Cost analysis for decision support in water supply systems rehabilitation: method and case study

Pinto, D.T. [1] and Covas, D.I.C.[2]

[1] Master Student in Civil Engineering, Instituto Superior Técnico, Technical University of Lisbon (TULisbon), Av. Rovisco Pais, 1049-001 Lisbon, Portugal. E-mail: diogotspc@gmail.com

[2] Assistant Professor, Civil Engrg. Dept., Instituto Superior Técnico, Technical University of Lisbon (TULisbon), Av. Rovisco Pais, 1049-001 Lisbon, Portugal. E-mail: didia.covas@civil.ist.utl.pt

ABSTRACT

The present research work aims at the development and the application of an operational model of cost analysis for decision support in water supply systems (WSS) rehabilitation. Thus, a state of the art review of the main components and the main techniques of conducts and tanks rehabilitation of the WSS have been carried out. In this literary revision, some existing models of WSS cost analysis have been described (CARE-W, WLC, a model from NRC and EPAL, S.A.., as well as a methodology of risk analysis according to ISO 31000, some financial concepts (e.g., direct, indirect and external costs), and financial indicators (e.g., present value, return on investment). The cost analysis model was structured in four distinct modules: Module 1 – Cost database; Module 2 – Infrastructure value indice; Module 3 – Whole life costing; Module 4 – Cost-benefit analysis. The methodology was applied to different case studies: Module 1 was the ground for the other modules; the module 2 to a water distribution network; module 3 to a main trunk and to pumping station; module 4 to a treatment station, pumping station and trunks and service connections. The necessity of rehabilitation of water supply systems, due to degradation, is increasing in importance, which being managed by entities of public overtone, implies a well-taken care of management at financial level.

Keywords: rehabilitation, water supply system, cost analysis and operational model.

1. INTRODUCTION

In developed countries, most water supply systems have been designed and constructed decades ago and, currently, water utilities have the challenge of keeping their systems operational, efficient and reliable to supply water in quantity and quality to populations (Covas, 2006).

The ageing of water infrastructures and equipment is natural and inevitable and, as these components reach the end of their useful life, leakage levels increase, breakdowns and supply interruptions become more frequent, and maintenance costs increase. As a consequence, water utilities must face the unavoidable choices to repair, rehabilitate or replace. Questions like what, where, when and how arise (Covas, 2006).

Nowadays, the decision cannot be taken merely by economic aspects, being essential to consider other factors, namely: the improvement of the service level, the improvement of the reliability of the system, or the minimization of disturbances caused for workmanships in course. Thus, the concept of non conventional integrated approaches arises. This type of analysis considers the totality of the construction direct costs, exploration and maintenance that occur in the system throughout all its useful life or for one determined period of analysis, as well as indirect costs, social and ambient associated to the system performances, in form to satisfy the necessities, in a sustainable form, of the entity, the customer, the society and the environment.

Water utilities can have two attitudes towards rehabilitation: reactive or proactive. In the reactive attitude, the rehabilitated pipes are selected according to emergency criteria (e.g., pipes that have failed or more often repaired) and to the forecast of road works (determined by other infrastructures' needs). This approach brings about a very low rehabilitation rate and the average network condition is very likely to create financial problems involving large investment in the following years. In the proactive attitude, water utilities plan the investment after assessing the structural condition of the pipes and forecasting their degradation. This policy requires a good knowledge of pipe network characteristics and failures, available in a computerized database, such as a Geographical Information System (GIS) (Saegrov *et al*., 1999, Engelhardt *et al*., 2000, Eisenbeis *et al*., 2002)

Recently, water utilities have started to realize the importance of having a proactive rehabilitation strategy to avoid future serious financial problems and, the tendency, today, is to start to develop short and long-term investment planning. However, adopting a pro-active strategy is not a straightforward task, and it requires the support of computer based decision models. Several conceptual and operational models have been developed in universities and research centres which can be classified in two types (Eisenbeis *et al*., 2002).

