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REPORT

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WP5
Elaboration and Validation of CARE-W Prototype

D12 - The CARE-W Procedure

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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

WP5 – Elaboration and Validation of the CARE-W Prototype

Report D12

THE CARE-W PROCEDURE

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CONTENTS

LIST OF FIGURES

1. INTRODUCTION

1.1 CARE-W Aims

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

This project is organised in the following Work 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 the CARE-W prototype;
- WP6: Testing and validation of the CARE-W prototype;
- WP7: Dissemination;
- WP8: Project management.

WRc is responsible for WP5 which is divided into three tasks. This report deals with the work undertaken for the first of these, viz.

Task 5.1 "**Develop the CARE-W procedure for optimising rehabilitation planning**. The individual CARE-W tools will be thoroughly evaluated in terms of their benefits, data requirements and inter-relationships (there will be some overlap of functionality and differences of approach due to local application). Some rationalisation or development may take place. The application benefits will be mapped and a procedure for optimum integration developed. It will be made clear, how to utilise the toolbox most efficiently in order to address a given problem or circumstance."

1.2 WP5 objectives

WP5 will produce the software application enabling a range of tools (identified and developed under work packages 1 to 4) to be applied methodically to the rehabilitation planning process. The specific objectives of WP5 are as follows:

- Specify the data input/output and storage requirements for the integrated CARE-W package;
- Produce a specification for software that will integrate the use of the tools defined in CARE-W in an optimal manner;

- Deliver working prototype software that will manage the information needed and results generated from the tools defined in CARE-W, enabling the integrated CARE-W package to identify optimum rehabilitation strategies.

1.3 Scope of this report

This report aims to present a rehabilitation planning procedure concordant with use of the CARE-W prototype (hereafter referred to as the Prototype) and demonstrate how CARE-W may assist in this process.

This document (D12) describes the procedure in general terms. A more technical discussion on the use of the tools, their data requirements and how they function together, is the topic of deliverable D13.

The structure of this report is as follows:

Section 2 describes a generic rehabilitation planning procedure applicable in most instances, regardless of the analysis tools available.

Section 3 describes how CARE-W may be applied to the procedure outlined in Section 2, and discusses the limitations of the procedure in terms of a complete computer-aided rehabilitation sequence.

2. A GENERIC REHABILITATION PLANNING PROCESS

2.1 Rehabilitation planning: An engineering perspective

Efficient planning requires the rehabilitation engineer or planner to be in possession of a substantial amount of background knowledge and experience on the types of problems faced, current performance and possible effective solutions. The engineer must be aware of the objectives of rehabilitation for each problem he faces, and apply sound judgement using all the tools at his disposal in an appropriate manner. This places a huge burden on the engineer when many rehabilitation methods are feasible and there are many solutions to improve service delivery to customers. The engineer can narrow his search for an acceptable solution by using strategic level data and knowledge of historical performance. However, scheduling rehabilitation over, say, a 2-year planning horizon is a complex multivariate problem and the engineer must be guided by a suite of useful analysis tools to help him choose the most cost-effective rehabilitation options from those available.

Figure 2.1 summarises a generic water mains rehabilitation process. It is described in more detail in the sections which follow.

