Condition Assessment of Water Services Infrastructure and the Determination of the Remaining Operational Life

Report to the
Water Research Commission

by

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This report has supplementary information that is available on the WRC website only. Please see page A-1 at the back for more on these.

Executive Summary

The management of physical assets involves a wide scope and range of processes and skills, including the initial acquisition, implementation, control of the use of the infrastructure, maintenance and the disposal of the assets in a manner that satisfies the constraints imposed by business performance, environment, ergonomics, and sustainability requirements. The WRC has identified the need for the development of guidelines for the assessment of water services infrastructure.

The focus of this research is on condition assessment of the water services infrastructure components and the development of a procedure to determine the remaining operational life (ROL) of these components. The research does not contain any detail of a prescribed protocol of how condition assessment for the different system components should be conducted.

The methodology included the review of existing operational information to gain insight into the procedures followed to conduct asset management and to relate the operational experience to the remaining useful life by formulating a relationship between the status and remaining life. The lack of obtaining sufficient data to be representative enough to define a relationship between the operational experiences and the remaining useful life necessitated the development of a conceptual model to calculate the remaining operational (useful) life of different water infrastructure components.

The aspects which were addressed in this research include:

- Data requirements to define the water infrastructure components;
- Conceptual model between performance and life expectancy;
- Applicable non-destructive techniques for condition assessment of water transfer infrastructure;
- Description of the economic evaluation techniques to compare replacement or refurbishment;
- Development of software (spreadsheet) to determine the remaining useful economic life.

The procedures developed in this research to determine the remaining operational (useful) life of different water infrastructure elements were included in a software package which supports the contents of this report. The software includes a number of key parameters which influences the expected remaining life.

Reference to obtain the associated supporting material and the software from the WRC website, is provided in **Appendix A**.

Acknowledgements

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The Reference group made important contributions and provides direction and support to the Project team for this project.

The patience, support and guidance of the Chairman and Manager of this study, Mr Jay Bhagwan, as well as the supporting staff of the WRC are greatly appreciated.

The Reference Group and Project Team responsible for this study consisted of the following persons:

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The contribution of Me Theresa Loggenberg a final year student from the University of Pretoria is acknowledged.

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1 Introduction to condition assessment of water services infrastructure

1.1 Background

The management of physical assets involves a wide scope and range of processes and skills, including the initial acquisition, implementation, control of the use, maintenance and the disposal of the assets in a manner that satisfies the constraints imposed by business performance, environment, ergonomics, and sustainability requirements.

The focus of this research is on condition assessment of the water services infrastructure components and the development of a procedure to determine the remaining operational life (ROL) of these components. The research does not contain any detail of a prescribed protocol of how condition assessment for the different system components should be conducted.

An effort was made to integrate engineering principles with sound business practice and economic rationale to develop some guidelines for condition assessment of water and sanitation services infrastructure. Non-destructive testing technologies available to define the condition of assets are referenced.

The major obstacles experienced during the research, could be summarised as follows:

- Lack of response and feedback from authorities on the history of asset breakdowns and repair frequencies;
- Unavailability of information or a database for the direct relationship between excepted functional remaining live and status description of water infrastructure components; and
- Apparent lack of a confined procedure on assessment management.

The following aspects were reviewed and are discussed in this report:

- Data requirements to define the water infrastructure components;
- Conceptual model between performance and life expectancy;
- Applicable non-destructive techniques for condition assessment of water transfer infrastructure;
- Description of the economic evaluation techniques to compare replacement or refurbishment; and
- Development of software (spreadsheet) to determine the remaining useful economic life.

1.2 Layout of this report

This report contains the following chapters:

Chapter 1: Introduction to condition assessment of water services infrastructure

Chapter 2: Identification and Description of the Data Requirements to Define the Water Infrastructure Components as defined in the relevant Regulatory Framework

Chapter 3: Conceptual model to relate performance and life expectancy

Chapter 4: Non-destructive techniques for condition assessment

Chapter 5: Economic evaluation techniques to compare the replacement and refurbishment cost for infrastructure and appropriate aids for the costing of these alternatives

Chapter 6: Estimation of the remaining life of infrastructure components

Chapter 7: References

APPENDIX A provides details of the supporting material and the software which can be downloaded from the WRC website.

2 Identification and Description of the Data Requirements to Define the Water Infrastructure Components as defined in the relevant Regulatory Framework

2.1 Introduction to Regulatory Framework

Against the background of exiting legislation, the infrastructure components which have to be reviewed are discussed in this chapter.

It is intended to provide a summarized review of relevant regulations, including standards, which may be applicable in order to identify and define data requirements for condition assessment of water infrastructure. Although the focus is on South African Regulations relevant to water infrastructure, the scope of the review shall, in general, also refer to international standards applicable to condition monitoring and technical risk assessment of engineered assets that constitute to the built environment.

In a “Final Draft” report, titled “Guidelines for Infrastructure Asset Management in Local Government, 2006-2009” published by the Department of Provincial and Local Government, Republic of South Africa, it is indicated that an Infrastructure Asset Management Plan (IAMP) be prepared for each of the sectors and that the IAMPs be used as input to the Comprehensive Municipal Infrastructure Plan (CMIP). The CMIP, which provides the capital works programme for new, upgrading and replacement and the operational and maintenance strategies, feeds into the Integrated Development Plan (IDP).

Reference is made to the “International Infrastructure Management Manual” (IIMM) which is recognized by the Word Bank as applicable to the management of municipal infrastructure practice. The IIMM was developed in New Zealand and Australia (The NAMS Group, 2006).

The document further describes the applicable legislation, standards, norms and accounting procedures to be applied when infrastructure asset management is reviewed. **Table 2-1** reflects the proposed responsibilities of the Municipalities and provides a time frame for the implementation of the IAMPs.

Table 2-1: Responsibilities of Municipalities and a timeframe for the implementation of asset management

Element of asset management	Requirement	Tips
IAM Policy	Council to adopt within 2 years	Commit to an implementation approach that is in line with the capacity of the Municipality
IAM Strategy	Optional as a separate document.	Do this once the IAM practices are mature.
IAMPs	IAMP for all sectors adapted by Council within a year (or IAMP scope covered in sector plan e.g. WSDP). Update each at least every 2 years.	Try one IAMP first, then expand to other sectors.
CMIP	First CMIP adopted by Council within 2 years. CMIPs summarise key information and strategic issues across all sectors (consistent with information indicated in the sector IAMPs). Update annually.	All the IAMPs need to be completed first, even at a high level. CMIP needs to be brief and in a format that is understandable to non-technical people.

The document (DPLG, 2009) contains a pro-forma table of contents for the IAM Plan and defines the level of details to be included. It provides a schedule (tasks and time allocation) for the implementation of these CMIPs. A key input driver remains sound data of the status of the infrastructure. **Figure 2-1** shows a simplified flow diagram of the process to establish an infrastructure asset register.

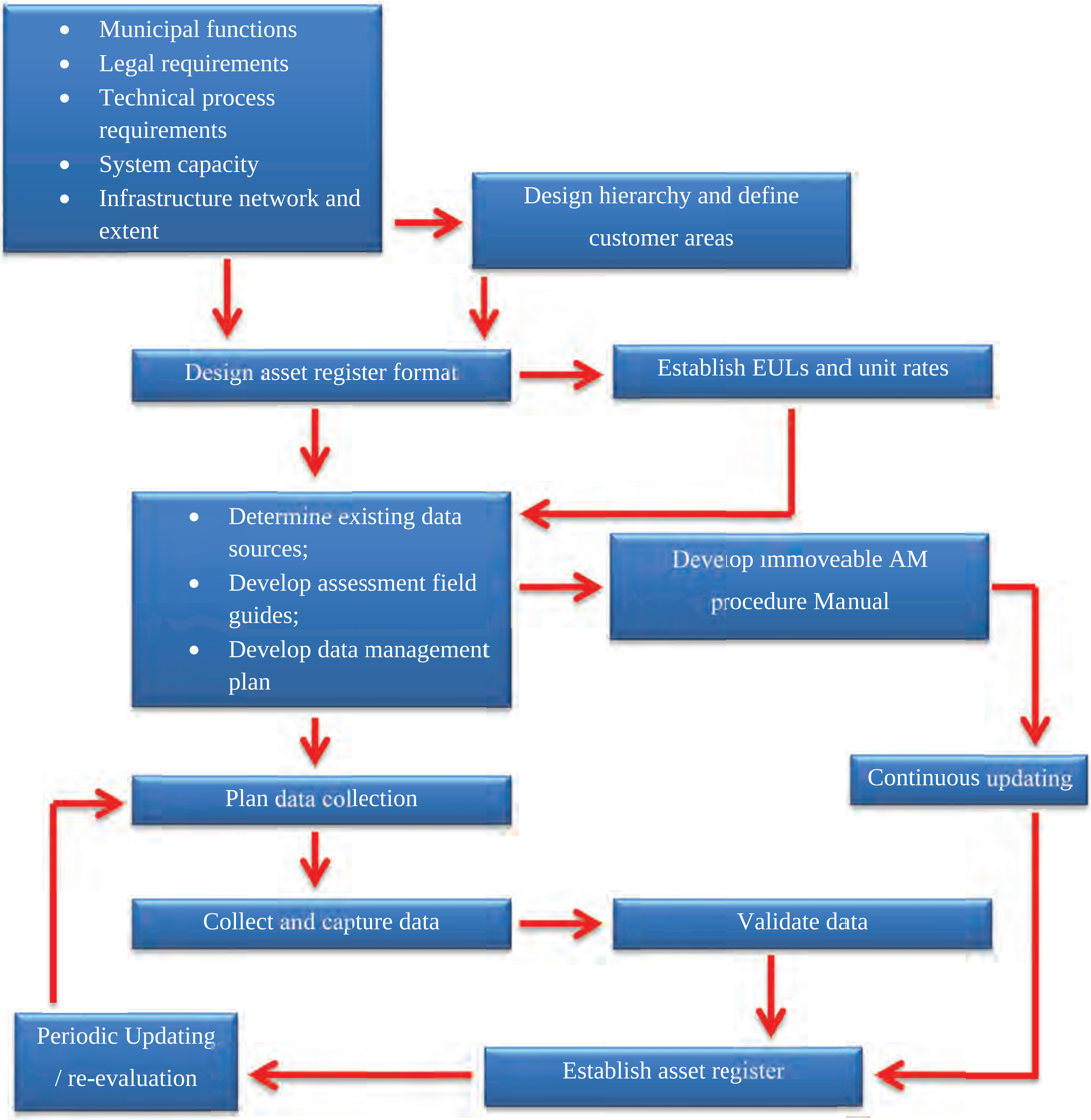

Figure 2-1: Simplified flow diagram of the process to establish an infrastructure asset register

Lastly a Toolkit is described to assist in the implementation of IAM with a description of the standards and criteria (DPLG, 2009) as well as the level of service. It is uncertain what the level of "buy-in" and rollout of the suggested implementation of the prescriptions of the Report (DPLG, 2009) is. The suggestion that the implementation should be in line with the capacity within the municipality will, with respect, delay the implementation of Asset Management on a Local and National level and will reduce commitment for the full implementation of asset management and reduce the urge for full responsibility.