The present research work aims the development of a cost analysis methodology that can be applied in water supply systems (WSS), that it serves of support to the decision in rehabilitation of the components that integrate the system. The methodology aims to be a support to the analysis of the current and future value of the infrastructure, using determined politics of rehabilitation, and will allow the comparison between different solutions of rehabilitation (i.e., possible scenarios of investment) and to rank in the time different investment priorities. A review of the state of the art in the domain of the rehabilitation, cost analysis and risk analysis in WSS has been carried out. Some relevant existing models in the scope of the WSS rehabilitation are presented (e.g., CARE-W). It is presented, also, a method of risk analysis, which must be incorporated in the cost analysis, to evaluate the uncertainties associated to the analysis. The concept of the infrastructure value index is also reviewed, as well as a characterization of the costs and the main used financial pointers in the analysis are presented. A model of costs analysis was established, which was divided in four modules: construction of the cost database; calculation of the infrastructure value index; whole life costing and cost-benefit analysis. The developed model was applied to case studies, aiming to show its capacities as tools of support to the decision in WSS. The main conclusions of the developed work, recommendations for the application of the methodology developed to other cases and recommendations for future works are presented.

2. MODELS TO DECISION SUPPORT IN WSS REHABILITATION

Model CARE-W

The model CARE-W (Computer-Aided Rehabilitation of Water networks) is a computational system to help organizations which provide water supply to decide in maintenance and expansion of the net (Alegre *et al*., 2006b).

The CARE-W Manager is the modules platform integrator and generates the database and a simplified Geographical Information System. It allows to introduce, to import, to export, to select and to manage data, to run the applications associated to each module and to represent geographically data as results.

The model CARE-W (Computer-Aided REhabilition of Water networks) has been developed as a multinational research programme aimed to develop methods to assist engineers to define and implement effective management of their water supply systems. Tests carried out with CARE-W in different water utilities have shown that some modules require a complex and time-consuming data preparation either because models require a huge amount of data (which is someway inevitable) or because data exist but information systems are not prepared to interact with CARE-W toolkit. This discourages utility engineers to use developed rehabilitation models, in particular in Portuguese water supply systems in which data do not exist, or exist but information is spread in different databases.

Model "Whole life costing"

Developed for Skipworth *et al*. (2001), cited for Alegre *et al*. (2006b), the model "Whole Life Costing (WLC)" considers, in relation to each infrastructure, the totality of the costs generated, on the part of the managing entity or indirectly on the part of the society, since the beginning of the intention of investment in the infrastructure until the o end of the respective useful life, including the deactivation costs (i.e., end of service). Using a methodology based on the costs that occur due to the different activities (Activity Based Costs - ABC), the model WLC, in the management of an infrastructure system, relates costs to the performance through amounts of reference that are main the responsible ones for these costs (cost drivers). Consonant the performance or results modifies due to an action or operation, in the same way the costs which are managed by these amounts of reference suffers modifications.

Model of the National Research Council

The model Water Mains Renewal Planner (WARP) proposed by Rajani and Kleiner (2001) is an application type, that integrates some models of analysis and forecast of ruptures in an only tool of decision support. The WARP is constituted by three modules: analysis of the standard of rupture of the trunks; short-term operational forecast (2 - 4 years); renewal plan in the long run.

Three types of factors exist that affect the rate of ruptures: the aging of the trunks associated to the corrosion and deterioration; ambient effect (e.g the temperature and ground); operational factors (e.g., rate of substitution or reinforcement of the trunks cathodic protection).

This model is a tool of decision support that includes: analyses short-term of standards of rupture in function of dependent time factors, to quantify the deterioration of the trunks on the basis of ambient and climatic factors; forecast of ruptures for the next years using imperfections in the service data; renewal plan in the long run using the rate of aging and substitution of trunks; selection of priorities to renew/to substitute trunks (Alegre *et al*., 2006b).

Model of EPAL, S.A.

The model developed to create a computational application of support to the investment strategy, has as background an analysis "Whole life costing".

