A RESEARCH PROJECT SUPPORTED BY THE EUROPEAN COMMISSION UNDER THE FIFTH FRAMEWORK PROGRAMMME AND CONTRIBUTING TO THE IMPLEMENTATION OF THE KEY ACTION "SUSTAINABLE MANAGEMENT AND QUALITY OF WATER" WITHIN THE ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

EVK1-CT-2000-00053

REPORT

No. 3.1 - June 2002

CARE-W: WP 3 – Decision support for annual rehabilitation programmes
D6 – Criteria for the prioritisation of rehabilitation projects

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COMPUTER AIDED REHABILITATION OF WATER NETWORKS

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CARE – W

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

WP 3 - Decision support for annual rehabilitation programmes

Tasks 3.1. & 3.2. – Criteria for prioritisation

D6 – deliverable [1]

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Lyon (F), June 2002

[1] *Reference*:
LE GAUFFRE P., LAFFRÉCHINE K., BAUR R., DI FEDERICO V., EISENBEIS P., KÖNIG A., KOWALSKI M, SÆGROV S.,TORTEROTOT J.P., TUHOVCAK L., WEREY C. (2002) CARE-W: WP3 – Decision support for annual rehabilitation programmes. D6 - Criteria for the prioritisation of rehabilitation projects. CARE-W (Computer Aided Rehabilitation of Water networks), EU project under the 5th Framework Program, contract n°EVK1-CT-2000-00053. Lyon (F): INSA-URGC, June 2002, 72 p.

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1 - INTRODUCTION

CARE-W project 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 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.

INSA Lyon is responsible for WP3, which is divided in 4 Tasks:

- Task 3.1: Criteria for selecting rehabilitation projects – technical concerns and technical costs
- Task 3.2: Criteria for selecting rehabilitation projects – external points of view
- Task 3.3: Survey of available multicriteria techniques and selection of relevant methods
- Task 3.4: Multicriteria procedure for annual rehabilitation programmes

Table 1 – Planning

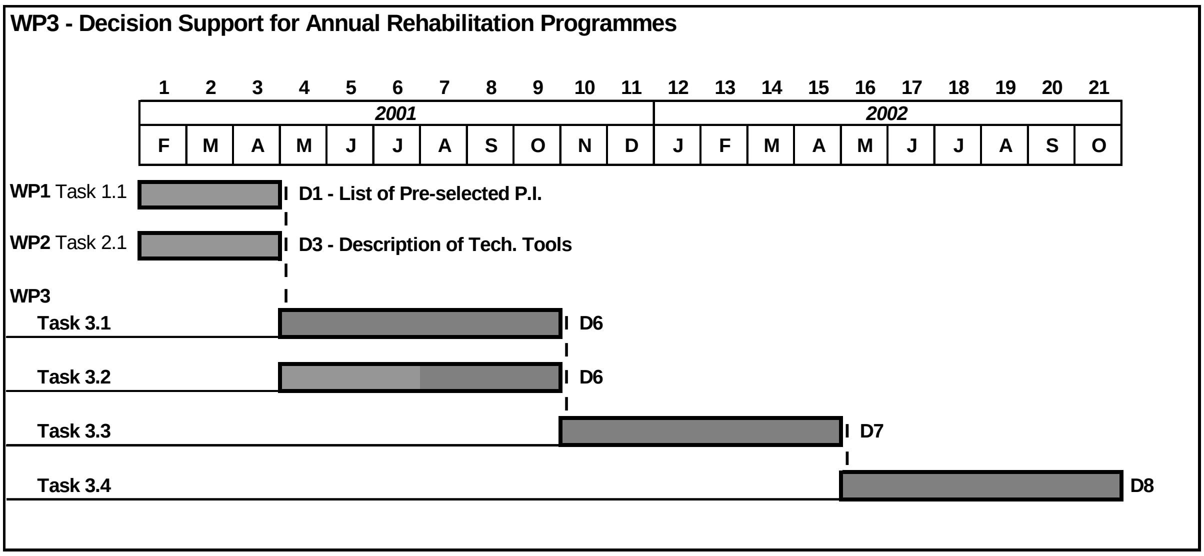


Table 2 – Deliverables

Deliverables	Delivery date	Nature	Dissemination level
D6 – Criteria for evaluating potential actions Criteria relative to technical concerns and technical costs *(Task 3.1.)* Criteria relative to the effects on social impacts *(Task 3.2.)*	+10	Th (theory) Re (report)	PU (public)
D7 – Survey of multicriteria techniques and selection of relevant procedures *(Task 3.3.)*	+16	Th (theory) Re (report)	PU (public)
D8 – Multicriteria procedure for annual rehabilitation programmes *(Task 3.4.)*	+22	De (demonstrator)	RE (Restricted)

This report refers to tasks 3.1 and 3.2.

2 - METHODOLOGY FOR TASKS 3.1 AND 3.2

2.1 Definitions and principles

2.1.1 About decision aid

The definition of an annual rehabilitation programme can be seen as a decision-making process including the four phases defined by H.A. Simon (1977):

i. Intelligence phase: the reality is examined under the environment, and the problem is identified and defined.

ii. Design phase: generating, developing, and analysing possible courses of action.

iii. Choice phase: search and recommend an appropriate solution to the design.

iv. Review phase: implementation of the result if the proposed solution is reasonable.

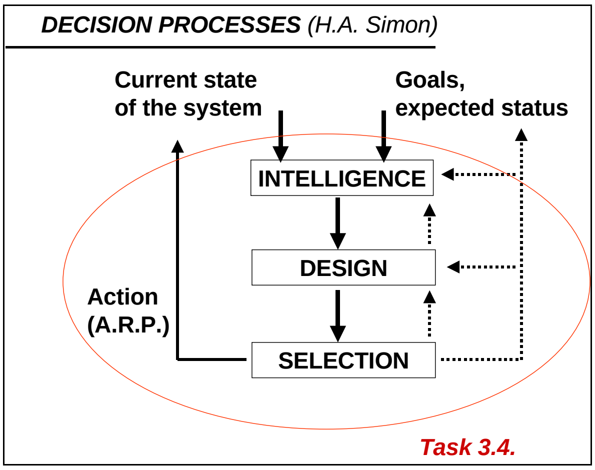


Fig. 1 – Decision processes according to H.A. Simon

Concerning the definition of annual rehabilitation programmes these four phases correspond to the following tasks:

i. Intelligence phase: problems (unacceptable or poor performances) are identified and defined in using performance indicators evaluated by monitoring or modelling. A preliminary set of 67 performance indicators have been defined in work package 1 (Melo Baptista, Alegre, 2001), part of them obtained directly from the IWA system (Alegre *et al*., 2000) and some new ones specific for the rehabilitation analysis.

ii. Design phase: possible actions can be defined in considering zones and pipes with unacceptable or poor performances. Rehabilitation of pipes that are located in a street concerned by the roadway (or other utilities) rehabilitation programme are also considered as possible actions.

iii. Choice phase: corresponds to the selection of actions that will be included in the annual rehabilitation programme. For this phase, a Multiple Criteria Decision Aid is developed in work package 3. This includes the definition of criteria (tasks 3.1 and 3.2) and the definition of multicriteria models (task 3.3) allowing the establishment of preference relationships between possible actions.

iv. Review phase: corresponds to the evaluation of an annual rehabilitation programme generated in selecting a set of possible actions. Decision Aid has to include arguments or explanations to justify an annual rehabilitation programme and the associated capital expenditure.

In order to explicit the third phase, let us consider the four reference problematics that have been defined by Bernard Roy (Roy, 1996):

1. $P\alpha$: Choice Problematic – help choose a best action or develop a selection procedure
2. $P\beta$: Sorting problematic : help sort actions according to norms or build an assignment procedure
3. $P\gamma$: Ranking problematic : help rank actions in order of decreasing preference or build an ordering procedure
4. $P\delta$: Description problematic : help describe actions and their consequences in a formalised and systemic manner or develop a cognitive procedure

Regarding the decision problems that we are considering in WP3, the expected decision support can correspond to the second or to the third problematic. The selection of a set of possible actions (for the definition of an annual programme) can be seen as:

- a procedure for sorting possible actions according to their effectiveness or efficiency (see Fig. 2);
- a procedure for comparing and ranking possible actions in order to select a sub-set of “best” actions that will be included in the annual programme (see Fig. 3).

The first option is more ambitious than the second one. In a sorting procedure each action has to be compared with norms. This requires defining rules or thresholds that allow assigning each action in a predefined category (e.g. no need for rehabilitation, pipe that has to be rehabilitated in the next 5 years, etc.).

The second option only requires comparing possible actions.

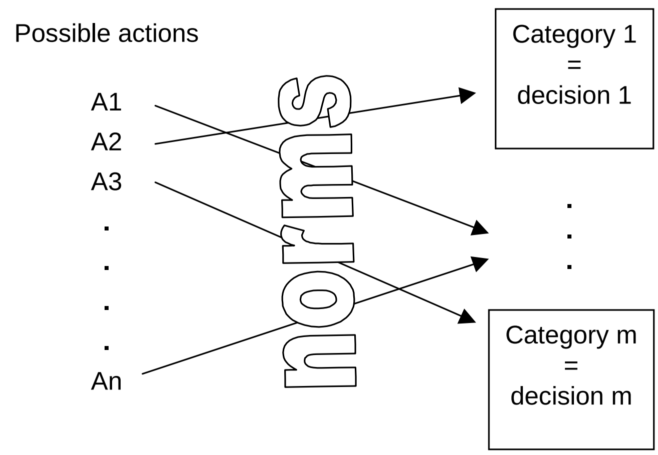


Fig. 2 – Sorting procedure: each possible action is assigned in a category according to norms. Each pre-defined category corresponds to a particular decision.

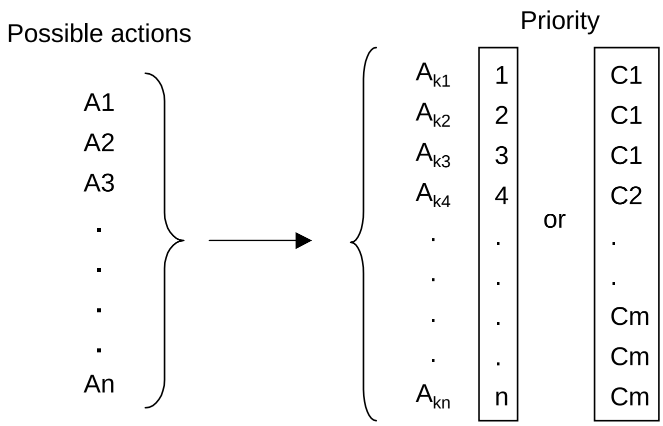


Fig. 3 – Ranking procedure: possible actions are compared to each other. Priorities can be defined in ordering actions (from the best one to the n^{th}) or in ordering sub-sets of actions (from class 1 to class m).

2.1.2 About potential actions or alternatives

B. Roy (1996) has defined a potential action (or candidate) as "an actual or dummy action temporarily judged as being realistic. (…)"

Some other terms are used in the literature to designate actions that have to be sorted or ranked: alternatives, or possible actions.

In this report we will use these expressions as synonyms.

Regarding the definition of annual rehabilitation programmes, two different sets of candidates can be defined and studied:

- each pipe ($i \in \{1,2,3,....n\}$) with performance deficiencies can be seen as a candidate (for rehabilitation);
- or: each rehabilitation measure (i,j) (method $j \in \{0,1,...,m\}$ applied to pipe i) can be seen as a candidate.

In the first case, a sorting procedure or a ranking procedure has to deal with problems. Each pipe is represented with a vector of performances. Pipes with unacceptable or poor performances correspond to problems and constitute candidates for rehabilitation

In the second case, a sorting procedure or a ranking procedure has to deal with actions (such as “no rehabilitation for pipe x”, “non structural lining of pipe y”, etc.). Each action has to be assessed with a vector of attributes representing the expected improvements on pipe performances and intrinsic characteristics such as the rehab cost or disruptions.

These two options could be combined in a decision procedure:

- a first step could consist in sorting or ranking pipes (or problems);
- a second step could consist in sorting or ranking rehabilitation measures for pre-selected pipes (or problems).

We will see in 2.1.3 how to define criteria in these two cases.

2.1.3 About criteria

We have selected two definitions in the MCDA (Multiple Criteria Decision Aid) literature:

☞ “A criterion can be defined as a tool that allows the comparison of alternatives according to a particular point of view” (Rogers, Bruen & Maystre, 2000)

☞ “A criterion is a type of model allowing the establishment of preference relationships between alternatives”. (Rogers, Bruen & Maystre, 2000)

2.1.3.1 Points of view:

Regarding the decision problems that we are considering in WP3, points of view can be divided into two types:

1. “Internal” points of view (points of view of the operator) corresponding to technical concerns and technical costs such as:
   - Rehabilitation costs
   - Repair costs
   - Water losses and corresponding costs
   - Energy cost
2. “External” points of view (of customers, road users, etc.):
   - disruptions associated with a particular rehabilitation method
   - impacts of water interruptions
   - damages and disruptions caused by bursts or repairs
   - water quality deficiencies
   - hydraulic deficiencies

Criteria and sub-criteria have to be defined to evaluate and compare candidates according to these various points of view.

Other aspects have to be taken into account to assess candidates:

- co-ordination with other utilities and roadway rehabilitation programmes
- co-ordination with service connection replacement programmes
- etc.

2.1.3.2 Establishment of preference relationships:

Each candidate is evaluated according to several criteria. In order to sort or rank these candidates, a performance matrix has to be calculated (Fig. 4): $a_{ih} = C_h(a_i)$ is the score (or performance) of action i according to criterion *h*.

	Criteria						
Candidates	C_1	C_2	..	..	C_h	..	C_M
a_1	a_{11}	a_{12}			a_{1h}		a_{1M}
a_2	a_{21}	a_{22}			a_{2h}		a_{2M}
..							
..							
a_i	a_{i1}	a_{i2}			a_{ih}		a_{iM}
..							
a_N	a_{N1}	a_{N2}			a_{Nh}		a_{NM}

Fig. 4 – Performance matrix with N candidates and M criteria

We have seen in 2.1.2 that candidates could be pipes ($i \in \{1,2,3,....n\}$) or rehabilitation measures (i,j) (with method $j \in \{0,1,...,m\}$ applied to pipe $i \in \{1,2,3,....n\}$).

In these two cases, criterion h has to represent the preference relationship between candidates according to a particular point of view (for example: water quality):

- <u>in the first case</u>: pipe a_i is preferred to pipe a_k according to criterion *h* if the problem associated with this criterion *h* is more severe on pipe a_i than on pipe a_k ;
- <u>in the second case</u>: rehab measure a_i is preferred to rehab measure a_k according to criterion *h* if the consequences expected with a_i are preferred to the consequences expected with a_k. These expected consequences might be: (see Fig. 5)
    - the expected performances after rehabilitation (this can be difficult to assess)
    - or the expected improvement of these performances: this expected improvement could be defined with a quantitative value (ΔP) or with a qualitative value derived from rules (high/moderate/low or score)

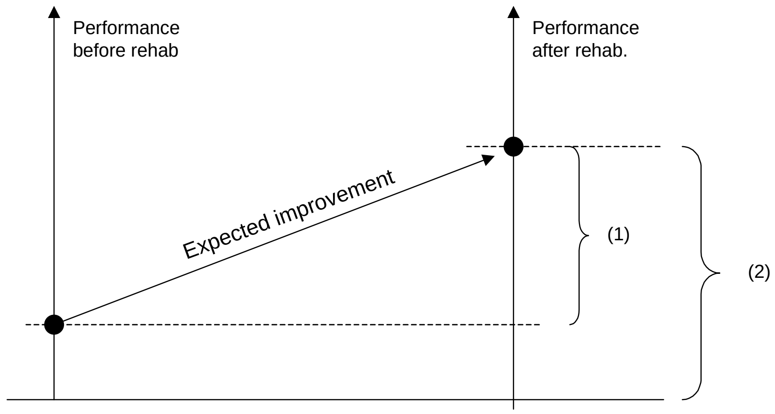


Fig. 5 – Two different ways of assessing the consequences of rehab measures. (1) is a qualitative or quantitative measurement of the improvement expected with rehabilitation; (2) is a measurement of the performance expected after rehabilitation.