A copy of this Draft Report titled: "Guidelines for Infrastructure Asset Management in Local Government" (DPLG, 2009) is referenced in **Appendix A**.

Complementary WRC projects that may, in some ways, inform on experiences (if any), or provide any relevant history related to condition assessment of water infrastructure within the South African context are reviewed. This chapter provides a preliminary impression of the application of the South African Regulations by authorities and operators of water services infrastructure. Based on the aforementioned reviews and preliminary impressions, an initial framework for the identification of data requirements that may be useful in support of the South African Regulations is proposed.

2.2 Review of Relevant Regulations and Applicable Standards

2.2.1 Overview within the South African regulatory context

The following relevant legislation is applicable to asset management:

- National Water Act No. 36 of 1998;
- Water Services Act No. 108 of 1997;
- Municipal Structures Act No 117 of 1998;
- Public Finance Management Act Nos. 1 and 29 of 1999;
- Municipal Finance Management Act No. 56 of 2003; and
- Government Immovable Asset Management Act No.19 of 2007

The following applicable references and standards have been identified:

- RSA National Treasury Asset Management Practical Guide 2003 and Guideline 2004;
- RSA National Treasury Asset Management Framework 2004;
- British Standards Institution Publicly Available Specification 55 (BSI PAS 55); and
- International Infrastructure Management Manual 2006, IMESA RSA edition.

The review of applicable standards indicates established and emerging international standards such as:

- International Electrotechnical Commission, (IEC) Dependability Series;
- International Standards Organisation, (ISO) Condition Monitoring Standards; and
- Australian and New Zealand Risk Management Standard AS/NZS 4360:2004.

The relevant South African regulatory framework with regard to the identification of data requirements for condition assessment of water infrastructure is summarized below. In general, none of the legislative regulations is specific about identifying data requirements for water infrastructure assets but, from the high level obligations, it can be deduced that this is implied anyway.

2.2.2 National Water Act No. 36 of 1998 (abbreviated as NWA)

Chapter 11, Section 109 of the NWA focuses on the requirement for environmental impact assessment with regard to "acquisition, construction, alteration, repair, operation and control of government water works". Section 116 of the same chapter mentions "safety and security" as well as "cost of protecting and controlling", whereas, Chapter 12

> *"… contains measures aimed at improving the safety of new and existing dams with a safety risk so as to reduce the potential for harm to the public, damage to property or to resource quality. To reduce the risk of a dam failure, control measures require an owner to comply with certain directives and regulations, such as to submit a report on the safety of a dam, to repair or alter a dam, or to appoint an approved professional person to undertake these tasks. These measures are in addition to the owners' common law responsibility to ensure the safety of their dams. An approved professional person has a statutory duty of care towards the State and the general public and must fulfil, amongst other things, defined responsibilities when acting under this Chapter. Not all dams are subject to regulation under this Chapter, and the Minister may exempt certain persons from its requirements. Only dams of a defined size, dams which have been declared to be dams with a safety risk, or dams falling into a prescribed category are affected. All dams with a safety risk must be registered. Compliance with any directive or regulation under this Chapter does not exempt an owner from complying with any other provision of this Act, such as the requirement for a licence or other authorisation for water use in respect of the dam."*

Although this is not explicitly stated, there is clearly an implied indication from Chapter 12, Section 120, paragraphs 3 (a) and (b), of the obligation to conduct condition assessment. The valid assumption here is that there is the more specific need to obtain data that describes both the safety condition of a dam and the risk of dam failure. The obligation for "monitoring, recording, assessing and disseminating information on water resources" as stipulated in Chapter 14 supports this assumption, albeit that the

> *"purpose of the national monitoring systems will be to facilitate the continued and co-ordinated monitoring of various aspects of water resources by collecting relevant information*

and data, through established procedures and mechanisms, from a variety of sources including organs of state, water management institutions and water users."

2.2.3 Water Services Act No. 108 of 1997 (abbreviated as WSA)

The obligation for "*monitoring, recording, assessing and disseminating information…*" is further amplified in the preamble of the WSA where one of the aims is "*…to provide for the gathering of information in a national information system and the distribution of that information…*" even though this is again not specific to condition assessment of water infrastructure assets.

2.2.4 Municipal Structures Act No 117 of 1998 (abbreviated as MSA)

Except for the customary function of municipalities in the provision of water services and operation of associated infrastructure, the MSA does not really stipulate obligations regarding the identification of data requirements for condition assessment of water infrastructure assets.

2.2.5 Public Finance Management Act Nos. 1 and 29 of 1999 (abbreviated as PFMA)

The PFMA "*promotes the objective of good financial management in order to maximize service delivery through the effective and efficient use of the limited resources*". A key PFMA objective is ensuring the timely provision of quality information to enable public sector managers to be held more accountable. This objective, in a sense, does resolve down to the identification of data for condition assessment of public water infrastructure assets.

2.2.6 Municipal Finance Management Act No. 56 of 2003 (abbreviated as MFMA)

In a manner similar to the PFMA, the MFMA also places emphasis on "*strategic approach to budgeting and financial management*" which, in the case of water infrastructure assets owned or operated by the municipality, will require information regarding the condition of such assets, especially for acquisition, operations and maintenance, replacement, renewal, and disposal planning purposes.

2.2.7 Government Immovable Asset Management Act No 19 of 2007 (abbreviated as GIAMA)

A key objective of GIAMA is "…to optimize the cost of service delivery by ensuring accountability for

- *capital and recurrent works;*
- *the acquisition, reuse and disposal of an immovable asset; and*
- *the maintenance of existing immovable assets."*

Clearly, such an objective may not be completely realized without the identification of data requirements for condition assessment of water infrastructure assets in the public domain.

2.2.8 RSA National Treasury Asset Management Practical Guide 2003 and Guideline 2004

The Guide and Guideline both provide information to assist public departments in the journey towards asset management to satisfy the requirements of PFMA and its 'derivates' MFMA and GIAMA. Section 3.3 of the Guide states that:

> *"PFMA Section 38 places the responsibility on the accounting officer for financial and risk management of the entity as well as the effective and efficient use of the resources thereof. The section further specifically tasks the accounting officer with the management, including the safeguarding and maintenance, of assets, and the management of liabilities".*

As may be extrapolated from **Figure 2-2**, there is clearly a 'legal' requirement to indicate the condition, useful life and residual value of the asset under the 'Performance' and 'Disposal' data sections.

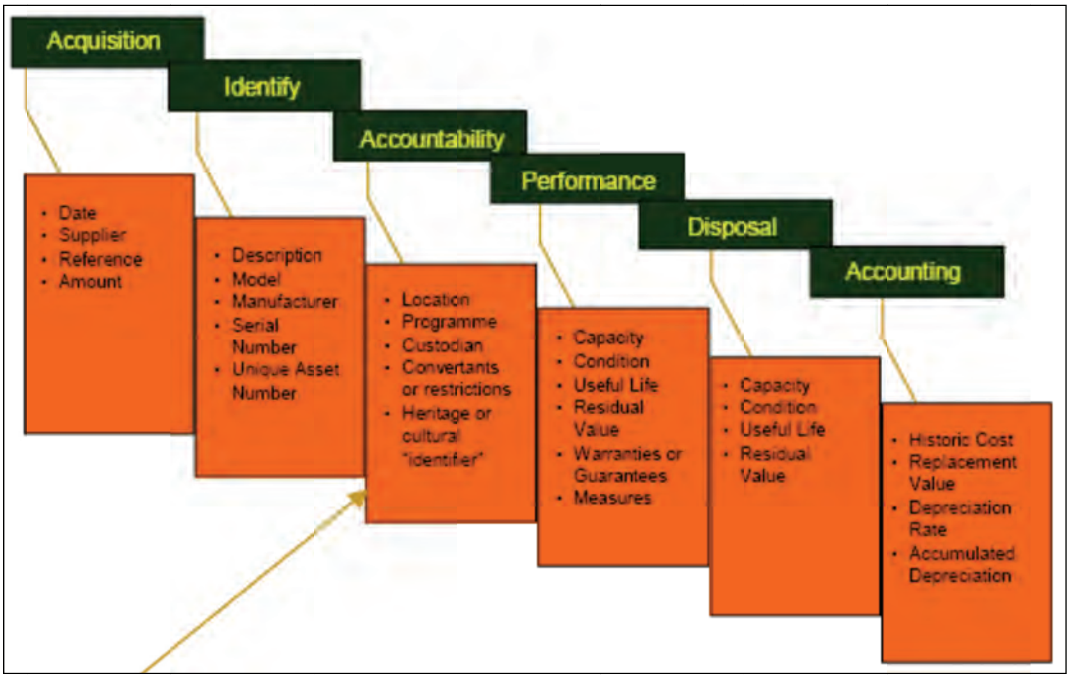

Figure 2-2: RSA NT Guide Asset Register Data Requirements

2.2.9 Other Standards

The BSI PAS 55 and the IIMM 'standards' more or less focus on the process for setting up asset management systems, and thus have ramifications for identifying data requirements for assets anyway. Detailed engineering data are typically specified in the various technical standards such as the IEC Dependability and ISO Condition Monitoring Series, as well as in technical risk management references. Some of the engineering data requirements from these technical references inform our proposed framework in Section 5 of this report.

2.3 Overview of Complementary WRC Projects

In this paragraph, some WRC sponsored projects that may inform the identification of data requirements for water infrastructure are briefly referenced.

2.3.1 WRC K5/1785 – Review of Technology Used in Strategic Asset Management: Existing and Future Needs

This study primarily investigated technologies available to water utilities that can be used to determine the condition of assets. Whilst observing that visual inspection was the most widely condition and risk assessment activity by water utility operators, the report remarks that:

"There are no standardized guidelines containing detailed descriptions for various asset types and that specify the available condition assessment technologies. Typical data collected during visual inspection includes the location, size, nature and value of the asset whilst no information is gathered that would give an indication of their reliability and current or future maintenance requirements".

The report also states that:

"The legislative drive for all assets is to be reflected in the balance sheets of municipalities, as well as public attention placed on asset management due to service delivery failures, are putting additional pressure on water utilities to collect more sophisticated data on their assets. This drive for more sophisticated data is expected to lead to an increased demand for condition assessment technologies".

The report also makes several recommendations which include that:

- Guidelines on the data that should be collected for the various types of assets should be developed.
- Condition indices should be developed that provide a standard point of reference across different water utilities.
- The number of different condition assessment technologies available makes setting minimum standards for condition assessments and reporting necessary to ensure that vendors have less influence and that data is comparable between utilities.

Therefore, this K5/1950 project follows-on from the recommendations cited in the K5/1785 report.