In this model, the results are analyzed from the calculation of the total direct and indirect costs present value which are associated to the system. The present value is calculated without consider the inflation rate, because it is only intended to compare investments, thus is indifferent to consider or not the inflation rate. The total present value not only includes the initial investment, reinvestments throughout the analysis period and direct costs that affect directly and financially the company, as well as the indirect, social and environmental costs. The results of the model are presented through the comparison of the present value gotten for the investment scenario with the corresponding present value of to the scenario *statu quo* (not investment).

3. METODOLOGY PROPOSED TO COST ANALYSIS

The present chapter has as objective the presentation of the methodology to follow in the implementation of the analysis tool costs developed in the scope of the Project AWARE-P. The project AWARE-P aims at the development of a computational application of support to the infrastructure rehabilitation of water supply systems and residual water draining systems constituted by different components, namely: "Data Management"; "Performance Assessment"; "Cost Assessment"; "Risk Assessment"; "Planning"; among others complementary tools. The project is developed in partnership of inquiry between a research team (IST, LNEC, SINTEF and Ydreams) and water related entities (AGS, Veolia, AdP services, SMAS O&A).

The tool of "Cost Assessment" was structuralized in four distinct modules, as it is presented in Figure 3.1.

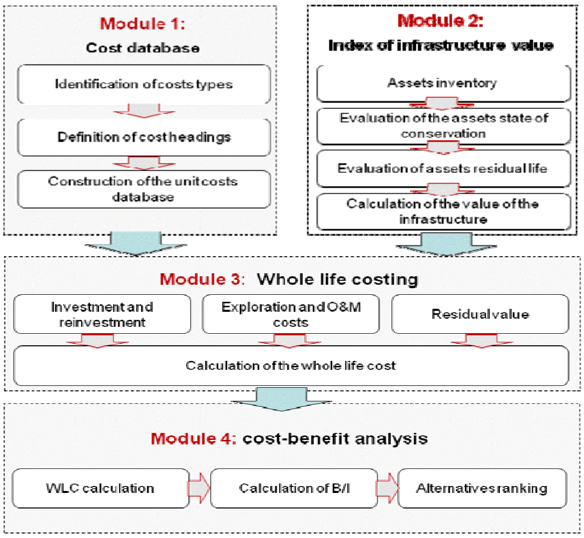

Figure 3.1 – Structure of the Cost Assessment module

Module 1 – Cost Database

To facilitate the calculation of inherent costs of the system for a given observation period, the elaboration of a database that relates the components of the system, the unitary costs (cost headings) and influencing factors (e.g., inflation rate), and the respective amounts of reference (cost drivers) is a precious aid.

The gathering, organization and posterior access to information referring to the WSS are essential for an efficient and realistic cost analysis. Thus, looking to organize the information by dividing it into categories of variables, listed as followed: Physical Asset; Environmental; Operational; Demographic and Consumers; Service Quality; Economical-Financial; Temporal.

The variables were divided by the previous referred categories, which have developed lists of variables with associated information. An example of the list of variables for the category "Service Quality" is presented in Figure 3.2. This list was based on the variables obtained from the Project of EPAL (Alegre *et al.*, 2006b).

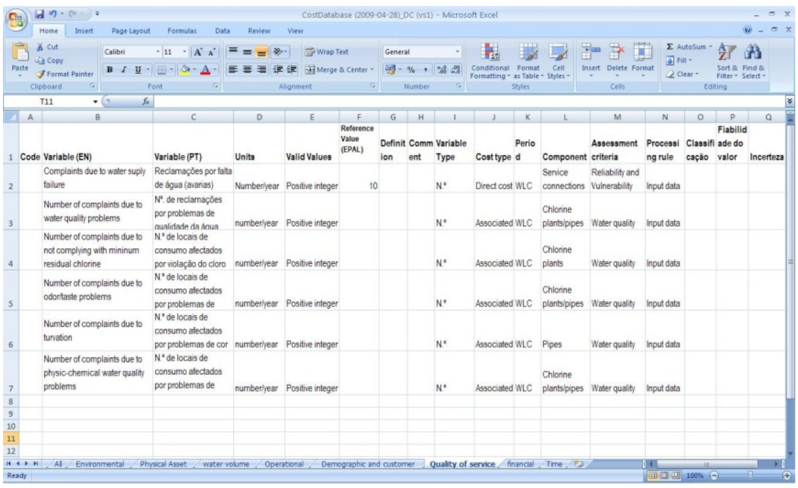

Figure 3.2- Example of Excel ™ database

Afterwards cost headings were divided by type of costs in the operator's perspective, namely direct, indirect and external costs.