In Appendix 2, examples are given concerning the construction of decision criteria for comparing rehabilitation projects. In MARESS (Multi-Attribute Rehabilitation of storm or combined Sewer Systems) (Reyna *et al*., 1994) (Delleur *et al*., 1998) criteria and sub-criteria are used to compare rehabilitation measures.

For example:

- $SCI_{ij} = SCI(i, j)$ is the value of criterion SCI (Structural Condition Index) for reach *i* rehabilitated with technology *j*);
- $HCI_{ij} = HCI(i, j)$ is the value of criterion HCI (Hydraulic Condition Index) for reach *i* rehabilitated with technology *j*).

$$HCI_{ij} = HCI_{i,0} \frac{D_{i,0}^{8/3}}{D_{i,j}^{8/3}} \frac{n_{i,j}}{n_{i,0}}$$

$HCI_{i,0} \left(\in \{0,1,2,..,9,10\} \right)$ is the Hydraulic Condition Index for reach *i* in the current situation and is determined from 3 "factors" (let say "Performance Indicators") calculated with SWMM:

- the maximum to design flow ratio
- the duration of surcharge
- the duration of flooding

$\frac{D_{i,0}^{8/3}}{D_{i,j}^{8/3}} \frac{n_{i,j}}{n_{i,0}}$ is a factor representing the expected improvement with rehabilitation measure *j* (with diameter *D* and Manning's roughness coefficient *n*)

For this criterion HCI, the process used to calculate the performance associated to a candidate (i,j) is a mixed process: one calculation is done with SWMM (to assess the current performances), and the expected performance (after rehab j) is obtained in combining the current value of the index (HCI_{i0}) and the expected improvement factor for rehab method j.

In Table 3 we propose different types of criteria that can be defined to compare pipes or to compare rehab measures.

Defining these different types of criteria leads us to distinguish **three types of approaches** (or 3 components) in the management of rehabilitation activities:

A) Corrective rehabilitation based on the assessment and hierarchisation of current observed deficiencies; performance indicators allow to put some "flags" on each pipe where continuous or recurrent deficiencies (directly associated with the pipe condition) have been recorded through the use of performance indicators.

B) Preventive rehabilitation based on the assessment and hierarchisation of risks; Predicted performances can be calculated with modelling tools or in using observed failure rates.

C) Corrective rehabilitation based on a diagnosis that is the identification and the hierarchisation of pipe contributions to zonal problems.

Table 3 – Types of criteria that can be defined to compare pipes or rehabilitation measures.

Context →	Pipe i $i \in \{1,2,3,....n\}$ (in the current state)	Rehab Measure (i,j) $i \in \{1,2,3,....n\}$ $j \in \{0,1,...,m\}$	← Context
E) Criteria regarding co-ordination: Pipe: - in a street concerned by the Rehab programme for the roadway or for other utilities - with service connections that are candidates for replacement - with service connections replaced during the last years - …	- A) Criteria directly derived from Performance Indicators evaluated for pipes (e.g.: Water interruptions) - B1) Criteria assessing predicted performances (e.g.: Risk of Water Interruptions, Risk of severe damage or major disruption, etc.) - C1) Criteria assessing the contribution of one pipe in zonal problems, in combining zonal PIs and pipe attributes (e.g.: Contribution to discoloured water, or pressure deficiencies, ..)	- B2) Criteria assessing predicted performances after rehab measure (i,j) (e.g.: Risk of Water Interruptions, etc.) - C2) Criteria assessing the reduction of zonal problems caused by the reduction of the contribution of pipe i after rehab (i,j) - D) Criteria associated with the characteristics of the technique j applied to pipe i: cost, surface disruptions, etc.	E) Criteria regarding co-ordination: Pipe: - in a street concerned by the Rehab programme for the roadway or for other utilities - with service connections that are candidates for replacement - with service connections replaced during the last years …

2.1.3.3 Possible expressions of criteria – Examples

Examples are given in the table below.

Table 4 – Examples of criteria

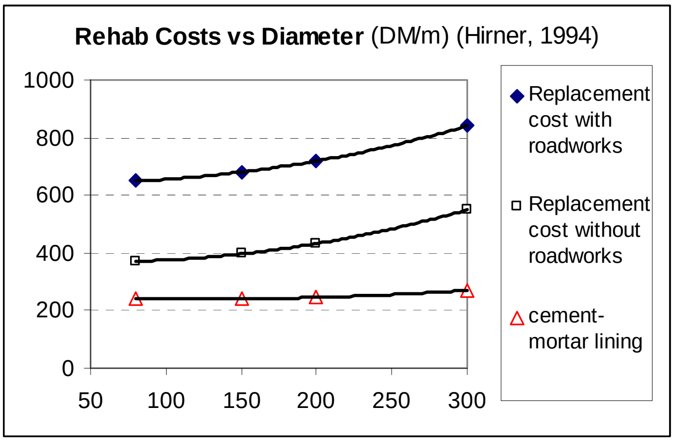
<table>
<tr><th>Type of criteria</th><th>Possible expressions of criteria – Examples</th></tr>
<tr><td>A)</td><td>Service Complaints for Water Interruptions: $SCWI(i)$ (No. / 100m / last 5 years)</td></tr>
<tr><td>B1)</td><td>Predicted Water Interruptions: $PWI(i) = PFR(i)EDI(i)NPS(i)$ (Person.hours / 100m / year) with:
- $PFR(i)$ predicted failure rate for pipe i
- $EDI(i)$ expected duration of interruptions (or MTTR: mean time to repair)
- $NPS(i)$ number of people supplied by the link</td></tr>
<tr><td>B2)</td><td>Predicted Water Interruptions (after rehabilitation): $PWI(i, j)$ (Person.hours / 100m / year)
$PWI(i, j) = PFR(i, j)\ EDI(i)\ NPS(i, j)$ with:
- $PFR(i, j)$ predicted failure rate for pipe i after rehab with technique j
- $EDI(i)$ expected duration of interruptions (or MTTR: mean time to repair)
- $NPS(i, j)$ number of people supplied by the link after rehab with technique j (this sub-criteria can be modified by rehabilitation with one or more new valves on a pipe line).</td></tr>
<tr><td>C1)</td><td>Contribution to Discoloured Water: $CDW(i) = DWZ(i) \otimes CDWZ(i)$ (points), with:
- $DWZ(i)$ Level of problem regarding Discoloured Water in the corresponding Zone (L0, L1, etc.)
- $CDWZ(i)$ Level of contribution of pipe i to discoloured water in the corresponding Zone (C0, C1, etc.)
$DWZ(i)$ and $CDWZ(i)$ can be combined according to an evaluation table as the following one:
<table>
<tr><td>L3</td><td>0</td><td>5</td><td>7</td><td>10</td></tr>
<tr><td>L2</td><td>0</td><td>3</td><td>5</td><td>7</td></tr>
<tr><td>L1</td><td>0</td><td>1</td><td>3</td><td>5</td></tr>
<tr><td>L0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td></td><td>C0</td><td>C1</td><td>C2</td><td>C3</td></tr>
</table>
$DWZ(i)$ could be determined from performance indicators if they are available for zones.
$CDWZ(i)$ could be determined with different approaches:
- in considering pipe characteristics (unlined iron pipes, age of pipes, ...)
- from water samples and analysis: turbidity, dissolved oxygen, iron and manganese concentration, etc. measured with low flow rate and high flow rate flushing.
- from water quality modelling (stagnation time, velocity, …)</td></tr>
</table>

<table>
<tr><th>Type of criteria</th><th>Possible expressions of criteria – Examples</th></tr>
<tr><td>C2)</td><td>
Reduction of Discoloured Water problems: $RDW(i, j) = DWZ(i) \otimes RCDW(i, j)$ (points), with:
- $DWZ(i)$ Level of problem regarding Discoloured Water in the corresponding Zone
- $RCDW(i, j)$ Reduction of the contribution of pipe i to discoloured water in the corresponding Zone
$DWZ(i)$ and $RCDW(i, j)$ can be combined according to an evaluation table as the following one:
<table>
<tr><td>L3</td><td>0</td><td>3</td><td>6</td><td>10</td></tr>
<tr><td>L2</td><td>0</td><td>2</td><td>4</td><td>6</td></tr>
<tr><td>L1</td><td>0</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>L0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td></td><td>No reduction</td><td>C3→C2
C2→C1
C1→C0</td><td>C3→C1
C2→C0</td><td>C3→C0</td></tr>
</table>
Criterion $RCDW(i, j)$ combines two sub-criteria:
- $CDWZ(i)$, level of Contribution of pipe i to Discoloured Water in the corresponding Zone
- $ERM(j)$, expected Effect of the Rehabilitation Method j
<table>
<tr><td>High</td><td>No reduction</td><td>C1→C0</td><td>C2→C0</td><td>C3→C0</td></tr>
<tr><td>Low</td><td>No reduction</td><td>C1→C0</td><td>C2→C1</td><td>C3→C2</td></tr>
<tr><td>No effect</td><td>No reduction</td><td>No reduction</td><td>No reduction.</td><td>No reduction</td></tr>
<tr><td></td><td>C0</td><td>C1</td><td>C2</td><td>C3</td></tr>
</table>
$ERM(j)$ can be defined as follows:
<table>
<tr><td>method</td><td>Open cut replacement</td><td>Pipe bursting</td><td>Structural lining</td><td>Non-structural lining</td><td>Aggressive cleaning</td><td>No rehab.</td><td>…</td></tr>
<tr><td>effect</td><td>high</td><td>high</td><td>high</td><td>high</td><td>low</td><td>No effect</td><td></td></tr>
</table>
</td></tr>
<tr><td>D)</td><td>
<u>Disruptions caused by rehab methods</u>:
In MARESS (Reyna et al., 1994) (Delleur et al., 1998) each rehabilitation method has an associated Disruption Level Index (DLI_j) ranked from 0 to 10, from less to more disruptive. A maximum rank of 10 is given to excavation and replacement and a 0 to no rehabilitation. In this approach the disruption level index is not depending on segment i.
Another way of defining a criterion relative to disruptions caused by rehab techniques consists in combining street characteristics and rehab techniques.
</td></tr>
<tr><td></td><td>
<u>Costs of rehab methods</u>:
A criterion associated with rehabilitation costs can be expressed as a function of the diameter of the rehabilitated pipe: $RC(i, j) = a_j + b_j \times D(i)\ [+c_j \times D^2(i)]$ (a_j, b_j, c_j are depending on rehab
</td></tr>
</table>

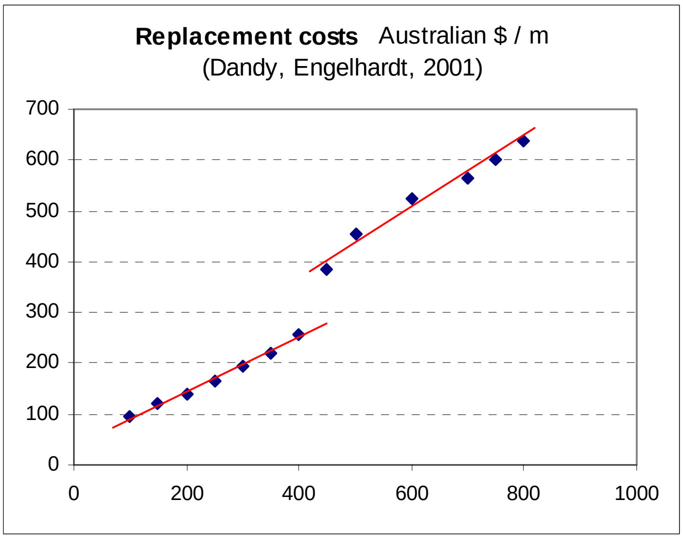
Type of criteria	Possible expressions of criteria – Examples

technique j)

Hirner (1994) presented the following relationships between rehab costs and diameter.



Dandy and Engelhardt (2001) (see appendix 2) have presented some figures from SA Water (South Australian Water Corporation). Small diameter pipes are replaced with DICL pipes (ductile iron-cement lined), other pipes are replaced with MSCL pipes (mild steel-cement lined). For these two cases the replacement cost appears as a linear function of the diameter.



Other parameters could be included in cost functions. S. Kennel (1992) has studied replacement costs and repair costs for 4 areas in the urban community of Strasbourg:

Replacement cost (FF/m) (1991)

	without S.C.		with Service Connections Repl.		
	Mini	Maxi	Mini	Maxi	Average
Centre	1577	3606	2060	3991	2745
North	696	986	1145	1343	1244
West	576	1222	726	2963	1028
South	648	1008	864	1667	1230

Repair cost (FF/m) (1991)

	Mini	Maxi	Average
Centre	1794	19756	7624
North	2704	7729	4540
West	2664	10120	5960
South	2889	15311	6839

Type of criteria	Possible expressions of criteria – Examples
	<u>Annual present costs of rehabilitation measures</u>: In order to compare rehabilitation measures with various expected lifetimes, all costs can be expressed as annual costs. In MARESS (Reyna *et al*., 1994) (Delleur *et al*., 1998) (see appendix 2) the annual unit construction cost is obtained in using 3 main information: $AUCC_{ij} = \frac{r(1+r)^{nj}}{(1+r)^{nj}-1} UCC_{ij}$, with: UCC_{ij} is the unit construction cost for rehab method j applied on reach *i* n_j is the expected life of the rehabilitation using technology *j*. r is the interest rate.

2.1.3.4 Levels of approach

We have previously distinguished 3 approaches or components in rehabilitation management:

A) assessment and hierarchisation of current pipe deficiencies (for corrective rehab)

B) assessment and hierarchisation of risk (for preventive rehab)

C) diagnosis / hierarchisation of pipe contributions to zonal problems (corrective rehab)

For these three approaches two levels of approach (at least) can be considered:

- level 1: criteria evaluated with a limited amount of data that could be quite easily available in water utilities; these criteria allow to compare alternatives and define priorities
- level 2: criteria evaluated with more detailed and/or sophisticated data; these level 2 data are results from modelling tools, results of sampling and analysis, or data allowing an economic assessment.

For some questions or aspects (e.g. water quality problems) these two levels can be associated with two steps. A level 2 approach (complementary investigations) could be decided after a level 1 approach allowing to define priorities for these complementary investigations (field investigations or modelling) on zones or pipes that have been pointed out during the first step.

2.2 Prioritisation of rehab projects in water utilities – Questionnaire & replies

In order to study the current practices and the expectations of water utilities, a questionnaire has been submitted to end-users.