2.3.2 WRC 897/1/01 – Improved Management of Assets in the Water Supply and Sanitation Industry

The report re-iterates that *"…to maximize the productivity of water services infrastructure assets, a sound understanding of the condition and performance of these assets is needed by those who own or administer them"*. The report emphasized the need for an asset register that *"records a basic set of information that is the same for every asset"*, and that it is *"necessary to measure and record the condition of each asset"*. The report suggests that the condition or structural integrity of the asset and its level of risk (measured as the product of cost and probability) should be *"recorded by means of a simple ranking system"*, for example, from the New Zealand IIMM (1996) (**Table 2-2**).

Table 2-2: WRC 897/1/01 suggested infrastructure ranking system

Rank	Description of Condition from a Maintenance Viewpoint
0	Asset is absent or no longer exists
1	Excellent condition – Only normal maintenance required
2	Minor defects only – Minor maintenance required (5%)
3	Backlog maintenance required – Significant maintenance required (10-20%)
4	Requires major renewal – Significant renewal/upgrade required (20-40%)
5	Asset unserviceable – over 50% of asset requires replacement

Among others, the report also cited as key issues (i) *"shortage of tests for monitoring asset condition"* and, (ii) *"limited know-how on methods of evaluating the condition and performance of the assets"*.

2.3.3 WRC Report No TT 375/08 – Guideline for the Inspection of Waste Water Treatment Works

From the viewpoint of unit operations, this report includes "checklists for *primary*, *comprehensive* and *quarterly* inspections" of Waste Water Treatment Works. Although the checklists include a section on maintenance, however, these inspection instructions fall short on specifying what condition data should be collected to validate structural integrity of an infrastructure asset. For instance, the report states that the *comprehensive* checklist should be applied *"…when a WWTW has failed the primary assessment, i.e., all aspects have failed or certain parts of the WWTW have serious failures. The checklist will aid in the identification of the problems and will help to make improvements..."* The argument here is that a failure is a terminal condition which should be avoided.

2.3.4 WRC K5/1700 – A Toolkit to Measure Sociological, Economic, Technical and Health Impacts and Benefits of 10 years of Water Supply and Sanitation Interventions in South Africa

"A unique outcome of the study is a WATER SUPPLY SYSTEM MONITORING TOOL, which will assist water supply service authorities and providers to assess the performance of small water supply systems in their respective constituencies".

2.3.5 WRC K5/1983 – Guidelines on Determining the Vulnerability and Risks of Water Services Infrastructure

This concurrent project "…aims to establish a methodology to manage the vulnerability and risks of water services infrastructure (design, operation and maintenance) and the means by which water services authorities are better able to manage these. It is envisioned that this will include both development of best practice guidelines and software tools."

2.4 Proposal for Data Requirements for Condition Assessment of Water Infrastructure Assets

The "Identification and Description of Water Infrastructure Components" is show in **Table 2-3**.

Table 2-3: Identification and description of Water Infrastructure Components

Infrastructure Asset Type				Design / Operating Reference	Com-ponents of Asset Type	Failure Modes of Asset/Com-ponents	Degra-dation Mechanism	Malfunc-tion Symptoms
Civil	**Mechanical**	**Electrical**	**Systems**					
Borehole						fracture		water quality, lithologic texture
Canal								seepage
Dam								
Manhole								
Pipeline						blockage, breakage, corrosion	Overpres-sure, damage	leaks
Pond								
Reservoir								
Tank					corrosion, abrasion			
Tunnel						blockage		
Weir						silting		
	Clarifier							
	Digester							
Fence								
	Filter / Strainer							
	Pipe					crack, fracture		
	Pump				bearing, impeller, shaft, casing		cavitation	
	Screen					blockage, breakage	deposition, clogging, screeching	headloss, reduced flow, overflow
	Valve							
		Meter						
		Motor			winding, shaft, bearing, casing			
		Instrumenta-tion						
			Control					
			Communi-cation					
			Extraction					
			Pumping Stations					
			Reticulation					
			Storage					
			Treatment					
			Transport					

The “Identification and Description of Generic Condition Categories for Water Infrastructure Assets” is reflected in **Table 2-4**.

Table 2-4: Identification and Description of Generic Condition Categories for Water Infrastructure Assets

				Technical Condition – Applicable to Component or System	
Condition Index	**Condition Indicators (CI)**	**Weight ranking of CI**	**Risk Indicator**	**Generic Condition Brief – Applicable to Component or System**	**Condition Code**
aggregate score of the weighted condition indicators on a scale of 0-100 that rates the condition of asset with a value of less than 20 = "unserviceable" and 100 = perfect; >80% = very good; 60-80% = good; 40-59% = serviceable; 20-39% = critical	Service condition requirement: Capacity/Loading Operating Environment		same as condition indicators + **CONSEQUENCE**	Fully loaded under optimal operating environment, probability of failure < 10%, PF interval > 0.7, compliant with standards and legislation, no backlog maintenance	A = Very good
	Failure probability PF interval			Optimal loading, probability of failure > 30%, PF interval < 0.7, compliant with legislation and standards, minimum maintenance backlog	B = Good
	Compliance to Regulation Maintenance Backlog			Reduced loading, probability of failure > 50%, PF interval < 0.5, compliant to legislation and many standards, maintenance backlog = planning horizon	C = Serviceable
	Hazard rate, i.e., Vulnerability to service and environment conditions %Remaining life			Reduced loading, probability of failure > 70%, PF interval < 0.3, compliant to legislation, maintenance backlog > planning horizon	D = Critical
				Minimum loading, probability of failure > 80%, PF interval < 0.2, non-compliant	F = Un-serviceable
CI{total} = x*CI(structural)+ y*CI(functional) + z*CI(environmental)					
Task:	conduct a survey of experts to (i) certify CI's , (ii) to agree CI{total} model, and (iii) to rank CI's				
CI(structural) = a1*parameter1 + a2*parameter2 +..+ aN*parameterN					
CI(structural) = b1*parameter1 + b2*parameter2 +..+ bN*parameterN					
CI(structural) = c1*parameter1 + c2*parameter2 +..+ cN*parameterN					

2.5 Models to determine the estimated useful life

2.5.1 References indicating the procedure to determine the replacement priority for water infrastructure

GLS has developed a model for the replacement and prioritisation infrastructure components and reflects the procedure in a Report to the Metropolitan Council of Tshwane (Pipe replacement prioritisation – Tshwane Case Study, 2011). A copy of this presentation is referenced in **Appendix A**.

2.5.2 Application of the replacement methodology used in Wadiso ® software by GLS

According to the report by GLS Consulting for Overstrand Municipality (GLS, 2009) a water pipe replacement model has been developed to evaluate potential replacement positions of pipes in a pipeline network.

It should be stated that the model to determine the remaining useful economic life developed for this project (Referred to as the "Asset management – Estimation of the Economic Remaining Life" or abbreviated to "EUL" model) bears similarities with the model developed by GLS Consulting. In both these models, key parameters that may have a significant influence on the pipeline's estimated useful life are identified.

One of the most significant differences between the models is that the GLS Consulting model has made use of a normalization factor to assign a specific percentage of influence to a parameter. The "EUL" model allows the user to define for each of the key parameters the potential impact for the "worst" and "best" scenarios. GLS has tried to incorporate a statistical approach to the model by selecting "likelihood of failure" and "Consequence of failure" parameters for each pipeline segment in a network of pipelines. Values are assigned to these parameters and multiplied with one another to give a "pipe replacement potential" parameter. The Project Team identified a "best" case versus a "worst" case scenario for their parameters in order to calculate the estimated remaining useful life of a pipeline. The GLS Consulting's model focussed on pipelines while the approach adopted by the research team included the assessment of water pipelines, sewer pipelines, pump stations, reservoirs and channels in the model (EUL).

The aim in this project was to include a user friendly and simple model which can be used by less experience technicians and even non-technical persons to evaluate the remaining estimated economic useful life of an asset and based on the findings be able to decide if the asset needs replacement or upgrading.

GLS Consulting uses the remaining useful life as a parameter in its model by simply taking the designed life of the asset and subtracting the current date from it. However, in the "EUL" model the approach is to scientifically calculate the remaining useful life by taking applicable key parameters into account.

It should be stated that both the "EUL" and the GLS Consulting's models needs to be calibrated and refined significantly before it can be used on a commercial basis.

2.5.2.1 *Key parameters of the GLS model*

- "Likelihood of failure" parameters include: Nominal diameter, reserve water pressure ratio, remaining useful life, Master Plan item Assessed condition, failure frequency, leakage volume, geology.

- "Consequence of failure" parameters include: high cost to consumer due to high water pressure, due to high flow, extended non-supply over time, high repair cost, flooding due to geography and strategic location.

2.5.2.2 *Key parameters of the EUL model*

Useful parameters which were included in the EUL are:

- Capacity of the components;
- Installation conditions;
- Illegal connections and usage;
- Operational standard and control; and
- Level of the capacity of the Contractor.

The EUL model also takes into account the effect of dynamic pressures induced onto the pipeline, operating duration, foreign matter, air valve operation, water quality and temperature fluctuations.

The failure frequency, leakage volume, repair cost and potential flooding were excluded in the EUL model.

3 Conceptual model to relate performance and life expectancy

3.1 Introduction

It is acknowledged that a large database of representative operational data from industry pertaining the performance, management and condition classification of the water services infrastructure will be required to obtain a relationship between performance and life expectancy.

The availability of a descriptive dataset from which the "performance-life expectancy" relationship for water infrastructure could be derived is not available and hence indirect parameters should be selected and reviewed to obtain a basis to reflect this complex relationship, if such a relationship does exist at all.

It has been indicated (WRC, Project Report 1785/1/09 "Review of Technology Used in Strategic Asset Management: Existing and Future Needs", 2009) which "Tools and Techniques" are currently available for the prediction of performance and the quantification of Risk of Water Infrastructure.

In a parallel WRC study K5/1988, the vulnerability of infrastructure is reviewed and it is therefore recommended that these documents be read in conjunction with this report.

Without a reliable database the approach in the following paragraphs is to identify the key parameters which will influence the expected remaining operational life or the residual value of the system components.

It however remains important to reflect some results of research conducted locally and abroad on the condition assessment of infrastructure components before the conceptual model is developed.

3.2 Condition assessment of ferrous water distribution systems

In South Africa steel/ferrous pipes are normally used either when high pressures are experienced (PN>16) or when the diameters are in excess of about 450 mm. The deterioration of ferrous pipes in water distribution systems were evaluated to obtain a better understanding of the deterioration of the pipes. In total 126 failed pipes were tested (Metallurgical examination, SEM, EDS and in some cases the presence of Sulphur Reducing Bacteria (SRB)) (Ringas et al., 1999).

The conclusion from the study revealed that the most common failure mechanism was weld corrosion followed by corrosion by SRB. Stray current corrosion was only contributing to 7% of the failures. A few galvanic corrosion examples were also noticed (carbon steel welded to a galvanised steel pipe).