Module 2 – Infrastructure value evaluation

The purpose of the infrastructure value evaluation is to elaborate a diagnosis of infrastructure condition, its location and its state of conservation, allowing to estimate the residual useful life and to evaluate its economic value. This diagnosis is essential to know the needs and establish priorities of intervention (Alegre, 2007).

This indice takes the value of 0,5 in infrastructures stabilized where the rehabilitation politics is adjusted. Values below of 0,5 indicate insufficient investment, and on the other hand values above of 0,5 indicate an over investment.

The methodology proposal by Alegre (2007) is presented in Figure 3.3.

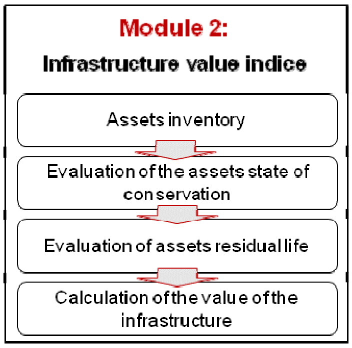

Figure 3.3 – Infrastructure value indice

Module 3 – Whole life costing

The Whole Life Costing (WLC) is an important tool for infrastructure management, which is used extensively to support project level decisions, and is being increasingly applied to enhance network level analysis (Ugarelli, 2009).

The main steps to implement the WLC method are presented in Figure 3.4.

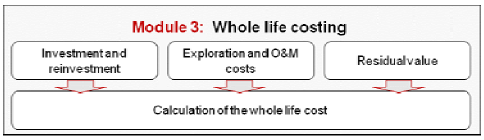

Figure 3.4 – WLC method

Module 4 – Cost-benefit analysis

The purpose of cost-benefit analysis is to compare investment scenarios for equal components or in order to compare investments of various natures, thus prioritizing them. This analysis is fundamental for determining if an investment is cost-effective, while comparing different scenarios for the same components, as well as ranking investments, by the Benefit-Investment ratio, by comparison with different component substitution scenarios. The method used in this analysis is presented in Figure 3.5.

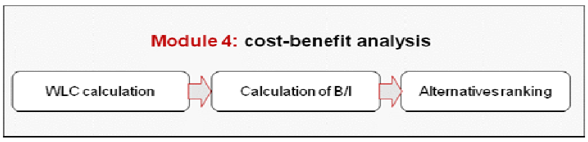

Figure 3.5 – Method of the cost-benefit analysis

4. CASE STUDY APPLICATIONS

The present chapter illustrates certain concepts previously cited in the methodology (*e.g.,* the IVI), and applies the cost analysis based on real case studies.

<u>IVI</u>

The evolution of the IVI (Module 2) is presented in Figure 4.1 in a sector of a water supply network using different rehabilitation policies. This sector was studied by Jacob (2006), evaluating water losses, designated by ZMC 320 around 2006.

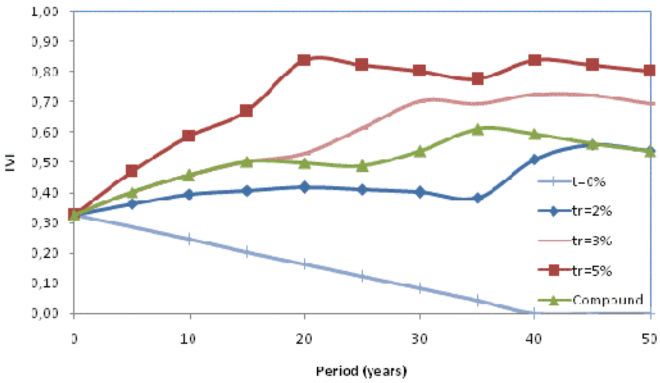

Figure 4.1 - Evolution of the index value of the infrastructure for different rehabilitation rates