Practices in rehabilitation management have been studied with two levels of details:

- main objectives of rehabilitation projects
- criteria used for prioritisation

2.2.1 Main objectives of rehab projects in water utilities

Replies from end-users are presented in two parts:

- Table 5 presents the overall results concerning the relative importance of objectives (of overriding importance / important / of minor importance / not important).
- In Fig. 6 a profile represents the practices and concerns of each utility. Each profile can be compared to a mean profile synthesising all the replies.

Table 5 – Objectives of rehabilitation projects

OBJECTIVES	is of overriding importance	is important	is of minor importance	is not important	data or tools missing (to take into account this objective) YES
Improve hydraulic performance	1 *	6 *	3	1	2
Improve water quality	5 *	5 **	2	-	3
Reduce operation and maintenance costs	3 **	7 ***	2	-	6
Reduce water losses	2 *	7 **	3	-	3
Reduce the number of mains failures and their consequences	6 *	5 ***	1	-	4
Reduce the age of water at the customer tap	-	3 **	5 *	4 **	5
Maintain or improve the average condition of network	3 **	6 ***	1	1 *	6
Other : Service connections renewal	2	-	-	-	1
Other: Water meter replacement	1	-	-	-	1
Other: Service connections in Lead	1	1	-	-	-
Other: Increase the total reliability of network	-	-	1	-	-
Other: Reduce the number of complaints	-	1	-	-	-
Other: Reduce abestos leng	-	-	1	-	-
Other: Coordination with other utilities or road rehabilitation	-	1	-	-	-

(*) means that one reply in this column is associated with the comment: “data or tools missing”

Importance of objectives			**Objectives**
3	is of overriding importance	H	Improve hydraulic performance
2	is important	WQ	Improve water quality
1	is of minor importance	OMC	Reduce operation and maintenance costs
0	is not important	WL	Reduce water losses
		F	Reduce the number of mains failures and their consequences
		AW	Reduce the age of water at the customer tap
		ACN	Maintain or improve average condition of network

Fig. 6 – Relative importance of the objectives according to 12 water utilities

2.2.2 Criteria for prioritisation

In the following table we present a synthesis of the replies concerning the criteria used to compare rehab projects and to define priorities of action for annual rehab programmes.

Table 6 – Criteria for prioritisation of rehab projects

●●● of overriding importance / ●● important / ● of minor importance / o not important.

WATER UTILITIES Criteria	ACOSEA (Ferrara)	Consorzio Acque Delta	LYON - SLA	TRONDHEIM KOMMUNE	BRNO	VAV (Oslo)	LAUSANNE	ROUBAIX TOURCOING	AGAC	DRESDEN (Drewag)	BRISTOL WATER	STUTTGART
Inadequate minimum system pressure with consequent customer complaints	●●●	●●●		o	●	●	●●●	o	●●●	●	●	●●●
Water quality standards not fulfilled (owing to network condition)	●●●	●●●	●●	o	●●	o	●●●	o	●	●●●	●●●	●●●
Restrictions on water uses due to water quality (owing to network condition)	●●●	●●●		o	●	o	●●●	o	●	●●●	o	●●●
Frequent and increasing number of relevant customer complaints	●●	●●	o	●●	●●	●	●●●	o	●●	●●●	●●	●●●
Failure rate (~~above threshold~~)[2]		●●	●●●	●●		●●●	●●●	●●●	●●	●		●●
Pipe condition												
Badly encrusted pipe	●	●●	●●●		●●	o	●●	o	●	●	●	●
Pipe prone to bursting	●●●	●●●	●●●		●	●●	●●●	●●●	●●	●●	●	●●
External corrosion	●●	●●	●●●	●●●	●	●●●	●●	o	●	●●	●	●
Leaking joints	●●	●●	●●●	●	●	●●	●●●	●●	●●	●	o	●●
Pipes susceptible to												
Ground movement	●	●●	●●●	●	●●	●●	●●	o	o	●●●	o	●●●
Stray current	●	o		●	●	●●	●●	o	o	●●●	o	●
Heavy traffic loading	●	●	●●	●	●	●●	●	●	●●	●	o	
Frequency of water interruptions	●●	●●●	●●●	●●	●	●●●	●●●	●●●	●●	●●●	o	●
Consequences of interruptions:												
Number of people supplied by the link	●●	●●●	●	●●	●	●●	●●	●●●	●●	●●●	o	●
Sensitive or key customers supplied by the link	●●●	●●●	●●	●●●	●●	●●	●●●		●●	●●●	o	●●●
Risk of severe damage or major street disruption from bursts	●●	●●●	●●●	●●	●	●●	●●●	●●●	●●	●●	o	●●●

[2] Some replies are missing, as we originally asked for the importance of the criterion: "*failure rate above threshold*".

Water Utilities / **Criteria**	ACOSEA (Ferrara)	Consorzio Acque Delta	LYON - SLA	TRONDHEIM KOMMUNE	BRNO	VAV (Oslo)	LAUSANNE	ROUBAIX TOURCOING	AGAC	DRESDEN (Drewag)	BRISTOL WATER	STUTTGART
High level of water losses in the area	●●●	●●	o	●●	●●		●●●	●●●	●●	●●	●	
High costs of flushing or repair	●●●	●	o	●	●	o	●●	o	●●	●●	o	●●●
Rehabilitation in conjunction with service connection replacement programme	●●●	●●	●●●			o	●●	o	●●	●●●	o	●
Hydraulic capacity problems	●●	●●		●	●	●●	●●●	o	●●	●●	●	●●
Work of other utilities in the same location	●●●	●●	●●		●●	●●	●●	●●	●●	●●●	o	●●
Roadway rehabilitation												
rebuilding	●●●	●●	●●	●●	●●●	●●	●●	●●●		●●●	o	●●
resurfacing	●●	o	●	●	●	●	o	●●●	●●	●●	o	●
Unusual diameter	o	o	o	●●	o	o	●	o	o	●	o	●
Unusual pipe material	o	o	o	●	●	o	o	o	o	●	o	●
Limited or restricted access to pipe(s)	●	●	o		●●	o	●	●●	o	o	o	●

Several types of criteria can be distinguished:

- Type 1: criteria associated with problems that (*a priori)* concern each water utility; these criteria are considered as important or very important in the decision process. This strong consensus can be observed for the following criteria:
  - Frequency of water interruptions
  - Sensitive or key customers supplied by the link
  - Risk of severe damage or major street disruption from bursts
  - Co-ordination with roadway rebuilding
- Type 2: criteria associated with problems that (*a priori)* concern each water utility; these criteria are mainly considered as important or very important in the decision process, but some contrasted attitudes exist. This can be observed for the following criteria:
  - Frequent and increasing number of relevant customer complaints
  - Co-ordination with roadway resurfacing
  - …
- Type 3: criteria associated with problems that do not concern every water utility; contrasted attitudes can be observed: these criteria can be considered "*of overriding importance"* as well as … "*not important*". This can be observed for the following criteria:
  - Inadequate minimum system pressure with consequent customer complaints
  - Water quality standards not fulfilled (owing to network condition)
  - …

3 - CARE-W CRITERIA FOR THE PRIORITISATION OF REHAB PROJECTS

Partner contributions:

In the following table “SC” denotes sub co-ordinators: for each point of view one partner has been responsible for the synthesis of contributions.

Table 7 – Contributions for tasks 3.1 and 3.2

Partners: / Points of view (objectives of rehabilitation programmes)	INSA	SINTEF-NTNU	V.U.T. Brno	Cemagref	WRc	Bologna -Ferrara
3.1. Criteria relative to Technical concerns & Technical costs						
3.1.1.1. Rehabilitation costs 3.1.1.2. co-ordination (with roadway or other utilities)	C	C		C	SC	
3.1.2. Effects of Rehab. Measures on Technical Costs						
3.1.2.1. Reduction of: Repair Costs	C			C		SC
3.1.2.2. Reduction of: Energy Costs					SC	
3.1.2.3. Reduction of: water losses and relative costs	C		SC	C		C
3.2. Criteria relative to external points of view						
3.2.1. Disturbances induced by Rehab. Measures	C				SC	
3.2.2. Effects of rehabilitation measures on social impacts:						
3.2.2.1. Reduction of: Potential impacts of non scheduled water interruptions	C		C	SC	C	C
3.2.2.2. Reduction of: Potential local damages induced by water mains bursts 3.2.2.3. Reduction of: Potential local disruptions induced by water mains bursts	SC	C		C	C	C
3.2.2.4. Reduction of: Water quality deficiencies (discoloured water)	C	SC	C	C	C	
3.2.2.5. Reduction of: Water pressure deficiencies 3.2.2.6. Improvement of: Hydraulic reliability		C	SC	C	C	

3.1 Criteria relative to technical concerns and technical costs

3.1.1 Rehabilitation costs & co-ordination (with roadway or other utilities)

3.1.1.1 Rehabilitation costs

Type of approach: **Costing approach**

Level of approach: **Unit costs** and **multipliers** that can be applied to a unit costs table. Each multiplier is determined in considering factors influencing the rehabilitation costs

Criterion:

The cost is expressed as an annual unit cost of rehabilitation:

$$\mathrm{A}UCR(i, j, ...) = UCR(i, j) \times F_1(i, j, ...) ... \times F_K(i, j, ...) \times k$$

with $k = \frac{r}{1-(1+r)^{-SL(RT)}}$

r is the discount rate

$SL(RT)$ is the estimated service life of the rehab technique

$UCR(i, j)$ is the Unit Cost (euro/m) for pipe i, technique j,

Pipe i is represented (depending on j) with attributes influencing the rehab cost: diameter & surface type

Multipliers that can be applied to unit costs

Multipliers	Factors considered[3]	Comments
$F_1(i, j, c)$	**Pipe depth**	Rehabilitation unit rates will increase with increasing depth of cover for open cut methods and, to a lesser extent, for trenchless techniques (due to deeper access pits). In the UK distribution pipes are laid at a standard depth of 900mm so it is not possible to derive an adjustment factor for depth from distribution pipe cost data. However an assessment of sewer laying unit costs with depth indicates a 7% increase per 1m additional depth. However, sewers are laid deeper than water mains and the relative increase in cost is likely to increase with depth therefore a value of 7% may overestimate the depth factor but is thought suitable in the absence of better data.
$F_2(-)$	**Seasonal variation**	It is understood that rehabilitation costs vary during the year in certain countries. A factor should be included for this but it will be set to unity and left to individual contributors/end users to adjust where appropriate.
$F_3(-)$	**Economies of scale**	There will be economies of scale on the length of mains to be replaced. An indication of the economy possible can be obtained from the current rehabilitation effort to date in a particular zone. An approximate estimate of

[3] Traffic class will also be important (due to increased traffic management costs) but is not included above. However, surface type is likely to be strongly correlated with traffic class.

		economies of scale is given in the following table :

Table 8 - Economies of scale

Length to be rehabilitated (km)	***Multiplier***
Less than or equal to 1 km	**1**
More than 1 km but less than 5 km	**0.95**
More than 5 km but less than 10 km	**0.9**
More than 10 km but less than 25 km	**0.85**
More than 25 km but less than 50 km	**0.825**
At least 50 km	**0.8**

$F_4(i, j)$	**Density of fittings**	Costs will vary significantly between rural and urban areas. This is reflected in the following lookup table:

Table 9 - Density of fittings

	Low		Medium	High	
Parameter	Threshold	Multiplier	Multiplier	Threshold	Multiplier
Service connection density (no/km)	<25	0.8	1	>100	1.3
Valve density (no/km)	<5	0.95	1	>20	1.1
Hydrant density (no/km)	<5	0.95	1	>20	1.1

$F_5(i, j)$	**Soil type**	Costs will vary with soil type and selected rehab techniques, namely:

Table 10 - Soil condition

Soil condition	Open cut	Pipe bursting
Silts and clays	**1**	**1**
Coarse granular	**0.95**	**0.95**
Rock	**1.3**	**1**
High water table?	**1.1**	**1**

UNIT COSTS

Unit costs for Norway:

The following list includes only material and technology costs for the different methods used in Norway. The costs are based on an investigation from 1997 and are increased by 10% inflation. The factor used for the calculation between NOK and EURO is 8,1. The figures are rounded slightly thereafter. The costs are valid for diameters between 150 and 300 mm.

Table 11 - $UCR(i, j)$ **Unit Rehab Costs for Norway**

METHOD	*COSTS [EURO/m]*	*DURABILITY [years]*
Cleaning	14	0-10
Structural methods:		
Pipe bursting	340	>50
Sliplining	220	>50
Modified sliplining (rolldown, subliner, swageline, etc.)	270	>50
In-situform	270	50
Non-structural methods:		
Cement mortar lining	110	25-50
Epoxy	110	25-50
flexible hose	220	50
Other methods:		
Micro tunnelling	540	100
Pipe pressing	480	100
Point injection	100	25
Traditional open trench replacement	540	100

(There are ongoing investigations on recent costs, but these results will not be available before 2002. The costs will then be split up by diameter, rehab length and other factors).

Unit costs for the UK

Assuming that the appropriate material is used for each surface type/diameter combination, from experience of the UK water industry and contractors used, a table of unit costs can be derived (Euro / m). These apply to an urban area (and, in the case of open-cut replacement, **plastic** is the assumed replacement material), pipes generally with 900mm of cover:

Table 12 - $UCR(i, j)$ **Unit Rehab Costs for the UK**[4]

Technique		*Open cut*				*Epoxy resin lining (ERL)*	*Sliplining*	*Pipe-bursting*
Diameter band (mm)	*Surface type*	Unsurfaced	Footpath	Minor road	Major road	All	All	All
<=80		56	73	89	105	65	73	81
81-105		65	89	105	121	65	81	89
106-155		73	97	121	137	73	89	105
156-205		89	113	137	161	81	105	129
206-255		105	137	169	194	89	129	161

[4] **All method costs assume that communication pipes** (the part of the service pipe between the main and property boundary) **are replaced** as a matter of policy. However, it is not necessary to remake connections during ERL if no communication pipes are to be replaced, and hence this method is cheaper if communication pipes need not be replaced.

3.1.1.2 Co-ordination

This aspect can be studied in considering the impact of co-ordination on rehab costs, or in using a scoring system taking into account "external" reasons for including (or not) a pipe length in the annual rehab programme, allowing to represent the utility's concerns.

a) Co-ordination & rehab costs

Economies may be achieved by co-ordinating distribution mains rehabilitation with service connection replacement and roadway rehabilitation.

The former may be done by defining unit costs of rehabilitation to be for work on the main only. Costs would then need to be added for replacing or remaking each service connection (or part of). This approach is used in the Waterfowl™ whole life costing approach.

In some countries the savings (to the water utility) achievable through co-ordinating mains rehabilitation with roadway rehabilitation can be significant.

Factors need to be produced for type of rehabilitation method (e.g. perhaps one factor for open-cut and a second for trenchless methods).

This will need to take account of the increase in costs to co-ordinate the activities. For this to be of use in the MCD, knowledge of planned roadway rehabilitation will also need to be input.

b) Scoring system.

Co-ordination of mains rehabilitation with other utilities or roadway rehab and service connection rehab can be seen as major criteria or non relevant criteria, depending on the water utility.