Research was also conducted on the microbial corrosion on common pipe materials (Ringas et al., 1999). Based on the review of microbial corrosion on mild steel, 304 stainless steel, 3CR12 corrosion resistant steel, galvanized steel and copper/brass it was found that:

- Tubercle formation and colonization by sulphur reducing bacteria were only present on the mild steel;
- Free-chlorine residual in water retarded biofilm and tubercle formation;
- SRB was the major contributor to pitting corrosion;
- Pitting corrosion initiated between 3 to 6 months after colonization of SRB; and
- Therefor unprotected mild steel is not suitable as piping material.

The Environmental Protection Agency of America (EPA) has compiled an extensive report on the "Condition Assessment of Ferrous Water Transmission and Distribution Systems – State of Technology Review Report" (EPA, 2009). This document contains relevant information on:

- State of the Art condition assessment of water mains
- Available technologies for asset assessment;
- Approaches to condition assessment;
- Key performance and cost improvement areas; and
- Prospects for short and long term improvements to condition assessment for ferrous water mains.

Reference is made to some case studies. The comparison of the experience from different utilities indicates that even in America there is a lack of a "National Standardized Asset and Failure Database".

It has been established that the main factors leading to pipeline failures can be summarized as shown in **Table 3-1** (EPA, 2009).

Table 3-1: Main factors leading to the failure of ferrous pipelines

Factor	Description
Chemical	Internal and external corrosion caused by aggressive fluid or soil, microbes, stray current, oxygen gradient and bi-metallic connections
Physical	Handling: Transport, storage and installation; Imposed traffic loads; Soil loads due to settlements; Point loads (bedding or backfill – impingements); Internal radial loads – pressure fluctuations; Axial loads from seismic activities, soil movement and water hammer; Thermal stress due to temperature difference between transporting liquid, pipe and soil; Damage by third parties – installation of nearby services; and Damage to external coatings or internal linings.
Other factors	Aging – accumulation of chemical and physical stressors; Material integrity – inadequate design, material flaws and manufacturing deficiencies; and Installation defects – incorrect bedding, backfill, jointing encapsulation and coating.

Predicting future performance is based on past performance history which could only be obtained from a well updated database or from the organizational intelligence. The expected remaining life is influenced by a number of factors, none of which has a linear relationship with the expected remaining life; emphasizing the need for a well maintained failure incident event description and operational database.

The key factors in a water main which could influence the expected remaining operational life are:

- Actual pressure loading;
- Actual external loading and other stresses; and
- Actual deterioration rate (corrosion for ferrous pipes, or leakage rate and failures in other materials).

The realization that data sets are hard to find and in cases unreliable, forces the assessment of the remaining life of any asset type to be based on Bayesian type theory ("reasonable degree of belief") (EPA, 2009). This again reflects the value of the experienced operational and maintenance staff, especially when the available database is short or it has not been designed to capture critical parameters of operational conditions, actual loading conditions and extent of deterioration.

A copy of this Report EPA, June 2009 is referenced in **Appendix A**, but can also be obtained from: www.epa.gov.us.

3.3 Deterioration of waste water pipelines in South Africa

Research was conducted on the corrosion of cementitious waste water pipelines (CSIR, 1996; Fourie, 2002). The well-known Virginia Sewer Corrosion Research Project reflects the experienced gained in South Africa on the corrosion expected in cementitious sewer pipelines (Goyns, 2011).

3.4 Condition assessment of waste water pipelines

3.4.1 Introduction

An overview of condition assessment technologies and investigative condition assessment approaches for wastewater collection systems was compiled by the EPA (EPA Contract EP-C-05-058, 2009). The following aspects were reviewed in detail:

- Identification of the characterize state of condition assessment technologies in wastewater collection systems;
- Evaluation and research of the relationship between performance and cost of innovative and advanced infrastructure monitoring technologies, some which were developed for other industries and their application in wastewater collection systems;
- Review of the transfer of CCTV technologies for general application; and
- Preparation of protocols, metrics and site selection criteria for field demonstration of innovative condition assessment technologies and decision support systems.

The Report titled: "White paper on Condition Assessment of Wastewater Collection Systems" (EPA, 2009) summarizes the current state of condition assessment technologies; review mechanics of pipe failures and discusses emerging and innovative technologies for sewer inspection.

3.4.2 Condition assessment

Condition assessment provides the critical information needed to assess the physical condition and functionality of waste water collection systems and to estimate the remaining service life and asset value. **Figure 3-1** reflects the steps of condition assessment.

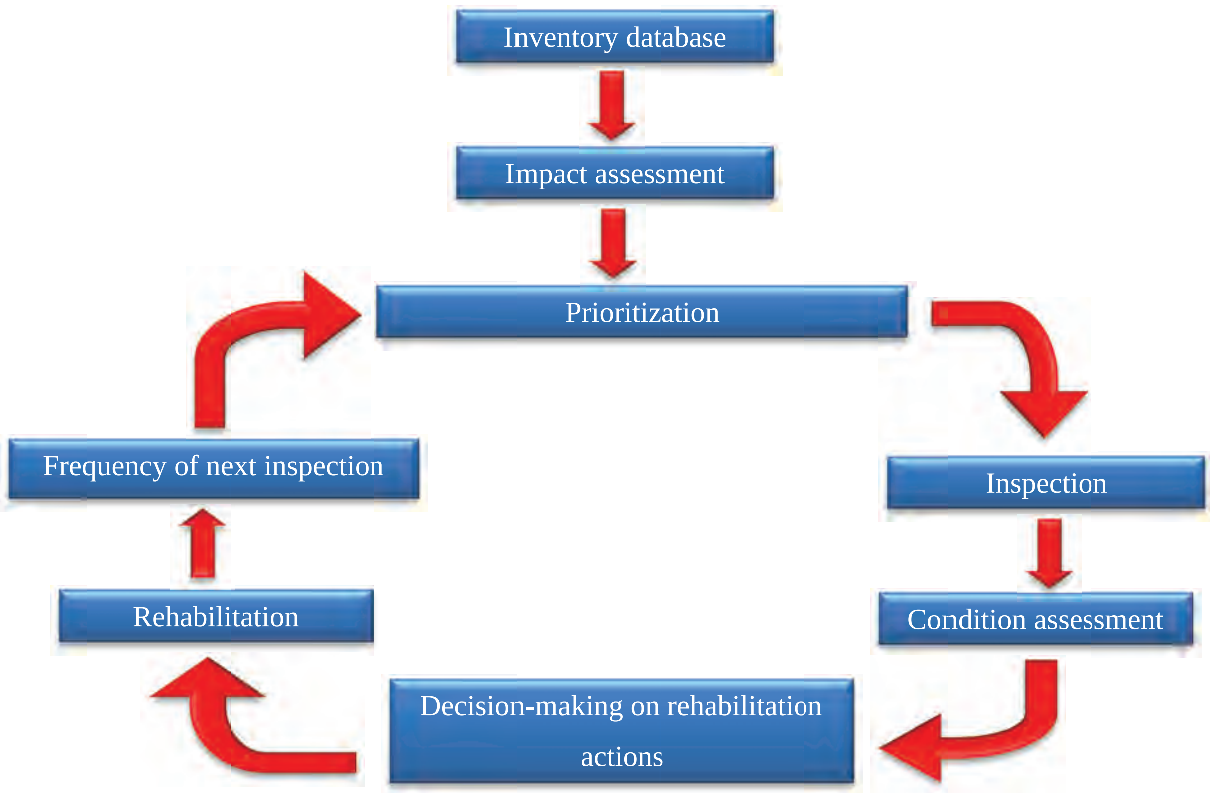

Figure 3-1: Steps of the condition assessment process

3.4.3 Dynamics of water collection failure

A dynamic failure of waste water collection systems needs to be described in terms of level, type and severity of the failure mechanism. The failure could be a sudden, catastrophic collapse or a restricted hydraulic capacity, or the contributions of other factors which will inhibit the system to perform as required. Condition assessment will detect defects, indicate the likelihood of failure and define the performance of the waste water collection systems. This aspect was not reviewed to any detail during this research.

In another publication (EPA, 2010) the condition assessment of wastewater collection systems are reviewed. A copy of this document is referenced in **Appendix A**.

3.4.4 Rehabilitation or replacement

Based on the information obtained from the asset assessment a decision to rehabilitate or replace the infrastructure needs to be taken.

In general the decision for rehabilitation/replacement of infrastructure components is made based on one or more of the following actions:

- Engineering calculations: Interpretation of inspection data deterministically. The review of the wall thickness and assessment of the hydraulic capacity is typical engineering calculations.
- Non-destructive testing (NDT) could be employed (Misiunas, 2008).
- Probability of failure: The objective is to provide a direct forecast of expected failures to occur. Practically this is difficult to implement because it will require excessive data and failures are normally site specific.
- Remaining life estimation: This procedure is commonly used to project the expected operational life of the asset. Standard coding systems were developed to define the condition and expected performance (NASSCO PACP standards).

Knowledge gaps and directives on research to be conducted to improve inspection technologies, to trace the condition of asset over time and to develop data management methods to compare historical data with the current condition and available technologies were referenced (EPA, 2009).

3.5 Infrastructure performance criteria and critical parameters influencing the life expectancy of water infrastructure

The review of the ability of water infrastructure components to perform in accordance with “fit for purpose” requires a thorough understanding of the intended purpose and status of the different component.

Asset management requires, amongst other a definition of the physical extent of the project, technical status, operational constraints, residual value and expected operational life. In the case of pumping mains the operational efficiency is a major concern, which might lead to the scenario where additional capital investments have to be compared with the high operating cost, especially the expected energy cost of an existing system. This is currently a major focus due to the limited energy production capacity in South Africa and the extremely high energy cost escalation of the energy sector.

Figure 3-2 reflects a typical cost breakdown for a pump station. Based on the current status of energy production in South Africa, it is realistic to anticipate that the operational cost component associated with energy will in all probability accelerate at a rate in excess of all the inflation indices.