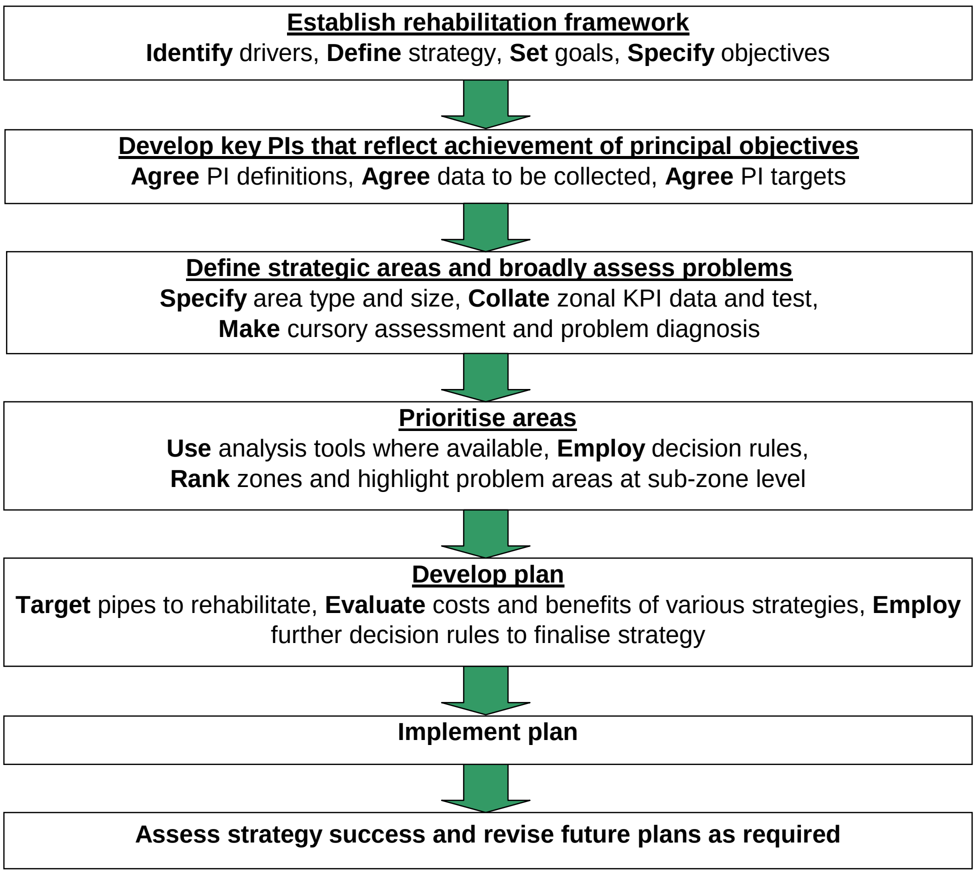

Figure 2.1 Generic rehabilitation planning sequence

2.2 Establish the rehabilitation framework

The first step is to establish the framework for managing the rehabilitation process. This would involve identifying the drivers which influence rehabilitation and, perhaps, assessing their relative importance. The drivers which are important will naturally vary from region to region, and country to country. For instance, water quality, leakage, burst rates, hydraulic performance, pipe condition and cross-utility co-ordination are all drivers which influence rehabilitation (to a greater or lesser degree) in most European countries. These drivers will determine the objectives of the rehabilitation work, which will in turn influence the overall rehabilitation strategy. The timescale over which the work needs to be carried out (the *planning horizon*) must be decided at this stage.

2.3 Define performance indicators and their requirements

Once the framework of the rehabilitation plan has been decided upon, key performance indicators (KPIs) can be defined. Targets for the KPIs would also be defined at this stage. These must reflect the current and predicted future drivers for the water company or municipality. In other words, one needs to *measure* to *manage*. For example, if customer complaints of ‘red’ water are high and this is a key concern of the water supplier, it makes sense to define, record and use performance data (e.g. number of complaints of discoloured water, and iron concentrations). The water supplier can then keep a close watch on the problem and monitor the efficacy of any remedial action taken, over a period of time.

This is also the correct time to assess data needs and validate all sources of data. Some KPIs will need data from a number of different and possibly disparate sources. Whilst it is important to ensure KPIs can be calculated from data available, a lack of data should not preclude the development of a particular performance measure if it addresses an important business or service issue. Instead, a way must be found to collect this information in order that the KPI may be validated and its use tested.