The following extract from Table 6 (replies to the WP3 questionnaire) displays contrasted replies from end-users:

Extract from Table 6

Water utilities	1	2	3	4	5	6	7	8	9	10	11	12
Rehabilitation in conjunction with service connection replacement programme	●●●	●●	●●●			o	●●	o	●●	●●●	o	●
Work of other utilities in the same location	●●●	●●	●●		●●	●●	●●	●●	●●	●●●	o	●●
Roadway rehabilitation												
rebuilding	●●●	●●	●●	●●	●●●	●●	●●	●●●		●●●	o	●●
resurfacing	●●	o	●	●	●	●	o	●●●	●●	●●	o	●

●●● of overriding importance / ●● important / ● of minor importance / o not important.

This leads us to propose a criterion "co-ordination" associated with a scoring table that will have to be defined or calibrated by each utility.

Table 13 – Example of a scoring system for criterion “co-ordination”

“external” reasons for including or excluding a pipe length in the annual rehab programme	*Open cut*	*trenchless technology*
Service connections have to be rehabilitated	+ 1	+ 1
Work of other utilities in the same location	+ 1	0
Roadway rehabilitation: rebuilding	+ 2	0
Roadway rehabilitation: resurfacing	+ 0.5	+ 0.5
…		
Service connections have been rehabilitated in the last 3 (or n) years	- 1	- 0.5
Roadway has been rehabilitated in the last 5 (or n) years	- 2	- 1
Roadway is planned to be rehabilitated later	- 0.5	0
Other utilities have been rehabilitated in the last 5 years	- 0.5	0
…		
Total	$\Sigma = ...$	$\Sigma = ...$

3.1.2 Effects of Rehab. Measures on Technical Costs

3.1.2.1 Repair Costs (Reduction of)

Type of approach: **costing approach**

Levels of approach: **1** (standard cost table) and **2** (construction of standard cost tables)

Criterion : ARC (i,j) annual repair cost for pipe i after rehab. measure j.

To assess this criterion two information are needed:

- PFR(i,j): the predicted failure rate of pipe i after rehab measure j (j=0 : no rehab)
- UCR(i) : unit cost of repair.

Two levels are proposed to assess the unit repair costs.

Level 2: construction of cost tables

A repair intervention typically brings about the following expense[5] (*Cost of Repair*):

CR = Crew + Equipment + Sleeve + Repaving + Overhead (1)

According to (Walski & Pellicia, 1982):

- Cost of crew = labor cost for a three-man crew + cost of a truck for the crew given per hour
- Cost of equipment (compressor and backhoe) varies slightly with the size of the pipe
- Cost of sleeve = f (length, thickness, diameter of the pipe). If diameter ≤ 300 mm the length of the sleeve is 300 mm if diameter > 300 mm then the length is 400 mm.
- Cost of repaving is considered for a 3.6 m long trench. A 1.5 m wide trench is used for 250mm and smaller pipes. A 1.8 m wide trench is used for 300-450 mm pipes, and a 2.4 m wide trench is used for 500-600 mm pipes.
- *Overhead cost* = an additional 20% is added to the repair cost (supervision and contingencies)

The cost for the Crew can be expressed by:

$$Crew = w \cdot n \cdot h / k$$

where: w = hourly cost per worker [€/hour]

n = number of workers involved [dimensionless]

h = "theoretical" hours of work per worker [hour]

k = Context Factor [dimensionless]

To evaluate ***h***, Walski (1982) proposed to adopt the following expression:

$$h = [(6.5 * Diameter^{0.285})/n]$$

where diameter is in inches and time in hours.

---

[5] Walski T. M. & Pelliccia A., (1982). Economic analysis of water main breaks. Journal of AWWA, 74 (1982), pp. 140-147.

Passing to SI measures of length, through a simple conversion (1 inch = 25 mm) we have:

$$h = [(16.27 * Diameter^{0.285}) / n]$$

where diameter is in mm and time always in hours.

Moreover, the Context Factor k[6] enables to compare the conditions of work in different places, i.e. the productivity of the crew as the scenario changes. It represents the percentage of time actually devoted by workers to repair operations, as influenced by level of urbanization, traffic jams or other restriction (e.g. existence of buildings of special interest in the area).

	Percentage of theoretical time of work h actually addressed to repair [%]	k	1/k
Countryside	100	1	**1**
Outskirts	80	0,8	**1,25**
City centre	40	0,4	**2,5**

The Context Factor (1/k) is higher in a city centre (where any intervention is affected by more bounds) than in countryside.

Level 1: standard cost table for each utility

The level 2 approach can be used for defining the standard repair costs.

Example 1:

In Grenier (1996)[7], the standard reparation obtained by the data analysis on 134 repairs, done in 2 years, has given the following results:

Manpower and machinery:

	manpower	van	compressor	motor-pump	excavator	lorry
% of repair using this machinery	100%	100%	66%	76%	91%	96%
Standard time	42 h	14h	1,8h	2,4h	3,7h	5,5h
Time rate (F/h)	95F/h	34 F/h	388 F/h	15F/h	346F/h	170F/h
Total (F)	3 090 F	476 F	461 F	27 F	1 165 F	898 F
Total (€)	**471**	**73**	**70**	**4**	**178**	**137**

Material:

	Filling material	sleeve
Standard quantity	8,5 t	1 unit
Unit cost	67 F/t	684 F/unit
Total (F)	570 F	684 F
Total (€)	87	104

[6] **Federici, G., C. Lubello, R. Pilar Mastria, and F. Menabuoni** (1999): *Un modello di costo per le tubazioni in opera di acquedotto e fognatura*. L'ACQUA, Rivista bimestrale dell'Associazione Idrotecnica Italiana A.I.I., 1, 1999, p.17-24

[7] **Grenier R**. (1996), Approche des coûts par les activités dans un service public de distribution d'eau potable – application aux travaux d'entretien du réseau, *mémoire d'Ingénieur ENGEES*, Strasbourg (France) : ENGEES. 99 p.

Example 2:

Standard repair costs in Lausanne (CH) taking into account pipe diameters and pipe context:

		Context	
	"easy"	normal	"difficult"
diameter < 300 mm	1900 €	3100 €	4700 €
diameter >= 300mm	3100 €	4700 €	6200 €

<u>Criterion : Annual Repair Cost for pipe i, after Rehabilitation measure j</u>

ARC (i,j) = PFR(i,j) . UCR(i)

UCR(i) can be assessed as presented above.

PFR(i,j) depends on

- the modelling tool used to assess failure rates,
- the hypothesis on the effects of rehab measures.

3.1.2.2 Energy Costs (Reduction of)

Criteria and sub-criteria: No criterion is proposed for this point of view. Marginal costs related to energy costs are considered in the point of view "water losses & associated costs".

Energy costs

Before attempting to quantify the financial impact of rehabilitation, it is worth investigating briefly the sources of energy use in water production. In terms of the **direct** effect on saving energy, the following actions are ordered in decreasing relevance:

Direct effect 'rating'	Action	Sub-action	Examples
1	Maintain/replace plant	Refurbish existing or introduce efficient plant	• Install new, efficient pumps • Variable speed pumps
2	Reduce pumping time	Reduce leakage	• Increase Active Leakage Control • Install pressure reducing valves
		Reduce consumer demand	• Install domestic revenue meters where none exist at present • Install grey water recycling schemes • Promote water conservation schemes (low-flush toilets; efficient shower heads; new, efficient 'white goods*')
3	Reduce chemical use	Reduce treatment requirements by reducing required treatment works throughput	• Reduce transport requirements to carry chemicals (fuel costs etc.)
4	Reduce demand for raw materials or building materials	Defer manufacture of mass concrete and other building materials	• Defer capital expenditure e.g. building new reservoir or water treatment works

* White goods: kitchen appliances, in this case those which use water. Dishwashers and [clothes-]washing machines are the most important.

It is notoriously difficult to monetise all benefits from rehabilitation but the major *energy* saving would seem to be borne from reducing the amount of water produced and distributed. From the table above, the main route to saving energy is through reducing demand, by repairing bursts and reducing leakage. Given that water losses and repair costs are considered elsewhere, we would recommend that energy costs be considered as part of each rehabilitation strategy and *not* as a discrete point of view. Energy costs form a small part of the marginal cost of water.

Marginal cost of water and leakage[8]

Water lost through leakage has a monetary value. The marginal cost of leakage is defined as the change in costs that result from a reduction of 1 m^3 in the level of leakage. Suppose it costs 2 euro to supply 10 m^3 of water, and the water lost through leakage is reduced by 1 m^3. If the cost of supplying 9 m^3 of water was 1,85 euro, the marginal cost of leakage is 0,15 euro. There is also a time dimension to marginal cost. Cost savings today are more valuable (in real terms) than cost savings in 5 years time. An investment decision made today may also impact on the attractiveness and availability of investment options in the future. Impacts on both operating and capital costs must be taken into account.

Marginal operating cost

Operating costs are an increasing function of throughput. A reduction in demand will thus directly reduce operating costs. Ideally, marginal operating costs would be estimated by considering detailed projections of all future operating expenditure and by examining how the present value of the series of annual operating costs changed with the level of demand. In practice, however, marginal operating costs are often assumed to be equal to unit variable costs. Unit variable costs are calculated by dividing the operating costs which are function of demand by the current throughput of water.

$$MOC \approx \frac{\sum OC(q)}{Q_T}.$$

Examples of operating costs are: pumping and boosting, water treatment, bulk purchase of water, equipment maintenance costs, and abstraction charges.

Marginal capital cost

A reduction in demand can affect capital costs in two ways: (1) a capital project may be postponed or (2) a capital project may be downgraded in size. The size of the effect depends on whether is project is wholly demand-driven or whether there are other issues (such as quality). Upgrading a treatment works may be to increase throughput *and* improve water quality into distribution, for example. A delay in the timing or scale of investment expenditure implies that the present value cost of the project decreases.

Capital expenditure which is related to the volume of water supplied typically falls into one of six categories: source works, treatment works, pumping stations, service reservoir, trunk mains, distribution mains reinforcement.

An estimate of marginal capital costs can be calculated by dividing the present value of the investment programme by the present value of the growth in water demand.

Marginal capital costs form the larger part of the marginal cost. The argument for capital deferment is therefore a strong one.

[8] Adapted from: UK Water Industry: Managing Leakage, *Setting Economic Leakage Targets (Report C)*, Engineering and Operations Committee, 1994, Appendix A.

3.1.2.3 Water losses and relative costs (Reduction of)

Type of approach: **Diagnosis – Definition of pipe contributions to zonal problems**

Levels of approach: **1 (based on P.I. for zones; no economic assessment).**

1) Ranking of zonal problems

For a level at which data are available (such as District Meter Area [UK], or Water Supply Zone, calculate the leakage cost, testing against a threshold, λ, i.e.

$$\text{Leakage (l/connection/day)} / 10^3 \text{ (litre/m}^3\text{)} * \text{MCW (€/m}^3\text{)} > \lambda \text{ (€/connection/day) ?}$$

MCW is the marginal cost of water (see 3.1.2.2. Energy costs)

At the same level, calculate an average repair rate (number/km/year) and test against a suitable threshold, μ , e.g. 0.4 repairs/km/yr.

This will give you the following table:

	Leakage		Repairs	
	Cost (€/connection/day)	Exceeds threshold?	Rate (no./km/yr)	Exceeds threshold?
Zone 1	1.4 λ	Yes	0.9 μ	No
Zone 2	λ	No	1.2 μ	Yes
Zone 3	0.8 λ	No	0.7 μ	No
…				

Zones could be placed, using their threshold exceedance, into RED (Yes x 2), AMBER (Yes x 1), and GREEN (No x 2) categories:

	FR(z) **failure rate >** μ	**FR(z)** **failure rate <** μ
LC(z) **Leakage cost** > λ	**RED category**	**AMBER category**
LC(z) **Leakage cost** < λ	**AMBER category**	**GREEN category**

2) Ranking of pipe contributions to water losses

Each pipe can be evaluated in using the priority class of the corresponding zone, and the performance indicators Op26_link, Op27_link and Op5_link.

3.2 Criteria relative to external points of view

3.2.1 Disturbances induced by Rehab. Measures

Approach: **Scoring system** combining:

1) A **Qualitative assessment,** by rehab method, of potential disturbances

2) **Modulation factors** representing the context

Criterion:

$$Disturbance\_Score(i, j) = Disturbance\_Score(Method\ j) + Correction\_Factor(pipe\ i)$$

Major factors considered

This point of view is intended to focus on social and environmental aspects surrounding rehabilitation. Key social/environmental impacts appear to fall into five main categories

- traffic disruption,
- inhibited access to consumers,
- impact on consumers of loss of mains supply,
- level of materials transport required,
- health risks in carrying out specified technique.

There are others (e.g. visual impact, impact on flora and fauna) which have been deemed less important given their transient effect are not included.

Qualitative assessment by rehab method

Disturbance will vary according to the rehabilitation method employed. Given the subjective nature of environmental assessment, it is felt a scoring system is more appropriate (Table 14):

Table 14 – $Disturbance\_Score(Method\ j)$

Method	***ERL***		***Sliplining***	***Pipebursting***	***Open cut***
Communication pipes replaced?	*No*	*Yes*	*Yes*	*Yes*	*Yes*
Traffic disruption / with co-ordination[9]	1 / 0	2 / 0	2 / 0	2 / 0	3 / 0
Access to properties	1	1.5	1.5	1.5	2
Loss of mains supply	1.5	1.5	1	1	1
Materials transport	0.5	1	1	1.5	2.5
Environmental health risk	0.5	0.5	0	0	0
Environmental contamination risk	1	1	0	0	0
Risk of trench collapse/public safety	0.5	1	1	1	1.5
Total	***6.0***	***8.5***	***6.5***	***7.0***	***10.0***

This shows traffic disruption and access to consumers will be most affected by open cut replacement. Inconvenience to customers owing to loss of mains supply is considered more serious as the period of time without mains water increases. ERL requires a 24-hour cure time plus time for subsequent flushing before bringing the pipe back into service. In some

[9] If the rehab. project is co-ordinated with roadway rehab., no traffic disruptions are considered.

cases, open cut replacement will keep the existing main in service until the new main is ready and so the impact on the consumer will be less than with ERL.

Materials for epoxy resin lining are lighter so materials transport for ERL gets a lower score. Pipebursting requires more new materials to be transported, and open cut requires the additional movement of backfill and road-making materials. Open cut replacement has greater risk of trench collapse and greater risks to public safety, failing appropriate cordoning and guarding of trenches. ERL carries a higher risk to ground and air contamination and to those working with ER (chemicals exposure) than other techniques.

For all methods, there is a much smaller risk to consumers of insufficient disinfection following rehabilitation and prior to bringing the main into service.

Other factors

The social/environmental disturbance of rehabilitation as scored above will be modulated by other factors such as the density of fittings and the number of sensitive customers. The following table gives corrections to the scoring in the previous table where these parameters are particularly low or high (Table 15):

Table 15 – Correction_Factor(pipe i)

	Low		**Medium**	**High**	
Parameter	Threshold	Add	Add	Threshold	Add
Service connection density (no/km)	<25	**- 0.5**	**0**	>100	**0.5**
Traffic class and density (if no co-ordination with road rehab.)		**- 0.5**	**0**		**1**
Sensitive customers (no/1000 connections)	<0.2	**- 0.2**	**0**	>2	**0.5**

→ Normalisation and scaling

The degree of disturbance to consumers and the local environment depends on the scale of the rehabilitation project. This has not been taken into account in any of the factors above. It is felt the factors above can be used to rank the *potential* impact of a rehabilitation scheme in a zone as well as looking at the effect of a project of defined size. In either case, the qualitative impact assessment carried out above may be scaled accordingly using the length of mains to be rehabilitated or, preferably, the number of consumers affected by the project.