<u>WLC</u>

An analysis through the lifecycle of two water supply systems components has been carried out, namely “main trunk” and “pumping station”, presented by Harlow (2005). The “main trunk” example shows how important is to include the risk in such analysis, and the “pumping station” case study shows the influence of the observation period and indicates the appropriated time to invest.

The case study “main trunk” present to different approaches – including only the direct costs of O&M (Approach 1) and other that includes also the risk (Approach 2), and the synthesis of costs associated to the statu quo and investment scenarios are presented in Table 4.1(Approach 1) and

Table 4.2 (Approach 2).

Table 4.1– “Pumping station”: synthesis of costs associated to the *statu quo* and investment scenarios in 2009 – Approach 1

Scenario	Risk	Risk associated cost	Investment
Statu quo	Failures due to the exposal to thermal variations	400.000 €/year • O&M costs	0 €
Investment	Unaccountable	Unaccountable	10 400 000 €

Table 4.2– "Pumping station": synthesis of costs associated to the *statu quo* and investment scenarios – Approach 2

Scenario	Risco	Custo associado ao risco	Investiment
Statu quo	Failures due to the exposal to thermal variations	400 000 €/year • O&M costs	0 €
	Failures due to flood occurrence	600 000 €/year • Water transport cost in trucks • Consumers disturbance costs • Industrial prodution failure costs • Others O&M costs	
Investimento	Unaccountable	Unaccountable	10 400 000 €

Based on the financial indicator "Return on Investment" (ROI), the case study results are presented in Figure 4.2.

(a) (b)

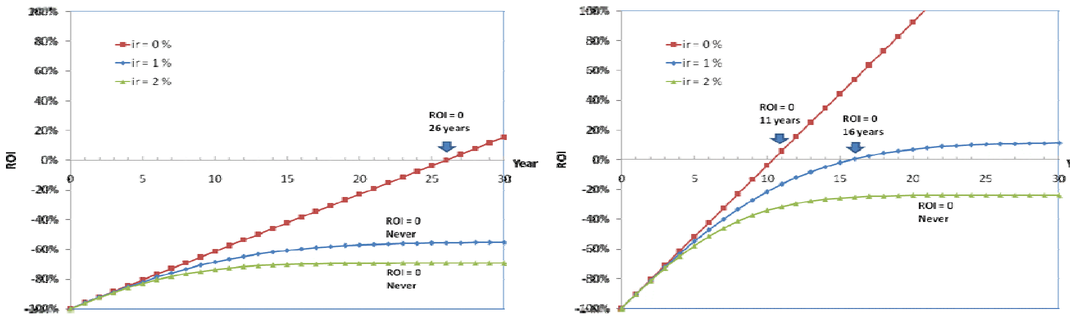

Figure 4.2 – Case study "Main trunk": evolution of the return on the investment (ROI); (a) Approach 1, (b) Approach 2

To better understand this case study, the synthesis of costs associated to the *statu quo* and investment scenarios in 2009 are presented in Table 4.3.

Table 4.3– "Pumping station": synthesis of costs associated to the *statu quo* and investment scenarios in 2009

Scenario	Risk	Risk associated cost	Investment in 2009
Statu quo	Low importance failures	4 000 €/year, at an annual interest rate of 3,5%	0 €
	Pump station failure, with normal distribution of probability: • Centered Average in 2015; • Standard deviation of 3 years; • Curve area = 1; • $CI_{95\%}$ between 2009 e 2021.	175 000 €	
Investment	Low importance failures	2.500 €/year, increasing at an 2% rate	220 000 €
	Pump station failure, with normal distribution of probability: • Centered Average in 2034; • Standard deviation of 3 years; • Curve area = 1; • $CI_{95\%}$ between 2028 e 2040.	175 000 €	

The financial indicator used in the "pumping station" case study was the total costs present value (PV), which allows comparing the scenario *statu quo* with the investment scenario. The comparison was carried through the years, considering that the costs of the investment scenario were constant over the years and calculating the costs of the scenario *statu quo*. The investment is cost-effective since the scenario *statu quo* costs exceed the investment scenario costs. The results are presented in **Figure 4.3**.