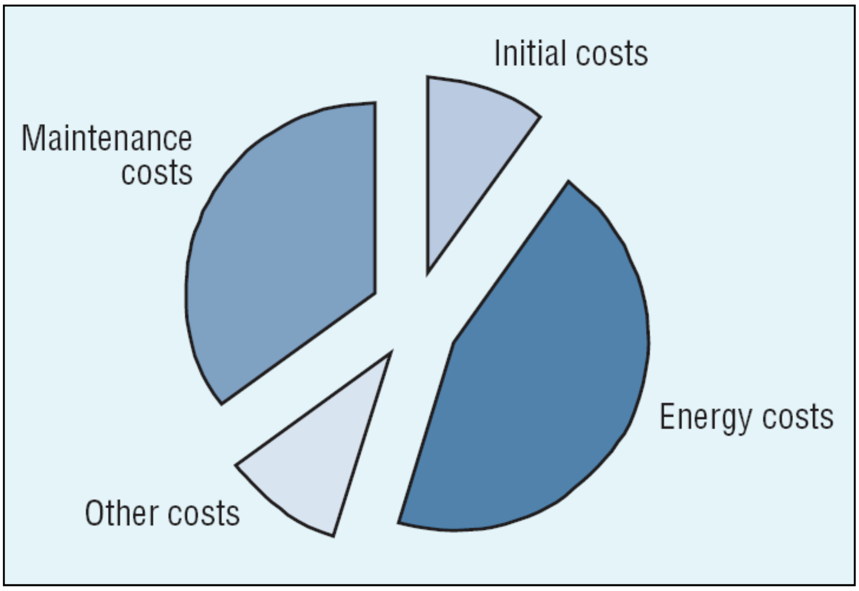

Figure 3-2: Typical cost breakdown of the life cycle costs for a pump station (Europump 2004)

During the verification phase of infrastructure it is essential to establish the intrinsic value of the components which can only be done if an accurate understanding of the efficiency and effectiveness can be quantified. This can be achieved by the assessment of available information a physical measurement of the performance of the system or system component.

In the next paragraph a conceptual model to define the remaining useful life and the residual value of typical asset types in the water industry, is discussed.

3.6 Identification of model variables to determine the remaining useful life

3.6.1 Introduction

It is fair to assume that the key parameters which determine the remaining life and operational functionality of any asset type in the water industry could be identified and that an objective weight or value of the influence of the selected parameter could have on the remaining life of the asset, could be determined. Remaining operating life assessment is based on the historical performance of the asset type.

It is assumed that the influence of the selected key parameter will range between a low and a high impact on the remaining life of the asset type. These values represent the boundaries of the potential influence of the parameter on the expected remaining life and could be presented as the “best” and “worst” scenario as it is further discussed in Chapter 6. **Figure 3-2** reflects a flow diagram of the assessment of the key parameter on the remaining life of the asset type.

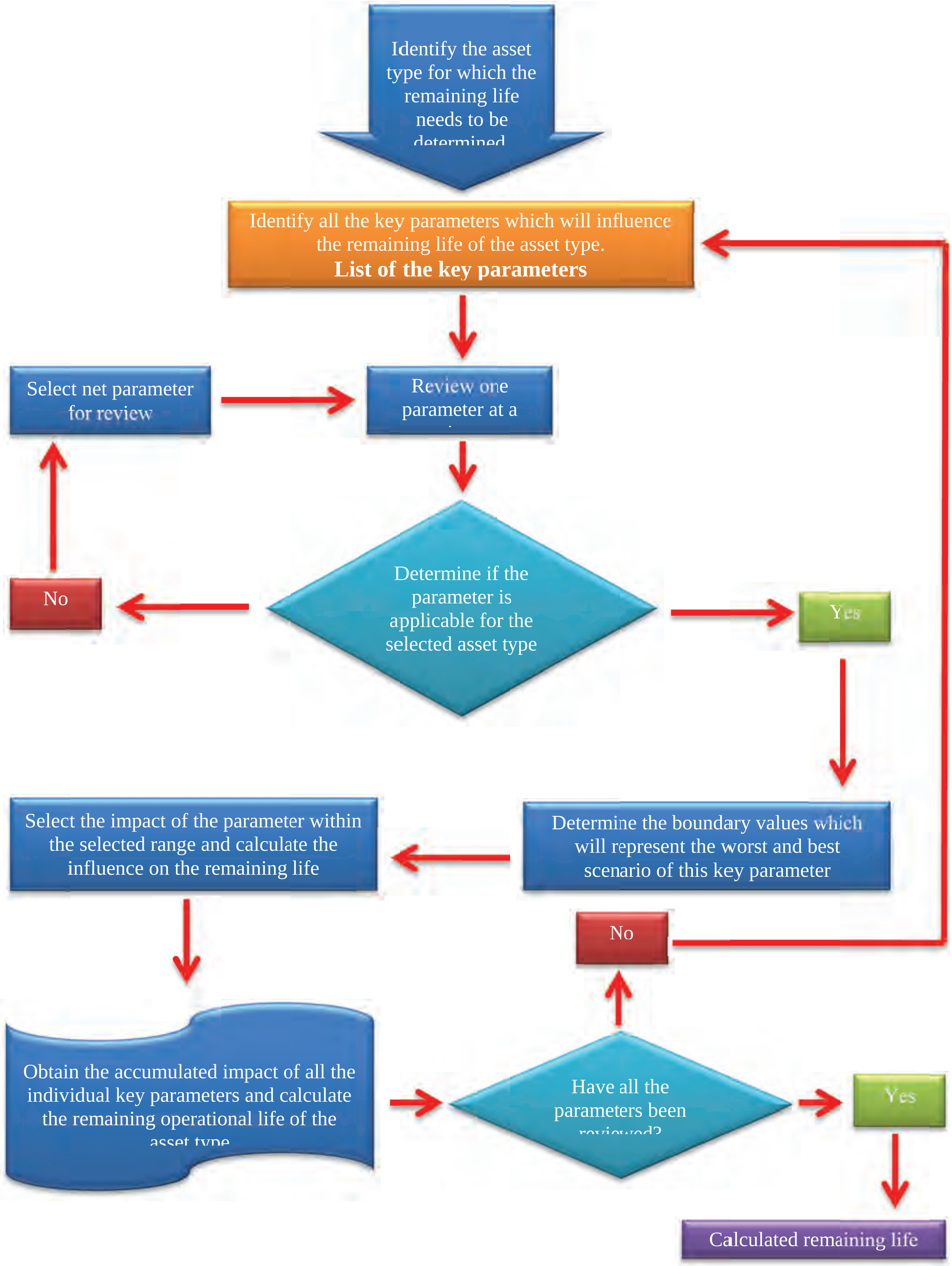

Figure 3-3: Flow diagram to highlight the actions to determine the influence of a certain key parameter on the expected remaining life of the asset type

3.6.2 Determination of the remaining life of a pipeline

The following few parameters should be considered in determining the useful life of a pipeline:

- Pipe material: How long can the pipeline withstand the internal and external environment?
- Installation conditions: Has the installation been done to acceptable standards?
- Installation procedure: The expected operating life will be influenced by the installation procedure and site supervision.
- Protective measures: Is the life expectancy of the pipeline dependent on the inclusion of protection equipment. Is the selected protection appropriate and has it been maintained?
- Hydraulic capacity: Can the demand be met using the system or should it be extended, refurbished or replaced?
- Water quality: Aggressive or scaling water could lead to corrosion or scaling of the pipeline.
- Operation of the system: How frequently is scheduled maintenance being conducted? Is the required production such that scheduled maintenance is disregarded?

If the influence of these parameters on the expected operating life can be determined, a simplified parameter assessment could be done to determine the expected remaining life of the system component from which the residual value or the replacement value could be determined and scheduled.

Firstly it has to be determined if any of the parameter are applicable for the specific assets type under review. The outcome can be a yes or no for which a value of either 1 or 0 (Zero) is allocated.

Secondly the influence of the parameter is assessed from a given set of values (**Table 3-2**) and finally the remaining life for the "worst" and "best" conditions is determined as follows:

$$ROL = NEOL + \sum_{i=1}^{i=n}((k_i) \times (APV_i - 1) \times NEOL) \qquad \textbf{... 3.1}$$

Where:

ROL	=	Remaining operational life or the remaining useful life (EUL)
NEOL	=	Normative expected operational life for the asset type
k_i	=	1 if the parameter do influence the remaining operational life or 0 if this parameter does not influence the operational life

APVi	=	Assessment parameter value for the specific key parameter under review
i	=	the specific parameter i of the total number of parameters
n	=	the number of parameters to be reviewed

Table 3-2 reflects the key parameters, parameter assessment outcome and assessment parameter value for a steel pipe for which it was assumed that the operating life was 45 years.

Table 3-2: Conceptual model for a steel pipeline

Review key parameter of the specific asset type	Parameter assessment outcome	Assessment parameter value, APV
$Q_{operting}/Q_{design}$	0.5	0.8
	0.8	0.7
	>1	0.3
Is the protection maintained and in good condition	Good	0.8
	Moderate	0.6
	Poor	0.4
	Alarming	0.2
Number of connections per Km	0	1
	2	0.8
	>3	0.2
Installation conditions	Good	0.95
	Moderate	0.85
	Aggressive	0.6
How well was the installation performed	Good	0.95
	Moderate	0.8
	Bad	0.3
Does the Water Quality influence the expected operational life	No	0.95
	Possible	0.75
	Yes	0.5
Is level of service acceptable to users	Yes	0.9
	Acceptable	0.7
	No	0.4
Do extreme operational conditions occur?	No	1
	Occasional	0.9
	Regularly	0.7

In the following paragraph this procedure is extended to reflect the sensitivity of the analyses for the different key parameters under review as well as an assessment of the "Worst Case" and the "Best Case" scenarios.

Table 3-3 provides a sensitivity analysis of the calculated remaining life for the "worst" and "best" expected scenarios.

Table 3-3: Expected operating life for a steel pipeline under the "Worst" and "Best" scenarios

Parameters selected to determine the Remaining Operational (Useful) Life (ROL) of the asset under review	Is the parameter applicable to the asset under review? (Yes = 1 and No = 0)	Worst case		Best case	
		NEOL	45	*NEOL*	45
		Asset parameter value	Influence of NEOL	Asset parameter value	Influence of NEOL
Capacity ($Q_{operting}/Q_{design}$)	1	0.7	-13.5	1	0
Sophistication of protection	1	0.9	-4.5	1	0
Illegal connections	1	0.85	-6.75	1	0
Installation condition (soil type, stray currents, high water table)	0	1	0	1	0
Construction standard (bedding, compaction, alignment)	0	1	0	1	0
Water Quality	0	1	0	1	0
Operational std (<55% of pressure, poor valve operation)	0	1	0	1	0
Temperature fluctuation & extremities	0	1	0	1	0
Calculated Remaining Operational Life (ROL)			**20.25**		**45**

Depending on the pipeline material the parameters which could influence the ROL will differ. The use of thermoplastic pipes at temperatures above 23 ^{0}C or the use of AC/FC pipes when the water is aggressive are examples of key parameters which will influence the remaining operational life of the pipeline. These parameters could be assessed under "temperature fluctuations" and "water quality".

In **Chapter 6** software developed for the estimation of the remaining operating life is discussed for other asset types in the water industry.

3.7 Procedure for the determination of the residual value of infrastructure

Different procedures and their shortcomings with regard to the determination of the residual value of the asset were referred to before (EPA, 2009; EPA, 2010). In these cases the residual values in financial terms, indicate what portion of the capital expenditure has not been benefited from the operation of the system up to that point in time. This residual value has little relevance when compared with the intrinsic operating value of the asset component.

The suggested procedures to be implemented in the conceptual model takes as premise that:

- Internal and external factors could shorten the operating life of a system; and

- That a time based relationship could be used to reflect the remaining operating life.