→ Notes on results

The factors in Tables 14 and 15 should be added together for each zone or rehabilitation project before any scaling according to project size. The qualitative factors in Tables 14 and 15 are additive since the figures in Table 15 are intended to make appropriately scaled minor *adjustments* to those major factors in Table 14. In most cases in Table 15, a medium route will be taken and no correction factor will apply. The use of multiplicative factors makes the resultant product too sensitive to the values in Table 15 and so has been avoided.

Although factors in this point of view may be mentioned elsewhere (such as in 3.1.1 Rehabilitation costs), the qualitative assessment presented here is complementary to the rehabilitation costs point of view in which a financial, quantitative analysis will be undertaken. These aspects may be combined in a multi-criterion decision analysis procedure without prejudice.

3.2.2 Effects of rehabilitation measures on social impacts:

3.2.2.1 Water interruptions

Type of approach: **Risk assessment**

Levels of approach: Two levels are proposed: level 1 in order to define priorities, level 2 aiming to quantify social costs associated with water interruptions

Criteria and sub-criteria for risk assessment :

2 criteria are proposed to compare alternatives (link i, rehab j), that is to say the effect of rehabilitation j on link i

SUB CRITERIA	CRITERIA
PBR(i,j) - Predicted Burst Rate (No/100m/year) **EDI - Expected duration of interruptions** (hours) **NPS(i) - Nb. of people supplied by the link** (person.)	**PWI(i,j) – Predicted Water Interruptions** (No./100m/year)*(hours)*(persons)
SC(i) - Sensitive Customers (No.)	**PCWI(i,j)– Predicted Critical Water Interruptions** (No./100m/year)*(hours)*(No.)
C_{DWI} – cost of domestic water interruption (€/person./hour) **C_{SCWI} (k) cost of sensitive consumer k water interruptions** (€/type of SC./hour)	

For level 1 we propose to use the information at the pipe level if it is available, if not, a density on a zone or a district can be used.

For level 2, a social cost valuation can be proposed.

Criterion **PWI**(i,j) – **Predicted Water Interruptions**

Level 1: PWI(i,j)=PBR (i,j) x EDI(i) x NPS(i)

With:

PBR(i,j) predicted burst rate[10] for link i after rehab j

EDI(i) is the expected duration of interruption, depending of the diameter, the type of failure…

NPS(i) is the number of customer supplied by the link, within a length of pipes between two valves.

[10] We propose to use the burst rate instead of failure rate, since if a leak is detected, the repair can be scheduled and announced. The impacts of interruptions are rather minimised, because customers are prepared to be without water for a certain time and they are able to countermeasure.

Level 2 : $PWI(i,j)=PFR(i,j) \times EDI(i) \times NPS(i) \times C_{DWI}$

With:

C_{DWI} cost of domestic water interruptions calculated **by zone**

Price of bottled water (€/liter) or proportional part of water price (€/liter)

x domestic consumption/person/year

x EDI/24/365

Criterion **PCWI**(i,j) – **Predicted Critical Water Interruptions**

Level 1: $PCWI(i,j)=PBR(i,j) \times EDI(i) \times SC(i)$

With:

PBR(i,j) predicted burst rate for link i after rehab j

EDI(i) is the expected duration of interruption, depending of the diameter, the type of failure…

SC(i) is the degree of sensitivity of customers supplied by the link, $\in [0,1]$

Level 2: $PCWI(i,j)=PFR(i,j) \times \sum_k[EDI(k) \times SC(i,k) \times C_{SCWI}(k)]$

EDI(k) can be valued for each type of sensitive customer k depending if the effect of the interruption will be equal or longer than the interruption duration

C_{SCWI} (k) cost of sensitive consumer water interruptions calculated **by type k of SC**

\- - -

Alternative or complementary approach:

<u>Criteria and sub-criteria for assessing the current situation</u>

We propose to define a list of criteria directly derived from Performance Indicator that can be evaluated for links. They can be used to compare links in a ranking procedure.

As these PI are relative to small pipe lengths, we propose to count events (interruptions and complaints) on a **five year basis.**

(If a **threshold** has been defined (national or local standard) for some of these PI, corresponding criteria could be calculated with 2 modalities: 0-Below Threshold / 1-Above Threshold.)

The 8 criteria evaluated for links could be:

Op26 link	mains failures [11]	(No./100m/last 5 years)
Op26d link	critical mains failures	(No./100m/last 5 years
Op27 link	Service connection failures	(No./100/connections/last 5 years)
QS11 link	Water interruptions	(person.hours/100m/last 5years) or (0/1)
QS12 link	Interruptions per connections	(No./100connections/last 5 years)
QS12a link	critical interruptions per connections	(No./100 connection/year)
QS26 link	Service complaint for water Interruption	(No./100m/last 5 years)
QS26a link	critical interruption complaints	(No./100m/last 5 years).(0/1)

When considering the frequency of water interruptions one should notice that not only the above calculated “consumer-hours of water-interruptions per link” must be an adequate criterion. The absolute number of water interruptions or their total duration on a link could be taken into account, as well. This is due to the fact that for any customer one break in 10 years might be acceptable without serious perception and maybe the second break in this period, too. But what about the third, fourth, fifth… break in the same period? The decreasing acceptance with the increasing number (and duration) of breaks even for a smaller number of customers could be a relevant aspect of the prioritisation of projects.

The corresponding criterion Predicted frequency of water interruptions PFWI(i;j) could be calculated from information already used for the above mentioned PWI(i;j).

Level 1: PFWI(i,j)= L(i) x PBR (i,j) x EDI(i)

PFWI(i,j) is the duration of water interruptions due to breaks on a link

L(i) is the length of pipe i

[11] **Definition of main failure** (in: IWA Manual of Best Practice « Performance indicators for water supply services », ALLEGRE & alii, 2000) :
« detected water leaks of transmission and/or distribution mains necessiting repair/renewal measures. Included are failures of mains, defective pipe connections, valves and fittings, caused by…. »

3.2.2.2 Potential local damages induced by water mains failures
3.2.2.3 Potential local disruptions induced by water mains failures

Type of approach: **Assessment and hierarchisation of risks.**

Levels of approach: **1** and **1'** (no quantification of economic consequences)

Five criteria allow defining priorities in comparing possible disruptive events (current risks, or 'residual' risks after rehab). This is done in taking into account burst or failure rates (observed or predicted) multiplied by aggravating factors, intensity factors, and vulnerability factors.

Criteria and sub-criteria:

→ Five criteria[12] have been proposed to compare alternatives (pipe i, rehab j)[13]

Criteria	Level
$DFH(i,j)$ risk of Damages due to Flooding in Housing areas (1)x(3)x(4)	1
$DFH(i,j)$ risk of Damages due to Flooding in Housing areas (1)x(3)x(5)x(6)	1'
$DFI(i,j)$ risk of Damages due to Flooding of Industrial or professional or public buildings (1)x(3)x(7)	1
$DFI(i,j)$ risk of Damages due to Flooding of Industrial or professional or public buildings (1)x(3)x(8)x(9)	1'
$DSM(i,j)$ risk of Damages due to Soil Movement (landslide) (2)x(3)x(10)	1
$DT(i,j)$ risk of major Disruptions to Traffic due to failures and repairs (2)x(11)	1
$DDI(i,j)$ risk of damage and/or disruptions on other infrastructures (1)x(3)x(13)	1

→ Two sub-criteria are associated with pipe i and rehab j

Sub Criteria	Used in criteria:
(1) $BR(i,j)$ Burst rate for pipe i (Op26aa)[14] after rehab j	DFH, DFI, DDI
(2) $FR(i,j)$ Failure rate for pipe i (Op26) after rehab j	DSM, DT

→ One sub-criterion is associated with pipe i and represent aggravating parameters:

(3) $D2P(i) = [Diam(i)]^2 \times Pressure(i)$ (aggravating factors associated with bursts)	DFH, DFI, DSM, DDI

→ Other sub-criteria are associated with pipe i and represent the urban environment:

(4) $SFH(i) \in [0,1]$ a value representing the Sensitivity to Flooding of Housing areas	DFH (level 1)
(5) $IFH(i)$, $\in [0,1]$, representing the possible Intensity of Flooding in Housing areas	DFH (level 1')
(6) $VFH(i)$, Vulnerable Values, $\in [0,1]$, representing the values possibly affected by flooding	DFH (level 1')
(7) $SFI(i)$ a value $\in [0,1]$ given by users, representing the Sensitivity to Flooding of Industrial or professional or public buildings	DFI (1)
(8) $IFI(i)$, $\in [0,1]$, representing the possible Intensity of Flooding in Industrial or commercial areas	DFI (level 1')
(9) $VFI(i)$, Vulnerable Values, $\in [0,1]$, representing the values possibly affected by flooding	DFI (level 1')
(10) $LS(i) \in [0,1]$ a factor quantifying the possibility of a landslide due to water movement	DSM
(11) $SR(i) \in [0,1]$ a factor quantifying the importance of the road	DT
(12) $SI(i) \in [0,1]$ a factor quantifying the sensitivity of urban infrastructure close to the link.	DDI

[12] A synthesis of these 5 criteria could be done with the criterion *DD(i; j,) risk of damages and disruptions due to failures*.
[13] The comparison of pipes (in current state) corresponds to j=0 (No Rehab.)
[14] For these 2 Performance Indicators (Op26 or Op26aa) values can be obtained in using:
Historical data: **No of failures / 100m / year** with a minimum of 5 years of historical data
Technical tools: models – according to the pipe characteristics – can calculate the predicted number of failures.

Each of the five criteria used to measure risks are expressed as a product: [$BR(i,j)$ x …] or [$FR(i,j)$ x …].

> For example, with a level 1' approach, $DFI(i,j)$ is determined by the following formula:
> $$\boxed{DFI(i,j) = BR(i,j) \times D2P(i) \times IF(i) \times VF(i)}$$
> with:
> $BR(i,j)$ Burst rate for pipe i (Op26aa) after rehab j
> $D2P(i) = [Diam(i)]^2 \times Pressure(i)$
> $IFI(i)$, Intensity Factor, $\in [0,1]$, representing the possible intensity of flooding
> $VFI(i)$, Vulnerable values factor, $\in [0,1]$, representing the values possibly affected by flooding

The reduction of these risks will be obtained in reducing BR and FR by rehab measures.

→ Some hypotheses have to be done about the effect of rehabilitation methods on burst rates and failure rates. We propose the following hypotheses:

Table 16 – Impacts of rehab techniques on failure and burst rates (hypotheses)

j	0 (No Rehab)	OC Open Cut repl.	PB Pipe Bursting	JR Joints repl.	SL Struct. Lining	NSL Non Struct Lining	Others (AC, …)
FR(i,j) =	FR(i,0)	0	0	PFR(i,0)	0	FR(i,0)	FR(i,0)
BR(i,j) =	BR(i,0)	0	0	BR(i,0)	0	BR(i,0)	BR(i,0)

For JR ("joints replacement and installation of special pieces") we suggest to consider that the rehabilitated pipe will only be affected by pipe failures: PFR(i,0) is the current Pipe Failure Rate, corresponding to PI **Op26a**.

Tables

Table 17 – Intensity of Flooding in Housing Areas IFH(i)

basement (Y/N)	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
ground floor above soil (Y/N)	1	1	0	0	**1**	**1**	**0**	**0**
significant soil slope (Y/N)	1	0	1	0	1	0	**1**	**0**
Normalized IFH	**0,84**	**0,78**	**1,00**	**0,91**	**0,15**	**0,00**	**0,44**	**0,33**
simplified IFH:	***1,0***	***1,0***	***1,0***	***1,0***	***0***	***0***	***0,4***	***0,4***

Table 18 – Vulnerable values in Housing areas VFH(i)

type of housing	**Normalized VFH**
individual housing with retail shop	**0,69**
individual housing without retail shop, allotments	**0,65**
rural housing	**0,65**
collective buildings with numerous flats	**0,56**
attached houses of small height	**1,00**
Attached collective buildings of small height	**1,00**

Table 19 – Intensity of Flooding in Industrial or commercial areas IFI(i)

significant soil slope	yes	no
Normalized IFI :	**1,0**	**0,70**

Table 20 – Vulnerable values in Industrial or commercial areas VFI(i)

	Normalized VFI
offices	**1,00**
industrial plant	**0,40**
big stores	**0,23**
wide industrial site	**0,22**
sports halls	**0,20**
industries allotment	**0,15**
education buildings	**0,15**
open air storage	**0,03**

Table 22: **Performance Indicators and information used to assess risks**

	Failures due to 3rd party	Bursts	"Visible" Leaks	Leaks detected by active leakage control	Flood risk DFH	Flood risk DFI	Traffic disrup-tion DT	Risk of Soil Move-ment. DSM	disrup-tion on infra DDI
Pipe failures	Op26 - Mains failures			Op5					
Joint failures							x	x	
Valve failures									
SC insertion point failures									
Service Connection failures	Op27 - Service connection failures								
Pipe failures	Op26a - pipe failures			Op5					
Joint failures	Op26b - joint failures			Op5					
Valve failures	Op26c - valves failures			Op5					
SC insertion point failures	Op27a - Service connection insertion point failure								
Service Connection failures									
Pipe failures		Op26aa			x	x			x
Joint failures									
Valve failures									
SC insertion point failures									
Service Connection failures									
Other information:									
internal aggravating factors:									
Diameter					x	x		x	x
Water Pressure					x	x		x	x
external aggravating factors									
Slope					x	x			
Risk of landslide								x	
vulnerability of the built environment									
simple zoning (for level 1)					x	x			
or									
basement (Y/N)					x				
ground floor above soil (Y/N)					x				
type of housing					x				
type of industry or commercial activities						x			
road class							x		
Sensitive infrastructure close to the link (main sewer, gas, etc.)									x

Appendix: Definition of rules based on previous studies

GENERAL PRINCIPLES

A “level 2” approach, for analyzing and taking into account local damages and disruptions caused by flooding following a pipe burst, would consist in assessing a priori the costs of such damages and disruptions. As the objective is to set priorities among pipes which are to be rehabilitated, we should be able to assess vulnerability of the near vicinity of each pipe and the specific damages resulting from a burst.

French literature suggests that damage due to either urban runoff (Picheral et al 1995, Hubert et al 1996) or water pipe burst (Kennel 1992) varies tremendously from one building to another. Moreover, the link between damage costs and flooding characteristics (water level, duration …) appear to be rather weak, provided these characteristics can be anticipated.

The present proposal consists in developing an intermediate “level 1 – level 2” approach:

- considering separate impact criteria for 1° damage to housing and retail shops scattered along the streets (outside shopping centers) 2° damage to industry and various professional or public buildings (considering properties of a sizable surface) 3° specific situations with high individual or collective hazard 4° disruptions of road traffic;
- using the best available information without spending important resources for detailed studies at small scale such as hydraulic modeling of each burst’s outflow, specific traffic model for each city area, detailed survey of each building and of its content …; this information may be observed damage costs (for instance compensation from the utility owner of from insurance), road traffic flows, typology of buildings in an area, average estate values of buildings …

The criteria which are proposed here are not economic cost assessments, and moreover the four criteria cannot be added, they are to be considered in a multi-criteria approach.

