can produce a prioritisation of the pipes within the particular city context by modifying several parameters. First end users may run all the tools included in the CARE-W toolkit system or a selection, depending on the problem to be solved (Performance indicator tool, ARP, Fail tool, and the Long Term Planning tool). During the simulation with CARE-W-ARP, different criteria can be used to compare pipes for rehabilitation which depends on specific context of the city and data availability (see figure 6 above), different weights can be allocated to the each criterion, and also different reference profiles, threshold and precisions can be used.

The use of this tool improves the decision process to be more transparent and communicable with conclusive evidence provided as to why decision to focus on particular pipes has been made. It gives illustrations and justifications to support a decision during discussion with elected representatives.

The implementation of CARE-W-ARP advises decision makers to think about impacts of deficiencies and not about the break rate of the pipe only. Thinking about impacts allows enhancing the global vision of deficiencies. Here is taken into account the environment of the pipe which is the soil, roads above, clients supplied etc and not the network only. It allows to make a decision "out of the water supply network" (from interviews with stakeholders), to combined urban issues with the water network. The urban environment is both upstream and downstream of the water supply network. Upstream because it causes the damages of the network (breaks, corrosion, etc) and downstream because it suffers the consequences of the damages (pollution, water disruption, traffic disruption etc).

A pipe ranked by CARE-W-ARP in the category C33 (high potential risk), is in practice not replaced if this pipe doesn't present physical failures. CARE-W-ARP method proposes on contrary to prove that its replacement can have benefits in regard of money savings and reduction on environment impacts (proactive management).
This is what researchers try to prove (see second level of testing). For example, in Reggio Emilia, researcher team had 5 years of data (between 1996 and 2000). They have made the assumption that CARE-W-ARP is used in 1998 and they calculate the benefits that it should have offer.

3. Transparency of decision-making process

The use of this tool improves

- Discussions and dialogues between municipal engineers of the water network and the elected representatives by the increase of transparency and communication
- The management of a given annual budget
- The consideration of environmental, social and economic issues in making a decision regarding pipe rehabilitation.

D. Expert assessment/analysis/comment of the tool effectiveness

1. Assessment by tool users

As the good elements of the tool use are discussed all the case study long, is discussed here essentially some improvements that could be done or that are ongoing.

The tool needs still some improvements:

- Improvement of the tool to take in account all the context dimensions (political choices) and end users preferences (see second level of testing by researchers).
- Improvement of the ease of use for end users.
- Improvement of the mapping (see figure 6) in order to be relevant and effective as a tool of decision making process. Actually, the mapping has an interest if water supply network area considered is not too wide. However mapping for example the 1100 km of the Greater Lyon water network is too wide and so doesn't give an effective overview of the results.

A limit of the tool is the necessity of assessing pipes for rehabilitation according to the same criteria. It means that the tool user should have the same information on all the pipes that he wants to rank. If a data is missing for the calculation of a criterion on a pipe, the criterion can not be used for the ranking.

2. Reviewer's assessment

One important point is the collaboration between researchers and local water managers. The success of this tool comes from the good communication and co-operation between them.

The main barrier of using this tool is the lack of available data (material, localisation and age of pipes, failure history etc). Thus CARE-W-ARP partners advocate, not directly, the implementation of data collections, logbooks and monitoring in order to create a water services record.

E. Additional information on the case study available

Websites	➢ http://care-w.unife.it/
References *concerning the case but also the key words or problem* (papers, articles, reports, laws, etc.)	➢ references: o LE GAUFFRE P., BAUR R., LAFFRECHINE K., MIRAMOND M. (2002), Multicriteria decision support for the annual rehabilitatiion programmes of water networks. Proceedings Int.Conf. Decision Making in Urban and Civil Eng. DMUCE'2002

	London (UK), 6-8 november 2002. ISBN 09043544 7 4, pp. 665-660 ; o LE GAUFFRE P., LAFFRECHINE K.,SCHIATTI M., BAUR R., Identifying priority projects for annual rehabilitation planning, International Conference Water Infrastructure Management : Planning Water Mains Rehabilitation Computer Aided Rehabilitation of Water networks (CARE-W). Bath (UK) 28th November 2003. o LE GAUFFRE P., LAFFRECHINE K., BAUR R., POINARD D., SCHIATTI M., Réhabilitation des réseaux d'eau potable : des outils multicritères pour la programmation annuelle. Conférence Internationale ASTEE (AGHTM)-EWA « Exploitation et maintenance des réseaux d'eau potable et d'assainissement », 4 & 5 décembre 2003 - POLLUTEC – Paris. o TORTEROTOT J.P., WEREY C., REBELO M., CRAVEIRO J., Réhabilitation des réseaux d'eau potable : les processus de décision et le projet CARE-W. Conférence Internationale ASTEE (AGHTM)-EWA « Exploitation et maintenance des réseaux d'eau potable et d'assainissement », 4 & 5 décembre 2003 - POLLUTEC – Paris.
Other sources (Interviews, conferences, discussions, etc.)	Several interviews with Pascal La Gauffre and Atem Haidar from INSA-Lyon and with David Poinard, Companie General Des Eaux (private water company of water suplly).
Contact details for further information	For further information, please contact: Pascal Le Gauffre pascal.le-gauffre@insa-lyon.fr