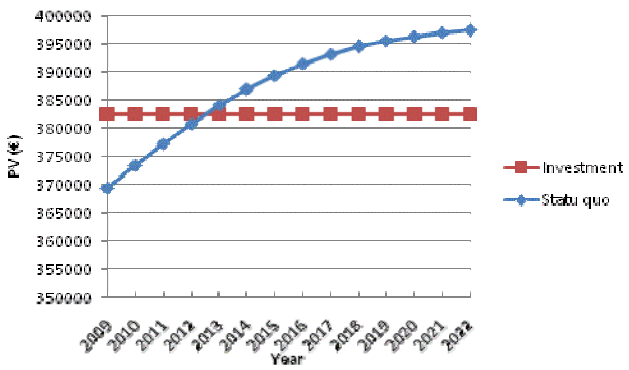

Figure 4.3 – Evolution of scenarios total costs present value

<u>Cost-benefit analysis</u>

The scope of this section is to establish priorities of three different investment scenarios, which aim the rehabilitation of different components – "trunks and service connections", "treatment station" and "pumping station" (Ferreira *et al*., 2006, Alegre *et al.*, 2006a, b) – based on a WLC analysis. The benefit of each investment is calculated by comparing the costs of the scenario *statu quo* and the investment scenario costs. The relative benefits of the case studies are presented in Figure 4.4, with an interest rate of 5%.

(a) (b) (c)

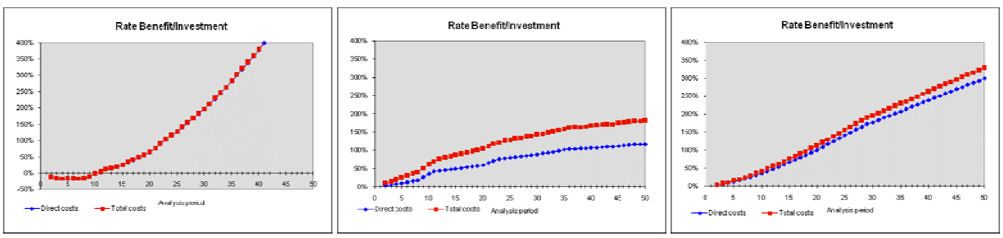

Figure 4.4 - Rate Benefit/Investment in the observation period of 2 up to 50 years, of the case study: (a) treatment station, (b) pumping station and (c) trunks and service connections

Case studies conclusions

The analysis allowed concluding that the IVI are a useful tool in the analysis of the infrastructure state of conservation, when calculated referring to the year of the analysis, being the advised state of conservation, in structures where the rehabilitation program is implemented and stabilized, traduced by an IVI value close to 0.5. In this case study the rehabilitation rate of 2% or the case of the compound solution was recommended, but the 2% rehabilitation rate has a lower total costs present value.

In WLC analysis, the importance of including the risk, an appropriate observation period and interest rate influence were enhanced. This type of analysis allows to estimate de costs in a given observation period, which can be used in the calculation of financial indicators (*e.g.,* ROI), making possible verifying the cost-effectiveness of the investment and the appropriate instant to do so.

The benefit-investment rate prioritizes the alternatives of investment, being the best and most cost-effective investment scenario with the highest rate value.

5. CONCLUSIONS AND RECOMMENDATIONS

The necessity of rehabilitation of water supply systems, due to degradation, is increasing in importance, which being managed by entities of public overtone, implies a well-taken care of management at financial level.

The generated model needs gathering and organization of information to a cost analysis, by constructing a database, in order to access this same information easily.