2.4 Define rehabilitation areas

The next step is to define the size of the areas to which the rehabilitation framework will be applied. These areas or zones should be defined by the rehabilitation engineer or planner. They could be areas that have been historically used for network management, such as the district meter area (DMA) favoured by many UK water utilities, or water supply zones, or another management unit. Working on small areas will be data-intensive but will provide highly specific solutions. Working on larger areas will require less data but will produce more general solutions, which will require further development before they can be implemented. The engineer or planner must decide on the appropriate balance. However these zones are decided upon, they need to be specified and the KPI information for each collated and used to develop an initial view of the performance of each zone. This would be a rudimentary prioritisation exercise, using complementary approaches of engineering judgement and knowledge of the historical performance of zones.

2.5 Prioritise areas

Once performance at the zone level has been identified it would be possible for the rehabilitation planner to decide on which zone(s) to investigate in more detail.

2.6 Develop the rehabilitation plan

2.6.1 Routes to developing a plan

There are three main options in deciding on which route to take in developing a rehabilitation plan. Each route will be valid in different circumstances, depending on the data available and on the desired outcome:

Option 1: All planning at strategic level
The rehabilitation strategy is derived from the top down; global spending levels are set strategically and broad areas for more detailed analysis are identified. A strategic rehabilitation plan is created with, possibly, a number of alternative rehabilitation scenarios.

Option 2: Strategic budgets set and pipe level targeting up to budget
The budgets for the rehabilitation schemes are set at a global level, i.e. for the utility or region. Rehabilitation schemes are then developed for particular areas or zones using more detailed knowledge and information. Schemes are only planned up to the ceiling set by the strategic budget. As investment is constrained by the strategic budget, the most critical problems will be given priority and further information may be sought to finalise those schemes which address these problems. Some negotiation is likely before plans are finalised.

Option 3: Pipe level build up of costs
A number of likely rehabilitation schemes are planned based on detailed pipe-level information for a given zone or area, and the costs and benefits summed over all pipes [bottom up analysis]. Likely schemes are prioritised and the rehabilitation plan for the year is negotiated.

2.6.2 Detailed planning

As stated previously, zones requiring further attention must be chosen to assist in meeting the business objectives of the water supplier. In terms of the customer, these must include maintaining existing service provision or, if the level of service is deemed unacceptable, improving service to customers. The steps in a detailed planning process will naturally be guided by the nature of the problem to be solved, the policy of the water supplier, industry regulation and available data.

Broadly speaking, however, many of the following procedures may be followed in the preparation of a rehabilitation plan. Some examples are given under each step for illustration:

- Collect additional recorded information on key drivers for zones of particular importance:
  - Performance indicator scores;
  - Water quality sample data;
  - Customer complaint data;
  - Detailed maintenance records.
- Conduct physical sampling:
  - Condition assessment of pipe cut-outs;

   - Supplementary water quality sampling at hydrants/customer taps.

- Confirm the principal cause of a performance shortfall, for example:

   - Supply pressure;

   - Water quality;

   - Water losses;

   - Pipe failures.

- Confirm the source of a problem, for example:

   - Hydraulic capacity

      - Is the supply network undersized or are there substantial water losses?

   - Distribution system in poor condition;

   - Treated water quality unacceptable (risk of failure carried over from water treatment)

      - Is the treatment plant failing? How?

- Investigate the type and frequency of performance shortfalls, and assess the risk of failure

   - Spreadsheet-based summary statistics;

   - Failure modes and effects analysis;

   - Probability and consequence of failing to meet required performance level;

- Identify a list of possible actions and calculate the cost-effectiveness of each action

   - Is my action feasible?

      - Is the work practically possible? Are there engineering problems?

      - Does the material, diameter and condition of the existing material allow the rehabilitation technique of choice to be used?

   - What effect does my action have on other parts of the network (what is the action's *sphere of influence*)?

   - Does my action impact on other performance measures other than the target performance measure (are there *secondary benefits* which should be acknowledged)?

   - Are there other grounds on which I should base my decision (*'tertiary' decision rules*)?

      - Can I co-ordinate my actions with other work, or conduct additional work at that location (e.g. replace lead and galvanised iron service pipes at the same time)?