In this paper, we are only addressing consequences of flooding due to pipes bursts, not impact of repair or replacement works. Moreover, we will not consider business losses within the criteria:

- provided valves are closed rapidly after noticing a burst, surface flooding duration should be limited;
- therefore, business losses will depend greatly on adaptive behaviors but also on the repair works in the street as well as on the time to repair flood damages;
- a criteria representing business losses either would be based on a correlation with a “physical damage criteria”, or would need a case to case identification of each industry and retail shop; this does not appear to be affordable for primary planning purposes.

DAMAGE TO HOUSING AND RETAIL SHOPS

We will here consider housing as well as retail shops which are scattered along the streets, but not gathered in shopping centers, supermarkets, big stores … Two approaches are proposed, according to available information on real damage costs due to pipe burst flooding.

No information on real costs: “modelling” approach

The basic idea, which is proposed here, is to assess a PDRD criterion (possibility of domestic and retail damage) by crossing or multiplying:

- a factor representing values / stakes vulnerable to potential flooding, in this case we consider the sum of estate values and furniture (and/or equipment) values per hectare; as the flooded surface following a burst cannot be anticipated without detailed hydraulic modeling or expertise, we will refer to surface densities of the belongings which may be flooded, given a typology of land uses,
- a factor representing the potential intensity of flooding and damage, given the characteristics of potential water flow on the soil (significant soil slope or not) and of buildings exposure to hazard (1° majority of buildings with a basement or without a basement 2° majority of buildings with a basement raised above the soil level or majority of buildings with a ground floor flush with the soil ; we don’t consider factors linked to hydraulic conditions of the network, as their potential impacts on flooding can’t be characterized without detailed investigations.

This means that a pipe, or pipes group, will have to be characterized by the description of its vicinity: land use type and global characteristics of buildings, soil slope.

Vulnerable values factor

We consider here the sum per hectare of estate values and furniture (and/or equipment) values for the ground floor only, not for all floors of a building: what happens in the upper floor won't significantly influence potential flood damage (as long as the structure of the building is not threatened). The potential presence of a basement will not be taken into account through this factor, but through the intensity factor.

The data shown below are taken from IIBRBS (1994), resulting from a pilot study on flood damage in the region around Paris. The values are transformed to be made non dimensional, factor 1 corresponding to estate and furniture value of ground floors in an individual housing area without retail shops.

Of course, if a decision-maker has figures specific to a city or country, he should consider them and possibly adapt the land use typology.

type of land use	**vulnerable values factor**	**number of flats and individual houses on ground floor per hectare**	**number of retail shops per hectare**
individual housing with retail shops	1.05	13	0.5
individual housing without retail shops, allotments	1	13	0
rural housing	1	13	0
attached houses of small height	1.53	20	2
attached collective buildings of small height	1.53	20	2
collective buildings with numerous flats	0.85	15	2

Intensity factor

Up to now, we don't have a significant data base on damage costs from flooding from pipes bursts, which would represent the diversity and statistical dispersion of real damage costs. Considering damage cost data from river flooding may be very inadequate. We propose hence to rely on the assumption that the relative effect of aggravating parameters may be comparable between flooding from rivers and flooding from water pipes, even if cost values are different.

We have analysed existing damage cost curves (cost as a function of water level) for individual housing flooded by rivers, where we could compare from homogenous sources houses with basement and houses without basements:

- DREIF 1986,
- Debizet and Caude 1986,
- Torterotot 1993 (both for fast raising flooding and slow flooding).

For each of the four pairs of damage curves (with / without basements), we calculated damage when water level is:

- 1 meter below the ground (significant basement flooding without surface flooding),
- 0.05 meter above the ground ("standard" level considered by Green et al 1987 for representing typical flooding from sewers),
- 0.20 above the ground, which we propose to consider for representing flooding when the soil has a significant slope and water level climbs against upstream walls of the buildings.

On the other hand, we had to consider buildings where the ground floor is elevated above the outside soil level : basing on surveys performed in several cities in floodplains (Torterotot 1993), we considered a standard average value of 0.30 meter for the elevation of such ground floors above the soil.

Damage costs were made non dimensional by dividing them, for any of the four damage curve sources, by the cost with 0.05 meter water above the ground when a house has a basement and a ground floor flush with the soil. The following table shows the results obtained for damage intensity factors.

3.2.2.4 Water quality deficiencies (discoloured water)

Type of approach: **diagnosis / hierarchisation of pipe contributions to zonal problems**

Levels of approach: level 1 / step 1: P.I. for zones;

+ level 2 / step 2: hydraulic modelling

Criteria:

The **fulfilment of EC-water quality norms** and the **number of complaints** should be used as two independent criteria[15] for water network rehabilitation. They should be judged against conditions relevant for the network, i.e.

- hydraulic functionality (detention time, pipe velocity, max velocity pr day),
- infiltration of pollution,
- Interaction water/pipe material.

Since the effect of hydraulic detention time and the interaction between water quality and pipe material strongly depends on the raw water quality, it is not advisable to create general rules for the interaction between water quality and pipe materials. The rehab planning should consequently be based on water quality monitoring.

The general rules for applying water quality criteria for rehabilitation could thus be:

- If the EC-norms for water quality are not fulfilled, and the reason is detention time, then a rehab plan to improve the hydraulic performance should be initiated.
- If the EC-norms for water quality are not fulfilled, and the reason is interaction water /pipe material, then the sites of interaction should be defined and concrete measures evaluated.
- If the EC-norms for water quality are not fulfilled, and the reason is infiltrated pollution, then the sites of infiltration should be defined and concrete measures evaluated.
- If level of water quality complaints are unacceptable, and the reason is detention time, than a rehab plan to improve the hydraulic performance should be initiated.
- If level of water quality complaints are unacceptable, and the reason is interaction water/pipe material, then the sites of interaction should be defined and concrete measures evaluated.
- If the level of water complaints is unacceptable, and the reason is infiltrated pollution, then the sites of infiltration should be defined and concrete measures evaluated.

The annual rehab planning should be assisted by a program of water quality monitoring and a computer network model. The water quality monitoring programme should include pH, Calcium, alkalinity, iron, lead, bacteria etc. depending on the local conditions. The computer model should be used for analysis of detention time and max daily velocity of each pipe.

The water quality monitoring programme will, as well as PI on quality complaints, give information on a **zone level**.

In the next turn, this information has to be transferred to the **pipe level**, to define candidates for rehabilitation. The hydraulic model with the data on water velocity and detention time will be an important tool in this process, together with information on pipe material, construction year, previous leakage and structures (valves, pipes) vulnerable with regard to infiltration of pollution.

[15] These two criteria are derived from the following performance indicators:
QS15 Quality of supplied water
QS 16 Aesthetic (QS 16a Water taste, QS 16b Water colour)
QS 17 Microbiological
QS 18 Physical-chemical
QS 22 Service complaints
QS25 Water quality complaints (QS25a Water taste complaints, QS 25b Water colour complaints)

Chosen approach

It is not intended to apply or develop a water quality model in the sense of simulating changes of water quality. This must therefore be based on the observation and analysis of measurement results and recorded customer complaints. Nevertheless, the analysis must utilise a water network model and possibly GIS to pinpoint the zone or pipe subject to water quality problems.

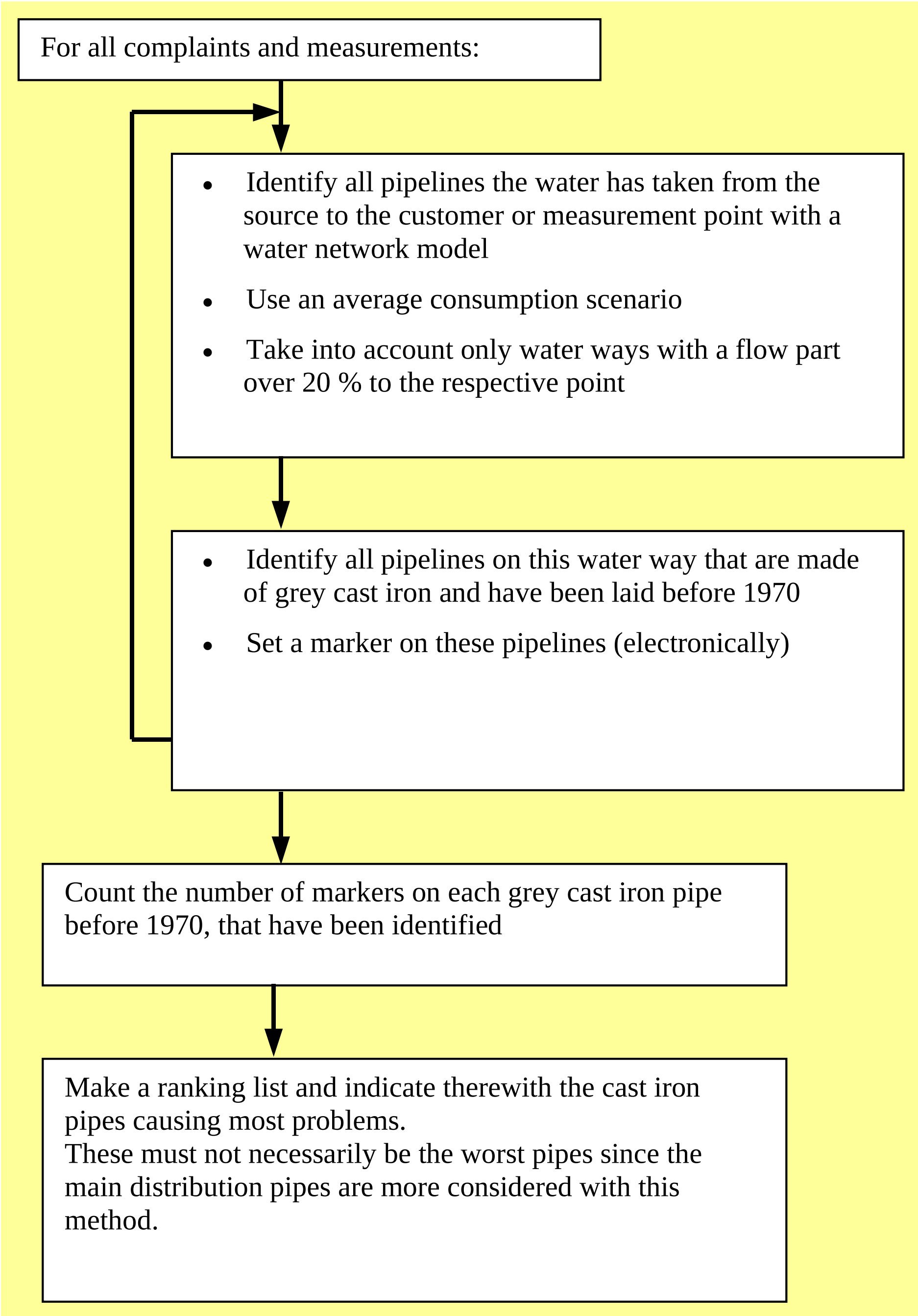
One problem in generating a routine for locating the reason for water quality deficiencies is the lack of knowledge for some processes in the network. Additional, most of the PIs related to water quality indicate only a general water problem. Turbidity for example can be caused by nearly anything and a complaint on bad taste or smell does not reveal the type of e.g. PAC or other components. Finally, most water quality deficiencies are brought in from a bad raw water quality or inadequate water treatment.

It is important to remember that the criteria water quality deficiencies in WP3 should only reveal pipe candidates for rehabilitation or confirm candidates that have been already chosen by other aspects. Raw water problems, bacteria regrowth or pressure drops should therefore not be considered. Also other aspects influencing water quality like sedimentation, re-suspension, flushing and cleaning are therefore not included.

Because of all these arguments, a simple routine is suggested to pinpoint rehabilitation candidates with the additional aspect of water quality. For the present, the routine should concentrate on **red water**, which is the problem in most cases, where water quality is influenced by pipe material.

Based on a hydraulic network model, supply zones have to be identified. Water quality complaints and measurements with an unacceptable result are counted and compared to a threshold level, which the respective water utility has to fix.

Once this threshold has been crossed the following routine can be applied:



Similar rules and routines can be set up for other relations between water quality deficiencies and pipe material, condition or coating.

Appendix: ***Towards a socio-economic assessment of water quality deficiencies due to pipes failures or degradation ?***[16]

General comments:

In the search for criteria representative of the impacts of water quality deficiencies, due to pipes failures or degradation, we investigated existing economic assessment works and data. This paper gives a brief summary of these investigations, which do not allow to propose economic criteria. Nevertheless, though the surely incomplete bibliography does not show usable results, assessment methodologies referred to may be applicable to our specific scope of interest.

The aim of an economic impact assessment is to deliver an economic value representative of the social significance of the impacts of water quality deficiencies:

- either a direct assessment based on consumers preferences expressed or revealed;
- or an indirect assessment of the economic cost or of a lower boundary of this cost; this is typically what may be assessed by averting expenditures (additional financial and time costs for avoiding an annoyance is at least worth the impact of this annoyance).

But in order to consider such costs in the rehabilitation decision making, we must be able to refer to the only impact of quality deficiencies from pipes failures and degradation, whatever other possible quality deficiencies may occur or exist. And ideally, in order to rank pipes or pipes groups causing quality problems, we should be able to link socio-economic costs of impacts to the importance of quality decrease, or to several degrees / types of quality decrease.

Partners of CARE-W project reacted to the typology of quality deficiency situations which might be considered as a consequence of pipe failures and degradations. The only situation, which was considered significant for rehabilitation decision making within a routine procedure was the following one: a water quality deficiency in the mid term ("semi permanent"), which induces water use limitations due to spontaneous preventive behaviours. It was concluded that discoloured water may be considered as representative of this situation.

We will further focus on the impact of water quality deficiencies, due to pipe ageing or degradation, on domestic water uses.

WHAT ARE THE POTENTIAL IMPACTED DOMESTIC USES?

Colour and taste of delivered tap water will show impacts, when deficient without violating public / regulatory use limitations, only on some of the domestic uses: we can think of tap water drinking and food washing and preparing, possibly baby bathing or clothes washing.

The impact on these water uses, and more generally the impact on consumer well-being, will depend on the perception of colour / taste alteration. As far as taste is concerned, perception varies with individuals, but it must be first considered that taste perception is less developed than sight or audition. Moreover, perception mostly refers to taste changes and comparison, rather than to "absolute" taste (MacRae et al, 1993).

First of all, what are the different domestic uses for tap water which are considered here ? In France, the average total tap water consumption estimated was 214 litres per day and per inhabitant (Drane, 1997): 1% of this amount for drinking, 6% for food preparing and washing. Moderate alterations of colour or taste will have consequences on a limited percentage of the total water consumption.

On the other hand, water quality deficiency will have a socio-economic cost referring to the water volume which is:

- not initially substituted by bottled water, whatever the reason (out of the "pipe impact" which we are considering),
- not successfully treated by domestic equipment (e.g. filters, softeners).

In four areas of the United Kingdom, Green et al (1993, see also Tunstall et all, 1993) performed a socio-economic study on tap water taste (among other service quality aspects). As an average, fresh tasting water was considered as happening with a medium frequency only, and only 74% of the 965 surveyed households stated that cold drinking water quality was acceptable (from 68 to 80%, varying according to areas). In fact, 35% of households bought water for a part of their consumption (from 27 to 51%, according to areas, average expense of £4.6 per month), 14% had purchased filters for tap water, 2% had purchased water softeners. 55% of surveyed households mentioned a non appropriate taste of tap water. This confirms that averting expenditures do not make for all impacted water uses.