The "Bathtub" relationship of an asset (Wayman, 2003) suggests that the initial failures after the implementation will reduce to a level which will be acceptable during the operation of the asset. Towards the end of the useful operational life the failures will increase again until the value of the asset to be fit for use is questioned.

If it is assumed that the time base operating life of a project is linear (it is appreciated that it is more complex than this), then it could be argued that for a specific infrastructure component, the expected economic life could be reduced as is indicated in **Figure 3-4**.

In the following example the residual value of the asset is determined for a steel pipeline.

A steel pipe was laid in an environment where cathodic protection was required due to excessive stray currents. During the construction, the pipeline was stringed along the trench but due to prolonged rain the contract period was extended for months. Shortly after the pipeline had been put into operation, the pipeline failed due to corrosion. Records indicated that the cathodic protection was operational, but that the corrosion was initiated during the period prior to the full installation of the cathodic protection (pipeline was unprotected).

This constitutes a lack of protection during the construction, which has reduced the operating life of the pipeline. The result is that the operating life reduces from $n_{original}$ to $n_{revised}$. Along the horizontal time axis at any time the residual value could be determined (linear relationship assumed).

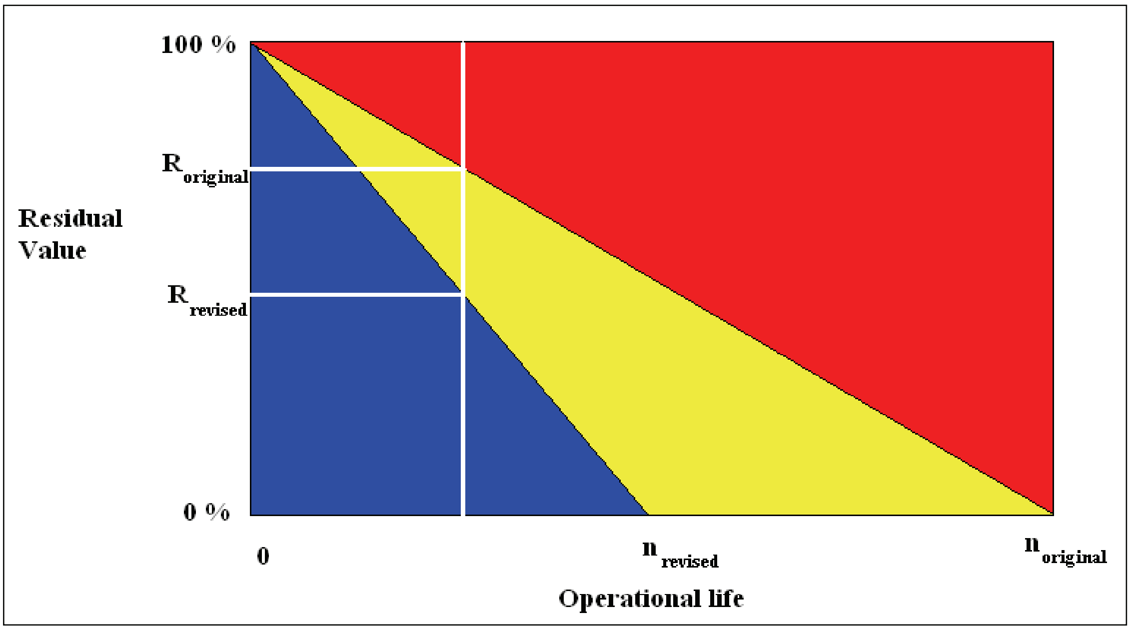

Figure 3-4: Relationship between the residual value and the expected operational life

This aspect was not further investigated in this research.

4 Non-destructive techniques for condition assessment

4.1 Introduction

Numerous techniques have been developed for the assessment of water and sewerage systems (EPA, 2010). The application of some of the available technologies is limited in South Africa by cost and probably the scale of the demand for these technologies. In the following paragraph the different non-destructive techniques are discussed.

4.2 Non-destructive inspection technologies

A variety of technologies are available for the assessment of waste water collection systems. **Table 4-1** reflects the typical application of the different technologies. **Table 4-2** reflects the typical failures of different pipe materials while **Table 4-3** indicates the type of the assessment procedures applicable for the different phases of the assessment of the infrastructure.

Table 4-1: Summary of the condition assessment technologies (EPA, 2009)

	Camera				Acoustic			Electrical & Electro-magnetic			Laser	Innovative technologies						
	CCTV	Zoom camera	Digital scanning	Push-camera inspection	In-line leak detectors	Acoustic monitoring systems	Sonar	Electrical leak location	Remote field eddy current	Magnetic flux leakage	Laser profiling	Gamma-gamma logging	Ground penetrating radar	Infrared thermography	Micro-deflection	Impact echo/SASW	Ultrasonic pulse velocity	Guided Wave Ultrasonic
Application																		
Pipe type	G	G	G	S	G, F	F	G, F	G, F, S	G, F, S	G, F, S	G, F	G, F, S	G, F, S	G, F, S	G	G	G	F
Pipe material	Any	Any	Any	Any	Any	PCCP	Any	NF	F	F, PCCP	Any	C	Any	Any	B	B, C	C	F
Pipe diameter (in.)	>6	>6	6-60	1-12	≥4	≥18	≥12	3-36	≥2	2-56	>4	TBD	18-30	TBD	N/A	>6	TBD	>2
Defects Detected																		
Sediment, debris, roots	x	x	x	x			x				x							
Pipe sags & deflections	x	x	Partial	x			x				x							
External pits & voids												x			Partial	x		x
Corrosion & metal loss			Partial				x		x	x	x							x
Off-set joints	x	x	Partial	x														
Pipe cracks	x	x	x	x			x	x	x	x						x	x	x
Leaks	x	x	x	x	x			x	x				x	x				
Broken pre-stressed						x			x									
Wall thickness									x							x	x	x
Service connections	x	x		x								x						
Bedding conditions												x	x					
Bedding voids												x	x	x	Partial			
Deteriorated Insulation														x				
Overall conditions															x			

NOTE:

Pipe type: G – Gravity line F – Force main S – Service lateral

Pipe material: NF – Nonferrous F – Ferrous B – Brick C – Concrete PCCP – Pre-stressed concrete cylinder pipe

TBD – To be decided

N/A – not applicable

Adapted from USEPA 2009a

Table 4-2: Typical failures of different pipe materials used in waste water systems (Thompson et al., cited in EPA, 2009)

Defect	Concrete			Ferrous		Ceramic		Plastic	
	Concrete pipe	Asbestos cement	PCCP/CCP	Cast iron / Ductile iron	Steel	VCP	Brick	PVC	HDPE
Internal pipe surface									
Root intrusion	x	x	x	x	x	x	x		x
Grease build-up	x	x	x	x		x	x	x	x
Pipe wall condition									
Cracks / broken pipe	x	x				x			
Internal corrosion		x	x	x	x				
External corrosion			x	x	x				
Leakage									
General	x	x		x		x		x	
Joint leakage			x		x				
Leaking laterals				x					x
Alignment / grade									
Alignment				x				x	x
Joint Misalignment	x	x		x		x			
Excessive deflection					x			x	x
Grade								x	x
Other	1						2	3	4

NOTE:

1 – Liner separation, weld failure
2 – Missing bricks, soft mortar, vertical deflection, collapse
3 – Lateral connections
4 – pressure capacity (force mains only)

Table 4-3: Typical non-destructive technologies applicable for the different stages of asset management

Program Objective	Flow data analysis	Camera			Acoustic			Electrical & Electro-magnetic			Laser	Innovative technologies						
		CCTV	Zoom camera	Digital scanning	In-line leak detectors	Acoustic monitoring systems	Sonar	Electrical leak location	Remote field eddy current	Magnetic flux leakage	Laser profiling	Gamma-gamma logging	Ground penetrating radar	Infrared thermography	Micro-deflection	Impact echo / SASW	Ultrasonic pulse velocity	Guided Wave Ultrasonic
Screening / Prioritization	x		x			x	x											x
Detailed inspection of internal surface conditions		x		x			x				x					x		
Detailed inspection of pipe wall integrity					x	x	x	x	x	x	x			x	x	x	x	x
Detailed inspection of pipe bedding and void conditions												x	x	x				

4.3 Non-destructive inspection technologies commonly used in South Africa

The common evaluation of the visual status of water conveyance systems is conducted by CCTV inspections. A number of companies offer this service.

The structural integrity of conveyance systems can be related to the extent of the deformation. A South African development of a “profilometer” has successfully been used to indirectly asses the structural integrity.

The use of the “smart-ball” technology is rapidly developing and is promising. The advantage of this technology is that it is uninterrupted and that multiple data could be gathered. The application in South Africa is developing.

5 Economic evaluation techniques to compare the replacement and refurbishment cost for infrastructure and appropriate aids for the costing of these alternatives

5.1 Introduction

The status description of infrastructure defines the efficacy, functionality and fit for purpose of the specific system component. Based on the status description, all infrastructure components which require replacement or refurbishment are identified and normally prioritised due to limited financial resources.

Based on the prioritized asset elements to be refurbished or replaced the budgetary review process is followed which amongst other require the following two actions:

- **Costing of the items** for the refurbishment, upgrade or replacement of infrastructure components; followed by;
- **Scheduling of the implementation** of the upgrade or replacement of infrastructure components.

Figure 5-1 provides a schematic flow diagram of the actions for the status review and financial process for the refurbishment or replacement of infrastructure.