    - Are there additional practical or financial obstacles (e.g. the action requires an unrealistic proportion of the available budget or resources; there are a number of sensitive and/or key customers in the sphere of influence)?

- ❖ Prioritise spheres of influence (likely rehabilitation zones) based on cost-effectiveness of proposed rehabilitation solution and devise plan.

These issues should be investigated at the detailed planning stage and the results will generate options for the rehabilitation plan. Preferred options can then be chosen based on considerations of cost-benefit, cost-effectiveness, risk management, and so on.

2.7 Implement preferred options and review rehabilitation plans

The works included in the rehabilitation plan should be undertaken as part of a structured programme which ensures that significant benefits are delivered as soon as is feasible and is cost-efficient to do so.

The success of the rehabilitation plan should be monitored throughout the implementation process and modifications made as necessary.

Monitoring should continue after completion to confirm that the expected benefits have been achieved and to identify any problems which may develop over time.

3. APPLYING CARE-W TO REHABILITATION PLANNING

3.1 General prototype description

The Prototype will be a versatile and powerful application, incorporating a variety of rehabilitation planning tools.

The general architecture of the CARE-W software is shown in Figure 3.1.

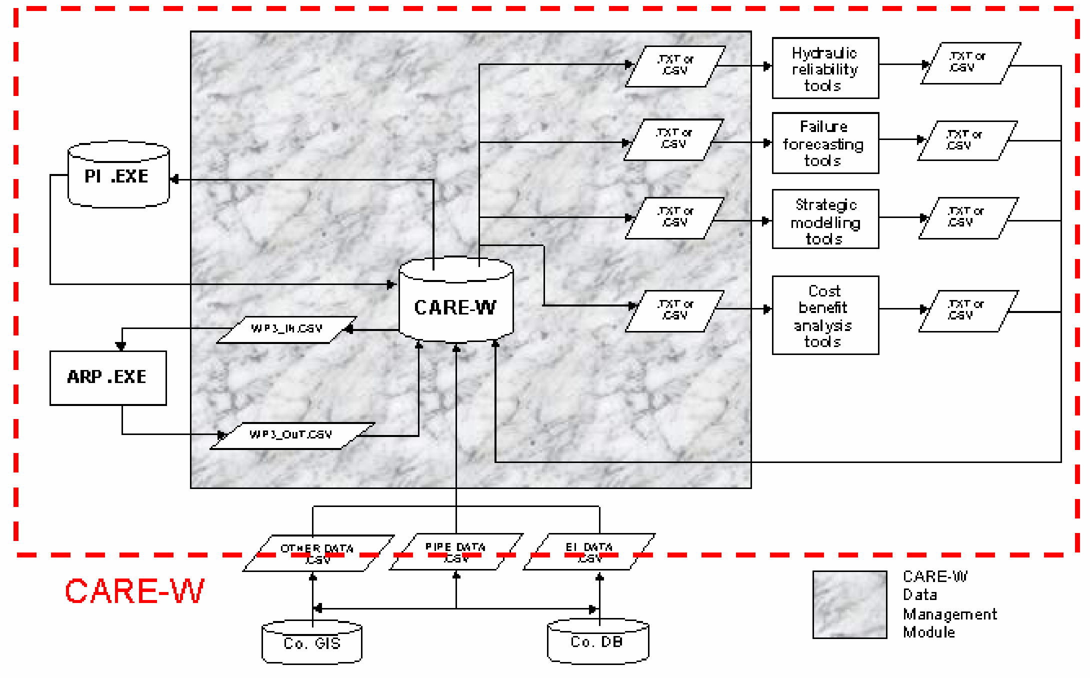

Figure 3.1 CARE-W architectural design

3.1.1 The central database

The heart of the software will be a database containing a number of tables which will be used to store information from a number of different input sources. The CARE-W software will manage the import of data to these tables through the user interface. Only information required for further analysis by CARE-W tools will be stored in the central database. Information will be stored once only. Geospatial elements, pipe-based information and zonal information will therefore be recorded in separate tables with suitable cross-referencing. Other tables will record utility, operating environment and performance data and, of course, also hold relevant results for use by the tools and reporting to the user.