Based on the IVI concept, it's possible to estimate the state of conservation of the analyzed infrastructure, as well as predict if the rehabilitation policies are arguable.

The costs related to a specific infrastructure can be estimated by a WLC analysis, which were the grounds of the cost-benefit analysis predicted in the developed model that provide decision support to a suitable rehabilitation policy.

6. REFERENCES

Alegre, H., (2007). *"Gestão patrimonial de infra-estruturas de abastecimento de água e de drenagem e tratamento de águas residuais."* Programa de investigação e programa de pós-graduação apresentados para a obtenção do título de *"Habilitado para o Exercício de Funções de Coordenação de Investigação Científica"*, LNEC, ISBN, (385 p.).

Alegre, H., Covas, D., Duarte, P., Monteiro, A. J. (2006a). Aplicação computacional, desenvolvida em Excel, para a análise da "*Estratégia de Investimento na Rede de Distribuição de Água de Lisboa."* LNEC, Lisboa, Portugal.

Alegre, H., Duarte, P., Monteiro, A. J., Covas, D., Ferreira, A. B., Melo, L., Luís, A. A., Carvalho, A., Sereno, J. (2006b). *"Apoio à EPAL no Estabelecimento de uma Estratégia de Investimento na Rede de Distribuição de Lisboa - Modelo Conceptual e Aplicação a Três Casos de Estudo - Relatório Final."* LNEC, Lisboa, Portugal.

Covas, D. (2006). *"Rehabilitation of water distribution infrastructures."* FCT

Eisenbeis, P., Le Gauffre, P., Saegrov, S. (2002). *"Chapter 5 - Water Infrastructures Management: an Overview of European Models and Databases."* Assessing the Future: Water Utility Infrastructure Management. AWWA Trends in Water Series , David M.Hugges, ed., AWWA, Denver CO, USA, pp. 61-80.

Engelhardt, M. O., Skipworth, P. J., Savic, D. A., Saul, A. J., Walters, G. A. (2000). *"Rehabilitation strategies for water distribution networks: a literature review with a UK perspective."* Urban Water, 2, 153-170.

Ferreira, A. B., Melo, L., Luís, A. A., Carvalho, A., Silva, A. R., Sereno, J., Alegre, H., Coelho, S. T., Duarte, P., Loureiro, D., Monteiro, A. J., Ramos, H., Covas, D. (2006). *"Apoio à EPAL no Estabelecimento de uma Estratégia de Investimento na Rede de Distribuição de Lisboa - Relatório das Actividades A1 e A2."* LNEC, Lisboa, Portugal.

Harlow, V. (2005). *"Risky business: two case studies in asset risk management."* Water Asset Management International, Março, 2005. Artigo WAMI

ISO 31000, *"Risk management - Guidelines on principles and implementation of risk management."* (Committee draft, 2007)

Jacob, A. C. (2006) "*Avaliação de perdas em sistemas de abastecimento de água: o caso de estudo da ZMC 320 da EPAL."* Universidade Técnica de Lisboa, IST, ISBN, Lisboa (229 p.).

Rajani, B. B. e Kleiner, Y. (2001). *"WARP - water mains renewal planner."* International Conference on Underground Infrastructure Research - UIR 2001 (Waterloo, Ontario, Jun, 2001), pp. 1-5, (NRCC-44680) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc44680/nrcc44680.pdf.

Saegrov, S., Baptista, J.M., Conroy, P., Herz,R.K., Le Gauffre,P., Moss,G., Oddevald,J.E., Rajani,B., Schiatti, M. (1999). *"Rehab. of water networks. Survey of research need and on-going efforts."* Urban Water, 1, 15-22.

Skipworth, P., Engelhardt, M., Cashman, A., Savic, D., Saul, A., and Walters, G. (2001). *“Whole life costing for water distribution network management”*, Thomas Telford Ltd.

Ugarelli, R. (2009). “Asset management of wastewater networks”. Dottorato di ricerca Ingegneria Idraulica: Scienze e Tecnologie dell’acqua. Alma mater studiorum, Universita’ di Bologna.