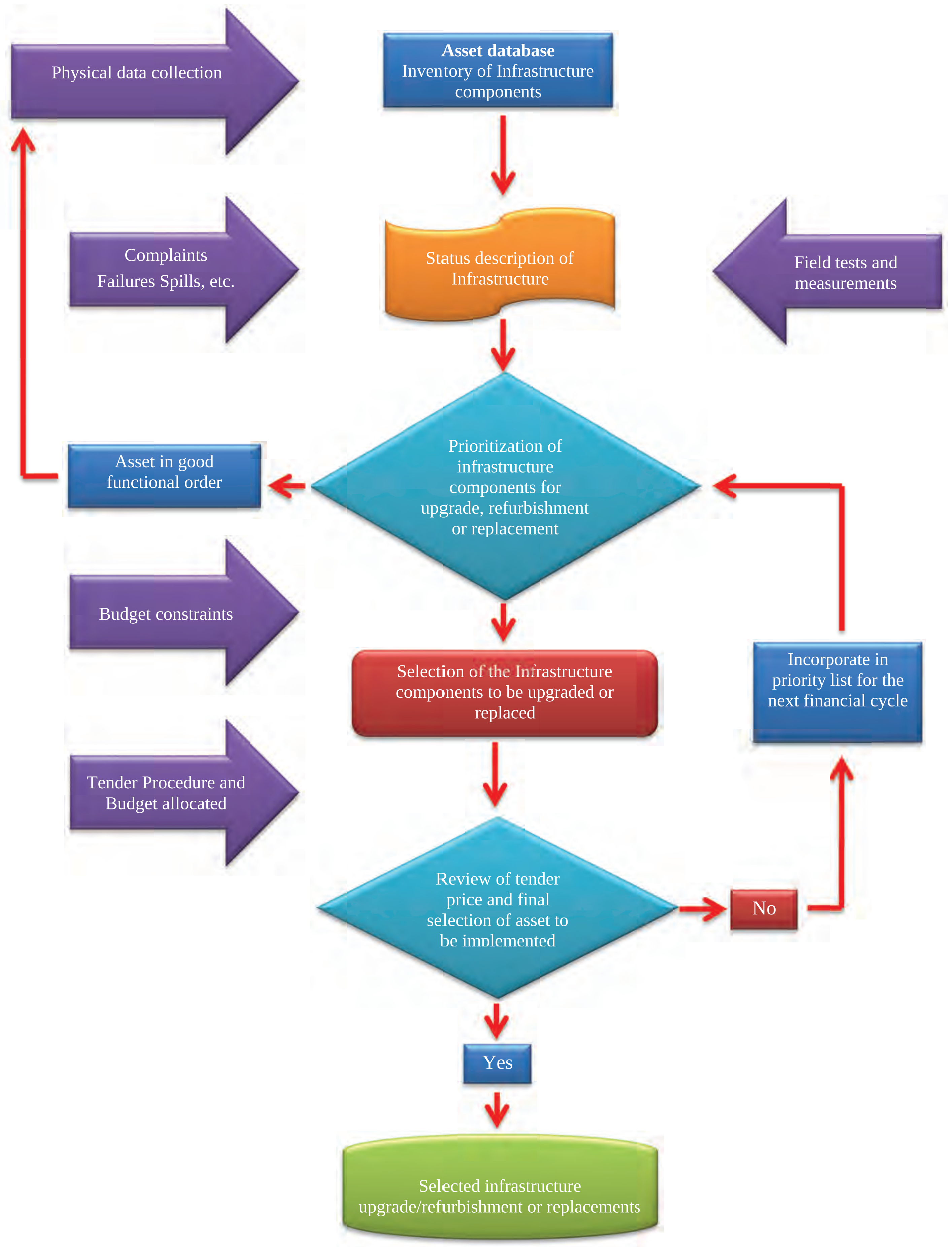

Figure 5-1: Flow diagram the assessment to replace Infrastructure Components

Since the new political dispensation in South Africa, the Department of Water Affairs (DWA) played a significant role in the implementation of infrastructure to address the backlog in service delivery related to water supply and sanitation. DWA developed a cost model to review and compare all the business plans from various consultants for the upgrade and installation of new infrastructure in different parts of South Africa. The “costing model” included parameters like the scale of the project, location, topography, geology, layout of the area to be serviced, le el of service, availability of contractors, total construction activity in the area, availability of suppliers for the construction material, construction period.

Another factor to be reviewed in ensuring sustainable service provision is to be able to predict or provide for services which could be damaged by natural or human interference. In a parallel study (K5/1983) the vulnerability of infrastructure is reviewed. It is recommended that the Report from this study be read in conjunction with the findings of that research.

The review of water infrastructures ability to perform in accordance to be “fit for purpose” requires a thorough understanding of the intended purpose of the component. This aspect was reviewed in Chapter 3. Should any alterations however be required, it is proposed that appropriate economic evaluation techniques be used to firstly establish the cost of the intended alteration to be implemented, followed by economic evaluation to verify the appropriateness of the investment.

5.2 Costing of infrastructure components

The WRC study K5/1992//3 determines the cost of certain infrastructure components which could be used to obtain cost estimates for the replacement of infrastructure elements.

It was indicated before that the Department of Water Affairs (DWA) has undertaken a project to provide a cost model for the estimation of new infrastructure. The approach which was implemented as the basis for the cost model was to establish the key parameters which will influence the capital cost requirement to provide the infrastructure component.

Table 5-1 reflects the key parameters which will influence the final capital cost for the provision of infrastructure.

Table 5-1: Key parameters which will influence the final capital cost for the provision of infrastructure

Parameter	Description
Location	The distance away from the main centres in South Africa will result in an escalated cost of the items required for the installation of infrastructure.
Topography	Steep slopes will increase the cost of infrastructure provision
Geology	The outcrop of hard rock will influence the cost of infrastructure provision.
Size of development	The scale of economy will influence the unit cost for the provision of infrastructure and will provide opportunity for bigger contractors to participate in the bid process.
Form of development	The layout of the development has a bearing on the final costs.
Level of service	The cost for infrastructure provision is dependent on the selected level of service.
Technology	The sophistication used for the project will influence the cost of the infrastructure.
Construction procedure	The use of labour versus heavy equipment will influence the cost of infrastructure provision.
Available skilful contractors	Unskilled contractors might submit a low Tender price to undertake the construction, but fail due to the lack of experience to manage, control and construct the infrastructure.
Financial and technical management of the project	The final cost of the project might escalate due to insufficient control and guidance to the contractor.

It is appreciated that the local- and macro-economic climate could influence to provision of the required input needed for the development of infrastructure. This needs to be recognized and incorporated as parameters which could influence the cost for the provision of infrastructure.

5.3 Economic evaluation techniques

5.3.1 Introduction

Various techniques, all based on the principle of discounted cash flows, can be used for cost-benefit analysis. The four most commonly applied techniques are:

- Present worth of cost (*PW*OC) technique;
- Net present value (*NPV*) technique;
- Benefit/cost ratio (*B/C*) technique;
- Internal rate of return (*IRR*) technique; and
- Life Cycle Costing (*LCC*).

5.3.1.1 Present worth of Cost (PWOC) technique

This technique selects the lowest cost alternative among mutually exclusive projects. All economic costs (i.e. the opportunity costs) associated with the provision, management, maintenance and use of each possible alternative project are discounted to their present worth. Given the objective of economic efficiency, the alternative that yields the lowest *PWOC*, is regarded as the most cost-effective (beneficial) proposal.

This method can be expressed as follows:

$$\mathrm{PWOC} = \mathrm{C_A} + \mathrm{PW(M + U)} \qquad \textbf{... 5.1}$$

where:

PWOC	=	present worth of cost
C_A	=	all costs incurred in establishing a facility (i.e. the opportunity cost of the investment)
PW(M + U)	=	present worth of all facility maintenance costs and user costs.

[Note that in the case of the null alternative (i.e. the existing facility whose possible replacement or upgrading is being investigated, and against which the other mutually exclusive alternatives are measured), PWOC = PW(M + U)]

When a proposed project will, because of lower user cost, induce additional demand higher than the “normal-growth”, the abovementioned criterion of lowest total service cost presents a contradiction in terms. Any induced demand will inflate the facility’s *PWOC*, thus defeating the objective of minimum cost.

5.3.1.2 Net Present Value (NPV) technique

This technique provides an economic performance measure that is used to:

- Select the best alternative among the mutually exclusive projects; and
- To help establish an overall economic viability of independent projects.

Net present value (*NPV*) is a technique whereby the present worth of investment cost is subtracted from the present worth of all the future project benefits. The present worth of both costs and benefits is calculated by using an official (social) discount rate. All projects reflecting a positive *NPV* are economically viable, while the project alternative with the highest such value is most suitable for implementation, as this will maximise the net benefit for the society as a whole.

The technique may be expressed thus:

$$NPV = PW(M_0 + U_0) - PW(M_A + U_A) + PW(CS_A) - C_A \qquad \textbf{... 5.2}$$

where:

NPV	=	net present value of benefits.
$PW(M_0+U_0)$	=	the present worth of facility maintenance costs and user costs of the null alternative.
$PW(M_A + U_A)$	=	the present worth of facility maintenance costs and user costs of a proposed alternative A.
$PW(CS_A)$	=	consumer surplus gained through additional usage induced by the proposed alternative A.
C_A	=	investment (capital) cost that is required to implement the alternative A.

If the NPV > 0 then the project should be implemented, but should the NPV be < 0 the investment does not provide an acceptable return.

5.3.1.3 Benefit/Cost Ratio (B/C) technique

This technique provides an economic performance measure used for the selection of the most advantageous independent project(s) by determining the ratio between the present worth of the future project benefits and the present worth of the project investment costs. The future project benefits are associated with the annual savings, relative to the null alternative, plus the consumer surplus gained through additional usage induced by the proposed facility.

The ratio between the sum of the discounted benefits and the sum of the project investment costs is obtained by dividing the former by the latter. All proposals with a ratio value greater than one are viable, while the one with the highest ratio value is economically the most advantageous. However, when mutually exclusive projects are compared, incremental analysis should be used to identify the best alternative.

The method may be expressed as follows:

$$B/C = \frac{PW(M_0 + U_0) - PW(M_A + U_A) + PW(CS_A)}{C_A} \qquad \textbf{... 5.3}$$

where:

B/C = benefit/cost ratio

5.3.1.4 Internal Rate of Return (IRR) technique

This technique provides an economic performance measure used for the selection of the most advantageous independent project(s). The distinctive feature of this technique is that its application does not entail a singular discounting procedure with one official rate only. Future benefits ("returns") for the period under review are discounted to the beginning of the period. The benefit of each year is calculated in the same manner as with the *NPV* and *B/C* techniques. The sum of these discounted amounts is compared with the discounted project investment cost. Different rates of discount are selected iteratively and applied until at a certain rate the sum of the annual discounted returns equals discounted investment costs. This rate is then referred to as the internal rate of return.

The project with the highest internal rate of return can be regarded as the most advantageous, although the actual criterion is to compare the rate thus obtained with the opportunity cost of capital as represented by the prevailing real discount rate.

If the prevailing real discount rate exceeds the prevailing social discount rate, the alternative is economically viable. However, when mutually exclusive projects are compared, incremental analysis should be used to identify the best alternative.

The relationship where IRR = r will result in:

$$PW(M_0 + U_0) - PW(M_A + U_A) + PW(CS_A) = C_A \qquad \textbf{... 5.4}$$

where:

IRR	=	internal rate of return
r	=	rate at which the left-hand and right-hand sides of the equation are equal, resulting in a NPV of zero.

5.3.1.5 Life Cycle costing

The importance of incorporating future expected cost to make a defined choice for which infrastructure option to implement, is essential. The "lifetime" cost include the capital that needs to be invested to purchase and install the infrastructure, the cost to operate and maintain, the potential loss due to downtime as well as the cost associated with the disposal of the facility.

This procedure is not only applicable for new investments but can also be used for the assessment of alternatives to existing infrastructure which requires extension or upgrading.

The high escalation of energy cost which is a major cost component in in water supply and sanitation requires that a LCC assessment is paramount. Material is available which describe the technique in more detail (TT278/06).