3.1.2 Datasets and projects

The unit of currency in CARE-W will be the *dataset*, which may be one of the following types: *network*, *sector*, or *cluster*. All datasets will belong to one or more *projects.* A project is merely a convenient grouping for working with and maintaining multiple datasets and model runs. In practice, the user will import his project data to a CARE-W project database.

A sector is understood as a collection of pipes which have been grouped under a reference name, typically an operational or management unit, e.g. water supply zone, hydraulic zone, district meter area. A cluster is understood, in practice, to mean a grouping of pipes with one or more identical attributes which may or may not lie within one sector. A network is understood to be the largest grouping of pipes, typically a collection of sectors of a company or municipality.

It is important to maintain and cross-reference general dataset information with information relating to the pipes which constitute that dataset. This allows reports to be produced consistently and efficiently.

3.1.3 Tools interaction

All external tools will be referenced by the CARE-W database according to a series of input and output protocols to be written by WRc in close consultation with the tool developer. On user request, the central software package will produce the necessary input and output files which may be read and interpreted correctly by each of the tools in order that information may be passed back and forth between the CARE-W database and the external tool in current use.

CARE-W was not intended to bind together the external tools produced as part of WP1, WP2, WP3 and WP4 in a fixed and constraining way, but rather to allow the user to use them individually or in a sequence appropriate to the data available for analysis.

In section 3.2, three routes to devising a rehabilitation plan using CARE-W tools in an integrated way, are suggested.

3.1.4 Help

The CARE-W software will contain both passive and active help facilities. The passive help will act as a reference guide for the more experienced or general interest user. Given sufficient information on the user's objectives in working with CARE-W and the data he has available, the active help facility will guide the new user in how to use CARE-W most effectively.

3.1.5 Scope of use

The Prototype will have the flexibility to allow the rehabilitation of networks to be planned at both strategic and tactical levels, or in other words, at various levels of complexity: network, zone or pipe. This flexibility is possible because of the nature of the tools that form the Prototype. It should be noted that the CARE-W software is a tool to *help* an engineer devise annual and strategic rehabilitation plans; it does **not**, and is **not intended to** produce the plan itself.

3.2 Options for rehabilitation planning

The CARE-W software will be of greatest use when some initial analysis of the problems identified in the target network has been carried out. This groundwork is necessary in all but the most cursory of planning exercises, and is explained in some detail in the previous chapter. The rehabilitation framework discussed in Chapter 2 must be embodied, in CARE-W terms, in the choice of applicable *points of view*, and relevant *performance indicators (PIs)* with their constituent pieces of *utility information (UIs)*.

Note that the stages described in sections 2.2 to 2.4 may be complemented by the use of a number of CARE-W tools in stand-alone form. For example, the PI tool of WP1 and the predictive tools of WP2 and WP4 may be run "offline" on a number of different datasets or scenarios to improve network understanding and help pinpoint areas of concern before a more integrated planning exercise is undertaken.

We shall begin, then, by discussing the planning options open to the Engineer having completed the initial development stages of his rehabilitation planning exercise. The CARE-W prototype will accommodate the three options identified in section 2.6, viz:

Option 1: All planning at strategic level
The rehabilitation strategy is derived from the *top down*; global spending levels are set strategically and broad areas for more detailed analysis are identified. A strategic rehabilitation plan is created with, possibly, a number of alternative rehabilitation scenarios.

Option 2: Strategic budgets set and pipe level targeting up to budget
The budgets for the rehabilitation schemes are set at a global level, i.e. for the utility or region. Rehabilitation schemes are then developed for particular areas or zones using more detailed knowledge and information. Schemes are only planned up to the ceiling set by the strategic budget. As investment is constrained by the strategic budget, the most critical problems will be given priority and further information may be sought to finalise those schemes which address these problems. Some negotiation is likely before plans are finalised.