Anadu and Harding (2000, see also Harding and Anadu 2000) showed that there was a link between perception of health risk and use of bottled water. Considering four Oregon cities, one with short term quality problems, one with mid-term quality problems, and two "witness" cases, they found that constant or very frequent consumption

[16] Note by UMR Cemagref – ENGEES GSP

of bottled water concerned 19 to 46% of households where quality problems existed, 16 to 21% elsewhere. Use of bottled water must not be considered as the consequence only of quality deficiencies.

In France, a national survey (IFEN 2000) showed that 39% of French drink only bottled water, 22% of them drank both tap and bottled water.

The impacts, which we aim at considering and possibly quantifying, will be different when the "initial consumption pattern" is different. Hence, the social and economic impacts will be characterised by:

- the “initial” or “reference” consumption behaviour (at least for drinking and food preparing) without additional quality deficiencies due to pipe ageing and degradation (% of people drinking exclusively bottled water, % of people having purchased filters …);
- the modified consumption behaviours following such deficiencies (and excluding any other reasons; motivation of behaviours must be carefully taken into account; Green et al 1993); these data can be site specific or taken from elsewhere, but the changing behaviour should not be "guessed" basing on other types of water quality problems;
- the socio-economic assessment of the corresponding impacts (for people changing their consumption behaviour, but also for others who are impacted too).

HOW COULD WE ASSESS SOCIO-ECONOMIC IMPACTS ON DOMESTIC WATER USE?

A first at hand criteria for quality deficiency impacts is a complaint ratio addressing quality, provided there is a careful registration of these complaints and of their content (Jones and Tuckwell, 1993), and provided we can compare complaint ratios with and without the quality deficiencies which we are considering.

Indirect economic assessment can be obtained by valuing the costs of averting expenditures, provided they respond to the considered quality deficiencies: money and time spent purchasing additional bottled water, filters … (Laughland et al, 1993). We did not find information which concerned taste and colour of drinking tap water (see above). We should not forget that by performing such an assessment, we would underestimate the impact:

1° averting expenditures (following the quality deficiency considered) are the minimum amount which concerned people are willing to pay to avoid drinking polluted water;

2° people who go on drinking tap water in case of water quality deficiencies also suffer from annoyances when these occur, even if they do not want (or if they are not able) to spend time and money for acquiring better water.

Economic analysis of domestic water uses has been performed through various studies and approaches. But we were not able to find an economic water demand model considering the quality of water among the explanatory parameters (Le Coz, 1998). The only approaches referred to, in the references identified, concern contingent valuation, with the assessment of willingness to pay for improving the quality of water: unfortunately, no one refers to quality deficiencies close to the ones which we are considering.

A very detailed methodological study was developed by the Middlesex University Flood Hazard Research Centre on behalf of OFWAT, on contingent valuation for quality improvements in water and sewerage services (Green et al. 1993, Tunstall et al. 1993). Taste of tap water was one of the studied aspects, in four areas of the United Kingdom.

Various conclusions can be drawn from this exploratory work:

- beliefs, opinions … must be analysed to be able to perform and understand results of such a contingent valuation; it includes opinions concerning the water utility or moral statements; preliminary interviews are also necessary for a better design of the complete survey;
- contingent valuation can be used for assessing economic value of water quality (in this case, taste);
- WTP (willingness to pay) is correlated with expressed acceptability of water taste, and hence with the fact of buying bottled water;
- some people who are not dissatisfied with the taste of water are willing to pay too for water quality improvements;
- WTP increases in average terms with housing income, but decreases with the water tariff (water quality is considered as a right, probably the more when water is more expensive): less people are willing to pay if tap water is more expensive, but those who are consider higher amounts of money.

The authors of this work, as well as Tervonen et al (1994), insist on being cautious with their quantitative results (WTP amounts), which are not to be applied out of the test areas. Tervonen et al considered a city in Finland, and found that housing income was not correlated with WTP, as also found Rollins et al (1997) in Canada. The latter refers to various contingent valuations performed in the USA and Australia. Anadu and Harding (2000) performed such work in two cities of Oregon with respectively mid-term and short-term quality problems (public notification advising to boil drinking water), compared with two other "witness" cities.

The results obtained by these various studies could not be applied to the type of quality deficiencies which we are considering, but the methods and approaches could be used: it would imply to perform comparative analysis on areas where the quality of tap water only differs by the impacts of ageing / degradation of pipes.

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3.2.2.5 Water pressure deficiencies

3.2.2.6 Hydraulic reliability

Type of approach: **Diagnosis / hierarchisation of pipe contribution to hydraulic unreliability**

Levels of approach: 2

Criteria and sub-criteria:

An index can be calculated for each link representing its criticality.

Tools developed in WP2[17] allow to define and to calculate this index

HCI(i,j): hydraulic criticality index for link i after rehab j

HCI(i,j) is affected by rehab j in reducing the repair rate

[17] Eisenbeis & al. (2002) CARE-W: WP2 – Description and validation of technical tools. D3 – Models description. June 2002.

3.3 Synthesis

Table 21 : Points of view, criteria, and required information
(UI: utility information, EI: external information)

Point of view	Criteria	Information	corresponding PI	UI	EI
Rehabilitation costs	AUCR(i;j)	Annual Unit Cost of Rehab.			
		• Material		X	
		• Pipe depth		X	
		• Seasonal variation			X
		• Density of fittings		X	
		• Soil type			X
		• Diameter		X	
		CSF(i;j) Co-ordination cost saving factor			
Co-ordination	COS(i)	Co-ordination score			
		• Schedule of service connection rehab		X	
		• Schedule of road work			X
		• Schedule of other utility rehab			X
Repair costs	ARC(i)	Annual Repair Costs			
		• Cost table, mean costs	Knowledge Base	(X)	
		• Street category			X
		• Failure rate	Op5_link Op26_link		
Water losses and relative costs	WLI(i;j)	Water losses index			
		• Failure rate observed	Op5_zone Op26_zone		
		• Leakage cost		X	
		• Failure rate	Op5_link Op26_link Op27_link		
Disturbances induced by rehab measure	DRM(i;j) DS(j)	Disturbance index			
		• technique scoring table	Knowledge Base		
		• Service connection density		X	
		• Street category			X
		• Sensitive customer		X	
		• Coordination with road work			X
		• Coordination with other utility			X

Point of view	Criteria	Information	corresponding PI	UI	EI
Water interruptions	PWI(i;j)	Predicted Water Interruption			
	PCWI(i;j)	Pr. Critical Water Interruption	QS26a_link		
		• Predicted Burst rate	Op26aa_link		
		• Duration of interruption		X	
		• No of people supplied by the link		X	
		• (No of) Sensitive Customers supplied by the link		X	
	PFWI(i,j)	Pr. Frequency of WI			
Damages and disruptions	DFH(i;j) DFI(i;j)	Damage due to Flooding in Housing areas, or Industrial or Commercial areas resp.			
	DSM(i;j)	Damage due to soil movement			
	DT(i;j)	Traffic Disruptions			
	DDI(i;j)	Damage and/or Disruption on other Infrastructure			
		• Diameter		X	
		• Pressure		X	
		• Slope			X
		• Risk of landslide			X
		• Street category			X
		• Basement			X
		• Ground Floor above soil			X
		• Type of housing			X
		• Type of activities			X
		• Sensitive infrastructure close to the link			X
		• Failure rate	Op5_link Op26_link		
		• Burst rate	Op26aa_link Op27a		
Water quality Deficiencies	WQD(i;j)	Water quality deficiencies			
		• Quality of water	QS15_zone, …		
		• Customer complaints	QS22_zone, …		
		• Material		X	
		• Installation date		X	
Hydraulic reliability	HCI(i;j)	Hydraulic criticality index			
		• Mean duration of repair		X	
		• Failure rate	Op5_link Op26_link		

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APPENDIX 1: DEFINITION OF CRITERIA, SOME EXAMPLES AVAILABLE IN PREVIOUS WORKS

MARESS (Multi-Attribute Rehabilitation of storm or combined Sewer Systems)
(Reyna *et al*., 1994) (Delleur *et al*., 1998)

In the expressions given below, we consider:

$i = 1 \text{ to } N \text{ pipes}$

$j = 1 \text{ to } M \text{ methods, with } j = 0 \text{ corresponding to "no rehab"}$

$x_{ij} \in \{0,1\}$

$L_i = \text{length of pipe i}$

Main criteria & sub-criteria defined in MARESS are the following:

$SCI_{ij}\ CFII_i\ L_i\ x_{ij}$ - **Structural Performance**

A structural performance is calculated in aggregating (multiplying) two sub-criteria:

- SCI_{ij} - Structural Condition Index (rehabilitated condition in reach *i* with technology *j*)
- $CFII_i$ - Consequences of Failure Impact Index, weighted average of:
  - SDF_i - Service Disruption Factor
  - TDF_i - Traffic Disruption Factor
  - $UDF_i = DUF_i\ CSF_i$ - Other Utilities Disruption Factor, with:
    - DUF_i - (Density of utilities factor?)
    - CSF_i - Cover / Size Factor

SCI_{ij} is a sub-criteria calculated for each candidate (i,j) which corresponds to rehab technology j applied to segment i.

$CFII_i$ is a sub-criteria only associated to segment i.

$HCI_{ij}\ x_{ij}$ - **Hydraulic Performance**

$$HCI_{ij} = HCI_{i,0} \frac{D_{i,0}^{8/3}}{D_{i,j}^{8/3}} \frac{n_{i,j}}{n_{i,0}}$$ Hydraulic Condition Index

$HCI_{i,0}\ (\in \{0,1,2,..,9,10\})$ is the Hydraulic Condition Index for reach *i* in the current situation and is determined from 3 “factors” (let say “Performance Indicators”) calculated with SWMM:

- the maximum to design flow ratio
- the duration of surcharge
- the duration of flooding

$\frac{D_{i,0}^{8/3}}{D_{i,j}^{8/3}} \frac{n_{i,j}}{n_{i,0}}$ is a factor representing the expected improvement with rehabilitation measure *j* (with diameter *D* and Manning's roughness coefficient *n*)

For this criterion, the process used to calculate the performance associated to a candidate (i,j) is a mixed process: one calculation is done with SWMM (to assess the current performances), and the expected performance (after rehab j) is obtained in combining the current value of index (HCI_{i0}) and the expected improvement factor for rehab method j.

$AMCUC_{ij}\ L_i\ x_{ij}$ - **Annual Maintenance & Claims Unit Costs**

$AMCUC_{i0}$ (the "as is" annual maintenance and claims unit cost) is assumed to be related to the original structural index condition index, SCI_{i0} and to the original diameter D_{i0} of the segment:

$$AMCUC_{i0} = (A \times SCI_{i0} + B)(a \times D_{i0} + b)\overline{AMCUC}$$

where $\overline{AMCUC}$ represents an average value

The annual maintenance and claims unit cost for rehabilitated pipe *i* using technology *j* is

$$AMCUC_{ij} = \frac{1}{C_j}(a \times D_{ij} + b)\overline{AMCUC}$$

$DLI_j\ L_i\ x_{ij}$ - **Disruption Level Index**

Each rehabilitation method has an associated Disruption Level Index (DLI_j) ranked from 0 to 10, from less to more disruptive. A maximum rank of 10 is given to excavation and replacement and a 0 to no rehabilitation.

Comment: In this approach, the disruption level index is not depending on segment i.

$AUCC_{ij}$ - **Annual unit construction cost**

The annual unit construction cost is obtained in using 3 main information:

$$AUCC_{ij} = \frac{r(1+r)^{nj}}{(1+r)^{nj} - 1} UCC_{ij}$$, with:

UCC_{ij} is the unit construction cost for rehab method j applied on reach *i*

n_j is the expected life of the rehabilitation using technology *j*.

r is the interest rate.

Criteria for water pipe replacement (Dandy, Engelhardt, 2001)

Pipe failure costs

The expected repair costs of pipe over its life will be determined by when it is replaced (if it all). These failure costs will include:

- $PVOB_i$, the repair costs experienced by the existing pipe,
- $PVNB_i$, the repair costs associated with the new pipe.

The expected repair costs are determined over a 50-years period in 10 5-years time steps.

The present value of costs of the repairs for existing pipes, if replaced at time step T_{ri} is calculated using:

$$PVOB_i(T_{ti}) = \sum_{t=0}^{T_{ti}} \frac{k \cdot BR(d_i, t) \cdot BC(d_i) \cdot BCF(LU_i) \cdot l_i}{(1+r)^{5t}}$$

with:

$BR(d_i, t)$: failure rate for diameter d_i at time step t (bursts/km/year) for pipe i

$BC(d_i)$: burst cost (see Table 22)

$BCF(LU_i)$: burst cost factor for land use LU_i (see Table 23)

l_i, length of pipe i (km),

$k = 2.5$ for $t = 0$ or $t = T_{ri}$, $k = 5$ otherwise,

r, the discount rate.

The present value of costs of future repairs for a new pipe of diameter d_{ni}, is calculated using:

$$PVNB_i(d_{ni}, T_{ti}) = \sum_{t=T_{ti}}^{10} \frac{k \cdot BR(d_{ni}, t) \cdot BC(d_{ni}) \cdot BCF(LU_i) \cdot l_i}{(1+r)^{5t}}$$

<u>Comments</u>:

In this approach, the sensitivity of the surrounding environment of a pipe is represented by a cost factor ($BCF(LU_i)$) associated with the land use (residential, commercial, major road, etc.) (Table 23).

This allows calculating indirect costs and aggregating them with direct costs in a single criterion ($PVOB_i$ or $PVNB_i$).

Cost of replacing pipe

The present value of the replacement cost of a pipe with diameter d_{ni} in time period T_{ri} is given by:

$$NPR_i(d_{ni}, T_{ri}) = \frac{1000 \cdot R(d_{ni}) \cdot l_i}{(1+r)^{5T_{ri}}}$$

with:

$R(d_{ni})$: cost/m length of replacing the pipe with diameter d_{ni} as given in Table 22.

Table 22 – Repair costs and replacement costs[18] (Dandy et al, 2001)

diameter (mm)	Repair cost (average for SA Water) (Aus $)	Replacement cost (Aus$/m)	pipe type
100	1 575	95	DICL
150	1 800	120	DICL
200	2 270	140	DICL
250	2 700	165	DICL
300	2 800	195	DICL
350	3 000	220	DICL
400	4 225	255	DICL
450	4 325	385	DICL
500	4 450	455	MSCL
600	4 450	525	MSCL
700	4 450	563	MSCL
750	4 450	600	MSCL
800	4 450	638	MSCL
850	4 450		

Table 23 – Land use factors (Dandy et al, 2001)

Land use	Cost case 1	Cost case 2	Cost case 3
residential	1.5	1.5	5
industrial	1.5	1.5	5
commercial	3	4	5
major roads	3	4	5
rural	1	1	5

[18] Figures from SA Water (South Australian Water Corporation), DICL: ductile iron-cement lined, MSCL: mild steel-cement lined

APPENDIX 2: QUESTIONNAIRE

Prioritisation of rehabilitation projects in water utilities
- QUESTIONNAIRE -

Water Utility:	CARE-W Partner:

- **UTILITY PROFILE**

	1998	1999	2000
Population supplied			
Water production (million. m³)			
Billed water consumption (million. m³)			

	1998	1999	2000
Mains network length (km)			
- transmission mains...............			
- distribution mains..................			
Number of service connections			

Are customer complaints recorded? Yes / No

If 'yes':

Are they geo-referenced? *Yes / No*

Are they split by pipe type? *Yes / No*

First year of records: .... __________

- **REHABILITATION**[1]

	1998	1999	2000
Total length rehabilitated (km)			
a) cleaning (km)			
b) non structural lining (km)			
c) replacement (km)............................			
Cost of rehabilitation (million Euro)...........			
a) cleaning (million Euro).....................			
b) non structural lining (million Euro)..			
c) replacement (million Euro)..............			
Number of service connections replaced .			
Cost (million Euro)			

[1] Definitions: (International Water Association)

Rehabilitation: any physical intervention that extends the life of the system and involves changing their condition or specification.