Option 3: Pipe level build up of costs
A number of likely rehabilitation schemes are planned based on detailed pipe-level information for a given zone or area, and the costs and benefits summed over all pipes [*bottom up analysis*]. Likely schemes are prioritised and the rehabilitation plan for the year is negotiated.

CARE-W reporting functionality will allow comparison of different options, say comparing annual investment requirements of options 1 and 3.

Options 1 to 3 are now explained in the context of the CARE-W toolkit. They are also shown in colour-coded form in Figure 3.2.

3.2.1 Option 1: Strategic Rehabilitation Planning

The main element of the Prototype utilised by this first rehabilitation option would be the long-term rehabilitation planning tool developed under CARE-W Work Package 4 (WP4).This planning tool will allow engineers or planners to assess the effects of particular rehabilitation strategies using the cohort survival model for annual network forecasting.

As a free-standing tool, the extended KANEW framework which constitutes WP4 requires a relatively small amount of information from the CARE-W database. As with all external tools, the user must ensure this information is available for use and that a input file for WP4 is created before its use. These steps may be handled through the CARE-W user interface.

The WP4 tool consists of three elements; the scenario writer, the rehabilitation strategy manager and the rehabilitation strategy evaluator.

The scenario writer assists the engineer or planner to write scenarios for the future condition and performance of a water supply system and the assets contained within it. These scenarios describe the interaction of various factors which will influence the behaviour of a network, over a 10-25 year planning horizon. The scenario writer creates three paths for the future of a given network, the best case scenario, the worst case and the most likely scenario. Each of these paths will produce information relevant to rehabilitation planning and the key factors which will influence the rehabilitation policy.

The rehabilitation strategy manager will allow the long term effects of rehabilitation policies or programmes to be simulated, in terms of changes to specific performance indicators. The rehabilitation strategy manager would be applied to a network as a whole, or to specific areas or zones. That network can consist of various types of asset, such as pipes of various materials, valves, service connections, etc. The rehabilitation strategy manager is based on hard data about the network and the rehabilitation policies that can be applied. The results would be expressed as a cost for a particular rehabilitation programme at a given point in time.

The rehabilitation strategy evaluator will compare the various rehabilitation options developed by the rehabilitation strategy manager based on the scenarios created by the engineer or planner using the scenario writer. The Evaluator will incorporate a multi-criterion decision-making function which will allow the selection of the most appropriate rehabilitation strateg(ies).

The WP1 tool will have input to this rehabilitation planning option by supplying current performance indicator information as the basis for applying deterioration profiles to trend key performance measures over time.

A key output from the WP4 suite of software tools will be strategic budgets for rehabilitation scenarios applied to a pre-determined planning horizon and dataset, typically at network or sector levels.

3.2.2 Option 2: Annual Rehabilitation Planning Within Strategic Budgets

As stated earlier, the objective of this planning option is to use strategic modelling (via the strategy manager of WP4) to set global budgets. Detailed planning is then carried out to determine annual rehabilitation needs for specific zones, whilst maintaining the 'hard' constraint of the strategic budget figure.

The first part of this procedure would therefore follow that set out in Section 3.2.1 above, to determine the strategic spend profile.

Once this information has been determined the WP1 tool can be used fully to re-calculate the PIs for a particular zone. In this instance the WP1 tool would be used at its most detailed level where data allows. Typically this would be cluster of a few pipes, but more commonly, a small sector of the network, such as a District Meter Area.

Where geospatial information is available, the GIS viewer incorporated into the prototype could be used at this point to view the elements of a particular zone that would be of interest to the rehabilitation planner. PI results for the zones of interest could be displayed. Alternative selections of sub-zones could be made and a new refined dataset created such that the working dataset contains only those pipes for further analysis. Standard methods of finding and selecting geospatial entities will be used, allowing the planner to select specific elements of a zone to incorporate them into the overall rehabilitation scheme.

The user has the option to include failure forecasting and hydraulic reliability data from running WP2 tools at this stage. If he has the data available, he may also use rehabilitation direct cost and benefit analysis results to supply the annual rehabilitation planning (ARP) tool with another criterion to judge which pipe categories to rehabilitate.

With or without WP2 and/or CBA, the user may then initiate the WP3 ARP tool which will take the definition of the dataset (a network, sector or cluster of pipe identifiers), together with associated performance, utility and context information, to rank pipes in order of rehabilitation need, i.e. the priority of action (high, medium or low priority). If CBA is used, additional information could be provided on when it needs to be rehabilitated, and the rehabilitation method which should be employed.

The user must ensure that the WP3 tools will meet the specific objectives set out by the rehabilitation management framework. It is important that the user’s key drivers are included in any decision support matrix. Only then can the ARP tool in WP3 rank the pipes according to the requirements set out in the original framework.

At this stage the engineer would review the data before finalising the rehabilitation plan, possibly by comparing outputs from different tools and a number of model runs with slightly different assumptions and boundary conditions. The final rehabilitation strategy will therefore be determined using engineering knowledge and experience of the operation and performance of a particular zone.

3.2.3 Option 3: Detailed Zonal Rehabilitation Planning

This option is a refinement of Option 2 and focuses on the detailed rehabilitation planning of specific zones. One key difference is the approach to prioritising investment. Budgets are determined from the rehabilitation requirements of each zone (bottom-up). There is no initial budget capping using strategic information.

Additional information on failures, maintenance and complaints data, plus hydraulic information would be sought. These would be used to supply failure forecasting and hydraulic reliability models developed as part of WP2. These tools produce a prediction of failure rate in years to come, or a hydraulic reliability based on information gleaned from hydraulic model data.

As well as the PI results applicable to the working dataset (refer to Option 2), WP2 modelling results may be combined with additional information from the user’s experience (their *knowledge base*) plus a range of optional contextual *external information* (EI) to supply the Annual Rehab Planning MCD tool in WP3 with a wealth of detailed pipe-based information. Again, the ARP will produce a prioritised ranked list of pipes according to the points of view chosen as user preferences.

Finally, the detail of the ARP outputs may be combined with the results of a strategy-based cost-benefit analysis to allow the mix of rehabilitation schemes to be negotiated. The costs and benefits of the chosen schemes may then be summed and the rehabilitation and investment plans devised.

3.2.4 Summary

Options 1 to 3 form the core of the procedure for applying the Prototype and are based on complementary methods whose results can be compared and reviewed.

Figure 3.2 summarises the principal options and steps taken on each route, in the context of CARE-W tools and the above discussion. Options are colour-coded to assist the reader. Common routes (such as WP4 in Options 1 and 2) are shown explicitly for each option. Steps which are not unique to one option are not coloured.