Relining: the removal of all deposits from inside an existing pipeline, followed by the *in situ* application of a non-structural lining to provide corrosion protection, such as cement or epoxy mortar (relining is sometimes referred to as scraping and lining, renovation or reconditioning).

Replacement: substitution of a new facility for an existing one where the latter is no longer used for its former objective. *Renewal* is a particular form of replacement in which the function of the new facility is the same as that of the existing. In practice this usually means that is of the same nominal diameter (for pipelines), power (for pumping systems), etc. In the case of pipelines, replacement includes the provision of a structural liner (sliplining). The new pipeline may or may not have the same carrying capacity as the existing pipeline.

- **MAIN OBJECTIVES OF ANNUAL REHABILITATION PROGRAMMES**

Please indicate the relative importance of the following objectives for the selection of rehabilitation projects **in your utility**.

Please mark the following objectives according to: **1 – is of overriding importance**
2 – is important
3 – is of minor importance
4 – is not important

*** – *data or tools missing*** (to take into account this objective)

Objectives:	**1**	**2**	**3**	**4**	* yes	* no
Improve hydraulic performance	❑	❑	❑	❑	❑	❑
Improve water quality	❑	❑	❑	❑	❑	❑
Reduce operation and maintenance costs	❑	❑	❑	❑	❑	❑
Reduce water losses	❑	❑	❑	❑	❑	❑
Reduce the number of mains failures and their conse-quences: interruptions, possible damages or disruptions	❑	❑	❑	❑	❑	❑
Reduce the age of water at the customer tap.......................................	❑	❑	❑	❑	❑	❑
Maintain or improve average condition of network............................	❑	❑	❑	❑	❑	❑
Other[1]: ______________________________	❑	❑	❑	❑	❑	❑
Other: ______________________________	❑	❑	❑	❑	❑	❑
Other: ______________________________	❑	❑	❑	❑	❑	❑

Comments:

[1] e.g.: asset value management, suppress a particular material, …

- **CRITERIA USED TO DEFINE ANNUAL REHABILITATION PROGRAMMES**

4.1. - HOW ARE REHABILITATION PROJECTS SELECTED?

1) with criteria and weights from national recommendations .... ❑
2) with criteria from national recommendations but different weights .... ❑
3) compliance with legislation and/or regulatory requirements .... ❑
4) with internal formalised decision rules .... ❑
5) after economic evaluation of projects.. ❑
6) mainly determined by road works .... ❑
7) in co-ordination with other utilities .... ❑

Comments:

4.2. – DECISION CRITERIA

Please indicate the importance of the following criteria for the selection of rehabilitation projects **in your utility**.

Please mark the following criteria according to:

1 – is of overriding importance
2 – is important
3 – is of minor importance
4 – is not important
*** – *data or tools missing***

Criteria	1	2	3	4	* yes	* no
Inadequate minimum system pressure with consequent customer complaints	❑	❑	❑	❑	❑	❑
Water quality standards not fulfilled (owing to network condition)	❑	❑	❑	❑	❑	❑
Restrictions on water uses due to water quality (owing to network condition)..........	❑	❑	❑	❑	❑	❑
Frequent and increasing number of relevant customer complaints	❑	❑	❑	❑	❑	❑
Failure rate above threshold .... Threshold: ___________________________________	❑	❑	❑	❑	❑	❑
Pipe condition						
- Badly encrusted pipe...	❑	❑	❑	❑	❑	❑
- Pipe prone to bursting	❑	❑	❑	❑	❑	❑
- External corrosion...	❑	❑	❑	❑	❑	❑
- Leaking joints	❑	❑	❑	❑	❑	❑
- other:______________________________	❑	❑	❑	❑	❑	❑
Pipes susceptible to						
- Ground movement	❑	❑	❑	❑	❑	❑
- Stray current..	❑	❑	❑	❑	❑	❑
- Heavy traffic loading	❑	❑	❑	❑	❑	❑
- ____________________________..	❑	❑	❑	❑	❑	❑
- ____________________________..	❑	❑	❑	❑	❑	❑
Frequency of water interruptions	❑	❑	❑	❑	❑	❑
Consequences of interruptions:						
- Number of people supplied by the link	❑	❑	❑	❑	❑	❑
- Sensitive or key customers supplied by the link .... *e.g.:* …..	❑	❑	❑	❑	❑	❑
Risk of severe damage or major street disruption from bursts.................................. *e.g.:* …..	❑	❑	❑	❑	❑	❑
High level of water losses in the area	❑	❑	❑	❑	❑	❑
High costs of flushing or repair	❑	❑	❑	❑	❑	❑
Rehabilitation in conjunction with service connection replacement programme.......	❑	❑	❑	❑	❑	❑
Hydraulic capacity problems	❑	❑	❑	❑	❑	❑
Work of other utilities in the same location...	❑	❑	❑	❑	❑	❑
Roadway rehabilitation						
- rebuilding...	❑	❑	❑	❑	❑	❑
- resurfacing	❑	❑	❑	❑	❑	❑
Unusual diameter..	❑	❑	❑	❑	❑	❑
Unusual pipe material	❑	❑	❑	❑	❑	❑
Limited or restricted access to pipe(s)	❑	❑	❑	❑	❑	❑
Other: ______________________	❑	❑	❑	❑	❑	❑

APPENDIX 3: IMPORTANCE OF OBJECTIVES & CRITERIA ACCORDING TO WATER UTILITIES

OBJECTIVE	ACOSEA (Ferrara)	Consorzio Acque Delta Ferrase	LYON - SLA	TRONDHEIM KOMMUNE	BRNO	VAV (Oslo)	LAUSANNE	ROUBAIX TOURCOING	AGAC	DRESDEN (Drewag)	BRISTOL WATER	Neckarwerke STUTTGART
IMPROVE HYDRAULIC PERFORMANCE	3	2	0	1	1	2	2	0	2	1	2	2
CRITERIA that can be associated with this objective												
Inadequate minimum system pressure with consequent customer complaints	3	3		0	1	1	3	0	3	1	1	3
Hydraulic capacity problems	2	2	0	1	1	2	3	0	2	2	1	2

OBJECTIVE	ACOSEA (Ferrara)	Consorzio Acque Delta Ferrase	LYON - SLA	TRONDHEIM KOMMUNE	BRNO	VAV (Oslo)	LAUSANNE	ROUBAIX TOURCOING	AGAC	DRESDEN (Drewag)	BRISTOL WATER	Neckarwerke STUTTGART
IMPROVE WATER QUALITY	2	3	2	2	3	2	3	1	2	3	0	1
CRITERIA that can be associated with this objective												
Water quality standards not fulfilled (owing to network condition)	3	3	2	0	2	0	3	0	1	3	3	3
Restrictions on water uses due to water quality (owing to network condition)	3	3		0	1	0	3	0	1	3	0	3
Frequent and increasing number of relevant customer complaints	2	2	0	2	2	1	3	0	2	3	2	3
Pipe condition **Badly encrusted pipe**	1	0		1	1	2	2	0	0	3	0	1

OBJECTIVE	ACOSEA (Ferrara)	Consorzio Acque Delta Ferrase	LYON - SLA	TRONDHEIM KOMMUNE	BRNO	VAV (Oslo)	LAUSANNE	ROUBAIX TOURCOING	AGAC	DRESDEN (Drewag)	BRISTOL WATER	Neckarwerke STUTTGART
REDUCE OPERATION AND MAINTENANCE COSTS	**3**	**2**	**2**	**3**	**1**	**2**	**1**	**2**	**2**	**2**	**3**	**3**
CRITERIA that can be associated with this objective												
High costs of flushing or repair	**3**	**1**	**0**	**1**	**1**	**0**	**2**	**0**	**2**	**2**	**0**	**3**
Limited or restricted access to pipe(s)	**1**	**1**	**0**		**2**	**0**	**1**	**2**	**0**	**0**	**0**	**1**

OBJECTIVE	ACOSEA (Ferrara)	Consorzio Acque Delta Ferrase	LYON - SLA	TRONDHEIM KOMMUNE	BRNO	VAV (Oslo)	LAUSANNE	ROUBAIX TOURCOING	AGAC	DRESDEN (Drewag)	BRISTOL WATER	Neckarwerke STUTTGART
REDUCE WATER LOSSES	**3**	**2**	**1**	**2**	**2**	**2**	**2**	**3**	**2**	**2**	**0**	**1**
CRITERIA that can be associated with this objective												
High level of water losses in the area	**3**	**2**	**0**	**2**	**2**		**3**	**3**	**2**	**2**	**1**	
Pipe condition: **Leaking joints**	**1**	**1**	**2**	**1**	**1**	**2**	**1**	**1**	**2**	**1**	**0**	

OBJECTIVE	ACOSEA (Ferrara)	Consorzio Acque Delta Ferrase	LYON - SLA	TRONDHEIM KOMMUNE	BRNO	VAV (Oslo)	LAUSANNE	ROUBAIX TOURCOING	AGAC	DRESDEN (Drewaq)	BRISTOL WATER	Neckarwerke STUTTGART
REDUCE THE NUMBER OF MAINS FAILURES AND THEIR CONSEQUENCES: INTERRUPTIONS, POSSIBLE DAMAGES OR DISRUPTIONS	**3**	**2**	**3**	**2**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**
CRITERIA that can be associated with this objective												
Failure rate ~~(above threshold)~~		**2**	**3**	**2**		**3**	**3**	**3**	**2**	**1**		**2**
Pipe condition:												
Badly encrusted pipe	**1**	**2**	**3**		**2**	**0**	**2**	**0**	**1**	**1**	**1**	**1**
Pipe prone to bursting	**3**	**3**	**3**		**1**	**2**	**3**	**3**	**2**	**2**	**1**	**2**
External corrosion	**2**	**2**	**3**	**3**	**1**	**3**	**2**	**0**	**1**	**2**	**1**	**1**
Leaking joints	**2**	**2**	**3**	**1**	**1**	**2**	**3**	**2**	**2**	**1**	**0**	**2**
Frequency of water interruptions	**2**	**3**	**3**	**2**	**1**	**3**	**3**	**3**	**2**	**3**	**0**	**1**
Consequences of interruptions:												
Number of people supplied by the link	**2**	**3**	**1**	**2**	**1**	**2**	**2**	**3**	**2**	**3**	**0**	**1**
Sensitive or key customers supplied by the link	**3**	**3**	**2**	**3**	**2**	**2**	**3**	**0**	**2**	**3**	**0**	**3**
Risk of severe damage or major street disruption from bursts	**2**	**3**	**3**	**2**	**1**	**2**	**3**	**3**	**2**	**2**	**0**	**3**
Pipes susceptible to:												
Ground movement	**1**	**2**	**3**	**1**	**2**	**2**	**2**	**0**	**0**	**3**	**0**	**3**
Stray current	**1**	**0**		**1**	**1**	**2**	**2**	**0**	**0**	**3**	**0**	**1**
Heavy traffic loading	**1**	**1**	**2**	**1**	**1**	**2**	**1**	**1**	**2**	**1**	**0**	

APPENDIX 4: DEFINITIONS

CARE-W WP1 – Report n°2:

FAILURES

Op5 - Active leakage control repairs *(%/year)*	Number of leaks detected and repaired due to active leakage control / total mains length x 100 *Op5 = D9/C6 x 100*
Op26 - Mains failures[19] *(No./100 km/year)*	Number of mains failures during the year, including failures of valves and fittings and excluding service connection insertion point failures / total mains length x 100 *Op26 = D25/C6 x 100* *If mains failures are to be used for regulating objectives, the use of a complementary indicator, similar to Op26 but excluding failures by third parties is advisable, as they are not a direct fault of the water undertaking. Number should exclude repairs under active leakage control.*
Op26a - pipe failures *(No./100 km/year)*	Number of pipe failures during the year, excluding failures of valves joints and links to service connections / total mains length x 100 *Op26a = D25a/C6 x 100*
Op26b - joint failures *(No./100 km/year)*	Number of joint failures during the year / total mains length x 100 *Op26b = D25b/C6 x 100*
Op26c - valves failures *(No./100 km/year)*	Number of valve failures during the year / total mains length x 100 *Op26c = D25c/C6 x 100*
Op26d – Critical mains failures *(No./100 km/year)*	Number of critical mains failures during the year, including failures of valves and fittings and excluding service connection insertion point failures / total mains length x 100 *Op26d = D25d/C6 x 100*
Op26e – Mains failures in sensitive areas *(No./100 km/year)*	Number of mains failures in sensitive areas during the year, including failures of valves and fittings and excluding service connection insertion point failures / total mains length x 100 *Op26e = D25e/C6 x 100*
Op27 - Service connection failures *(No./1000 connections/year)*	Number of service connection failures during the year / number of service connections x 1000 *Op27 = D26/C32 x 1000* *If service connection failures are to be used for regulating objectives, the use of a complementary indicator, similar to Op27 but excluding failures by third parties is advisable, as they are not a direct fault of the water undertaking. Number should exclude repairs under active leakage control.*
Op27a – Service connection insertion point failure *(No./100 km/year)*	Number of failures that occur in the insertion point of the service connection / number of service connections x 1000 *Op27a = D26a/C32 x 1000*
Op28 - Hydrant failures *(No./1000 hydrants/year)*	Number of hydrant failures during the year / total number of hydrants x 1000 *Op28 = D27/C31 x 1000* *If hydrant failures are to be used for regulating objectives, the use of a complementary indicator, similar to Op28 but excluding failures by third parties is advisable, as they are not a direct fault of the water undertaking. Number should exclude repairs under active leakage control.*

[19] This definition differs from the present IWA's one. In the latter it is not clear whether the service connection insertion point failures shall be accounted for.

CARE-W –Definitions proposed in WP2

Failure: A failure is a leak or burst involving a repair on the pipe.

Burst: Default occurring instantaneously, often caused by the break of pipe body. It involves in all the cases a repair of the pipe because of damages and hydraulic failure.

Leak: Default of the pipe, minor or not, often caused by a crack on pipe body or a problem of tightness at the joint. It doesn't involve always a repair. It does when it is located (after leakage control) or when water appears in the road. With time it can become a burst.

Leaks can then be distinguished in different categories:

- Leaks not detected,
- Leaks detected after a current leakage control,
- Leaks detected after a leakage control caused by a suspicion of leak,
- Leaks directly detected because of flood or water on the road or sidewalk.

These information rarely exist in maintenance data. According to the service, all these types of leaks are included or not as failure.

Location of the leak on the link can also be given: Joint, body or even valve.

Finally failure can be assigned to 2 elements: principal main or service connection. The point of junction between these two elements belongs to service connection.

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