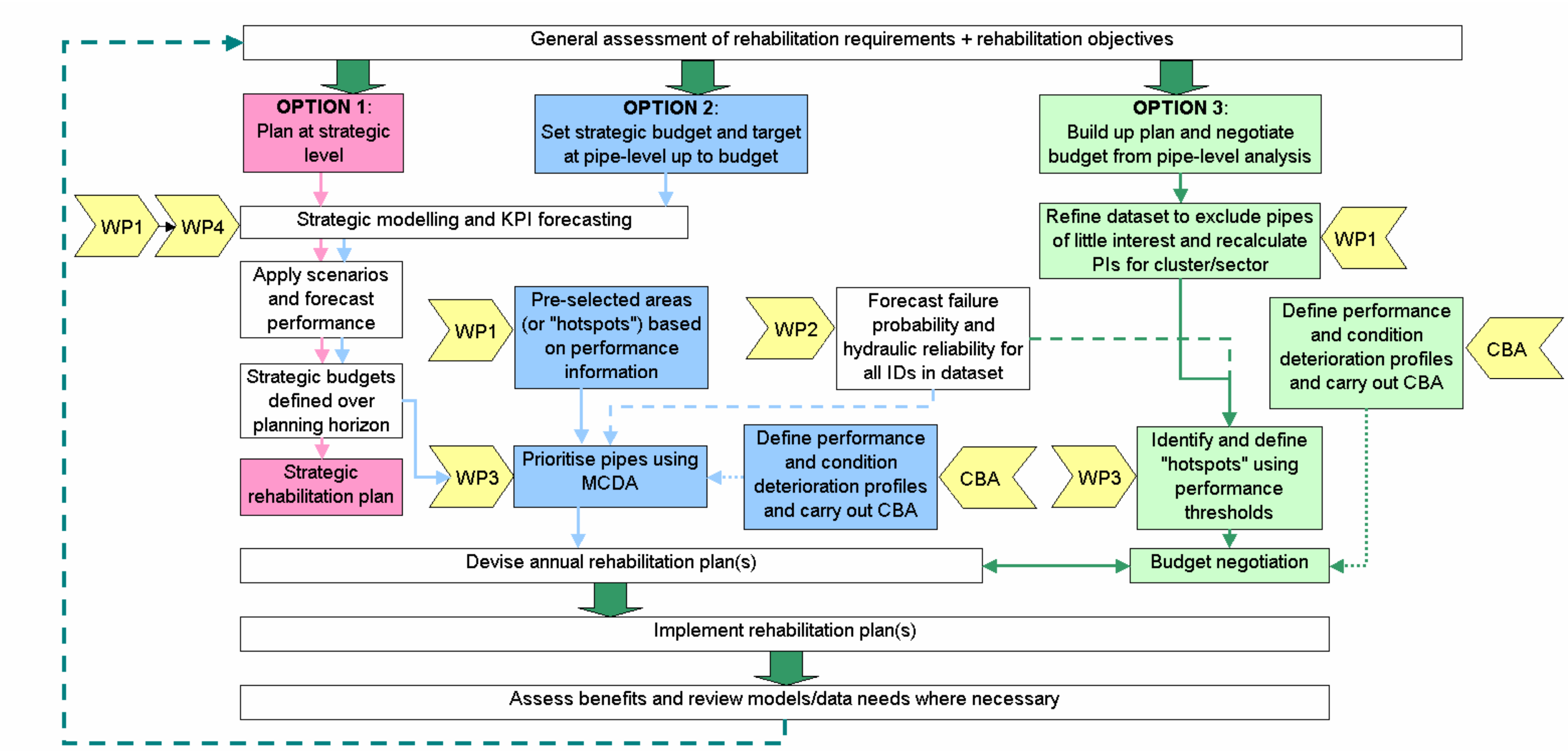

Figure 3.2 Rehabilitation planning with CARE-W tools

3.3 Limitations of the CARE-W procedure

As stated previously, the WP2 tools currently produce a prediction of failure rate in years to come, or hydraulic reliability indices based on information derived from hydraulic model data. Few other performance measures are predicted as part of WP2. This is regarded by some as a limitation in the ability to supply comprehensive, predictive, pipe-level performance data to the multi-criterion decision making (MCD) component in WP3. This is important if all major factors contributing to pipe lifetimes and service to customers are to be modelled before a decision is taken.

The gap may be partially closed by the introduction of performance forecasts in the WP4 suite of tools, and, at the pipe level, by using cost-benefit analysis tools such as WRc's Waterfowl™. Modifying Waterfowl's key assumptions to fit the assumed deterioration of different aspects of performance (such as the change over time in discoloured water complaints, or the increase in water losses as a result of deteriorating condition) would allow enhanced decision-making through application of a tried-and-tested cost-benefit analysis technique.

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