The cost elements to be reviewed under the LCC technique should incorporate the following cost components:

$$LCC = C_c + C_{ic} + C_e + C_o + C_m + C_s + C_{env} + C_d \qquad \textbf{... 5.5}$$

Where:

C_c	=	Initial capital cost
C_{ic}	=	Installation and commissioning
C_e	=	Energy cost
C_o	=	Operation
C_m	=	Maintenance
C_s	=	Downtime / loss of production
C_{env}	=	Environmental cost
C_d	=	Decommissioning

The time value of money however requires that a base year for the calculation of LCC be determined and that the NPV of all the cost elements be determined.

5.4 Appropriate aids for the costing of alternatives infrastructure options

The WRC funded study, K5/1992//3 provides the bases for the cost estimation and comparison for alternative infrastructure options. The findings and recommendations of this study should be read in conjunction with this report.

6 Estimation of the remaining life of infrastructure components

6.1 Introduction

The reliability to estimate the potential failure of an infrastructure component is related to a historical representative database for the asset type, containing descriptive parameters of the current status which could be used to predict with a fair amount of certainty when a failure could be expected and what the failure would entail.

To reflect on the expected future behaviour of the infrastructure of our water services, a full understanding of the operational parameters, liquid characteristics, installation conditions and material characteristics (related to operational history, liquid characteristics and installation conditions) would be required. Such relationships do not readily exist for the different components of water infrastructure and sanitation systems.

In Chapter 3, where the conceptual model to relate the performance and life expectancy was discussed, it was indicated that it is practical to limit the assessment of the remaining useful life to a few selected key parameters for which data is available or could be obtained.

The purpose of this chapter is to extend the conceptual model, proposed previously in Chapter 3 and to provide a software package to determine the remaining operating life for the following water infrastructure components:

- Pipelines (water);
- Sewer pipelines;
- Pump stations;
- Channels; and
- Reservoirs.

Previously the boundary values of the key parameters were referenced to be the “worst” and “best” scenario. The inclusion of an “intermediate status description” which represents the current condition has been included here with the intentions to provide a more representative “feel” of the status of the asset.

6.2 The parameters which influence the expected useful life of the water infrastructure

6.2.1 Introduction

Each of the infrastructure categories listed above, remaining life will be determined by a number of parameters. The identification of the critical parameters and their influence on the remaining operational life could be subjective, and hence a value range for the parameter value is suggested to reflect the "worst" and "best" expected remaining life scenarios.

Based on operational experience, an allocation can be made to reflect the influence on the remaining life for the "worst" and "best" scenarios. It is possible that under certain conditions the key parameter could lengthen the expected useful life of the infrastructure component. As an example of this it could be argued that in the case of a collector sewer pipeline where an internal liner is still functional and intact after the sewer line has been in service for the expected economic life, the liner could extend the expected useful life to beyond the economic life of the sewer pipeline.

The proposed model to calculate the expected remaining life is based on the assumption that critical identifiable and measurable key parameters exist which will influence the useful life.

It is assumed that a "parameter value" can be identified for the "worst" and "best" scenarios and that all other outcomes will be flanked by these boundary parameter values. Based on these assumptions, the procedure to determine the influence of the critical parameter on the expected useful life can be summarized as follows:

- The critical parameters which could influence the expected useful life of the infrastructure are identified for each of the infrastructure categories. In the case of a pipeline, the critical parameters which could be used to estimate the useful life could include the following:

    1. Capacity ($Q_{operating}/Q_{design}$);
    2. Sophistication of protection (internal liner, external coating, cathodic protection);
    3. Illegal (informal) connections;
    4. Installation condition (soil type, stray currents, high water table, infiltration into pipe);
    5. Construction standard (bedding, compaction, alignment, indentations, over-insertion of couplings, visible seals);
    6. Water Quality (internal aggressiveness, pH, visible biofilm growth);

7. Operational standard (<55% of pressure, poor valve operation, dynamic pressures, pump start and stop duration);
8. Temperature fluctuation & extremities;
9. Operating time (24/7, day only, night only);
10. Foreign matter inside pipe (sediment or debris); and
11. Air valve operation and placement (position, size, connection to pipe).

- The next step of the assessment requires the determination of the relative importance of the specific parameter on the expected useful life of the infrastructure component. In the case where, say only the six of the above listed parameters (Capacity ($Q_{operating}/Q_{design}$; Sophistication of protection; Illegal (informal) connections; Level of service to users; Operating time; and Air valve operation) will influence the useful life.

- Each of the critical parameters could influence the expected remaining life of the infrastructure in a nonlinear way. This is expressed as a "worst case" and a "best case". If "Illegal" (informal) connections are used as an example to explain the influence on the expected remaining life the two cases could be judged as follows:

  - "worst case" – Illegal (informal) connections could reduce the capacity to provide the desired demand to the legitimate user and could increase the losses and enhance possible contamination. If the expected life of the pipeline would have been 45 years, the "Worst case" could reduce the life with a number of years which could be calculated as follows:

    Reduction of life for the "worst case" as a result of Illegal connections = 45 * Application value of the factor * ("Parameter value for Illegal connections $_{(Worst\ Case)}$" – 1). By populating the values, the reduction in the operational life could be = 45*1*(0.85-1) = -6,75 years. The "Parameter value for Illegal connections $_{(Worst\ Case)}$" needs to be defined by a qualitative assessment of the potential impact of illegal connections on the operational life of the pipeline.

  - Similar for the "best case" the same parameters could be reviewed to indicate the upper expected value for the remaining useful life of the asset. The output from this analyses provide a "worst" and "best" case scenario to managers who need to prioritize and budget for upgrade or replacement of infrastructure components.

For each of the infrastructure classes, the procedure to determine the "remaining operating life" (ROL) or the "estimated useful life" (EUL) is discussed and illustrated in the following paragraphs.

6.2.2 Pipelines

The selected parameters which will influence the remaining useful life for pipelines are reflected in **Table 6-1**.

Table 6-1: Selected critical parameters to be reviewed for pipelines

Critical Parameters/criteria	Outcome	Asset parameter value #
$Q_{operating}/Q_{design}$	0.5	0.8
	0.8	0.7
	>1	0.3
Is the protection maintained and in good condition	Good	0.8
	Moderate	0.6
	Poor	0.4
	Alarming	0.2
Number of illegal connections per Km	0	1
	2	0.8
	>3	0.2
Installation conditions	Good	0.95
	Moderate	0.85
	Aggressive	0.6
How well was the installation performed	Good	0.95
	Moderate	0.8
	Bad	0.3
Does the WQ influence the expected operational life	No	0.95
	Possible	0.75
	Yes	0.5
Is level of service acceptable to users	Yes	0.9
	Acceptable	0.7
	No	0.4
Do extreme operational conditions occur?	No	1
	Occasional	0.9
	Regularly	0.7
Operating time	24/7	0.7
	day only	0.85
	night only	0.95
Foreign matter inside pipe	Occasional	0.65
	After repairs	0.85
	Never	1
Air valve operation and placement	No de-aeration	0.8
	Normative location	0.9
	Effective with accumulator	1

Note:

\# *Range of the parameters to be obtained from experience in different areas*

Table 6-2 reflects the influence on the expected useful life for the pipeline.

Table 6-2: Influence of different parameters on the useful life of pipelines

Parameters selected to determine the Remaining Operational (Useful) Life (ROL) of the asset under review	**Is the parameter applicable ? (Yes – AV = 1 and No – AV = 0) #**	**Worst case**		**Best case**	
		NEOL	**45**	**NEOL**	**45**
		Asset parameter value ##	**Influence on NEOL**	**Asset parameter value ##**	**Influence on NEOL**
Capacity ($Q_{operting}/Q_{design}$)	1	0.8	-9	1	0
Sophistication of protection	1	0.8	-9	1	0
Illegal connections	1	0.85	-6.75	1	0
Installation condition (soil type, stray currents, high water table)	0	1	0	1	0
Construction standard (bedding, compaction, alignment)	0	1	0	1	0
Water Quality	0	1	0	1	0
Operational std (<55% of pressure, poor valve operation)	0	1	0	1	0
Level of service to users	1	0.9	-4.5	0.9	-4.5
Operating time	1	0.85	-6.75	0.95	-2.25
Foreign matter inside pipe	0	1	0	1	0
Air valve operation	1	1	0	1	0
Calculated Remaining Operational Life (ROL)			**9**		**38.25**

Note:

 # Indication if the parameter is relevant for the infrastructure element under review – outcome of AV is either 1 or 0.

Values to be populated in the shaded areas.

In this case the expected minimum operating economic life for the pipeline ("Worst Case") will be 9 years.

6.2.3 Sewer pipelines

The selected parameters which will influence the remaining useful life for sewer pipelines are reflected in **Table 6-3**.

Table 6-3: Selected critical parameters to be reviewed for sewer pipelines

Critical Parameters/criteria	Review scenario	Outcome	Asset parameter value #
Installation (Depth, foundation, material)	Depth of installation (m)	<1.5	0.95
		<2.5	0.9
		>3.0	0.85
Operating life since installation or replacement	Operational life since installation	<5	0.8
		<10	0.6
		<15	0.4
		<20	0.2
Spills and blockages	Frequency of spillage	3 per year	0.8
		1 in two months	0.6
		weekly	0.2
Structural damage (Inside and outside)	Occurrence of structural damage	1 in 2 km	0.7
		2 in 1 km	0.5
		4 in 500 m	0.3
Infiltration	Infiltration as % of design flow	<5%	0.95
		<15 %	0.9
		> 20 %	0.6
Sedimentation	Locations of sedimentation	every 6th Manhole	0.9
		Every 3rd manhole	0.6
		every manhole	0.3
Stagnation	Stagnation distance	Between 2 manholes	0.9
		Over 3 manholes	0.7
		Over 6 manholes	0.6
Third party interference	Vandalism (third party interference)	One in 5 years	0.9
		Once in two years	0.7
		Every 6 months	0.5

Table 6-4 reflects the influence on the expected useful life for the sewer pipeline.

Table 6-4: Expected useful life for the sewer pipeline

Parameters selected to determine the Remaining Operational (Useful) Life (ROL) of the asset under review	**Is the parameter applicable ? (Yes – AV = 1 and No – AV = 0) #**	**Worst case**		**Best case**	
		NEOL	**30**	**NEOL**	**30**
		Asset parameter value ##	**Influence on NEOL**	**Asset parameter value ##**	**Influence on NEOL**
Installation	1	0.9	-3	0.95	-1.5
Operating life since installation or replacement ###	1	0.8	-6	0.8	-6
Spills and blockages	1	0.8	-6	1	0
Structural damage (Inside and outside)	0	1	0	1	0
Infiltration	1	0.7	-9	0.95	-1.5
Sedimentation	0	1	0	1	0
Stagnation	0	1	0	1	0
Third party interference	1	0.9	-3	1	0
Calculated Remaining Operational Life (ROL)			**3**		**21**

Note:

\# *Indication if the parameter is relevant for the infrastructure element under review – outcome of AV is either 1 or 0.*

\## *Values to be populated in the shaded areas.*

\### *Operational life since the time of installation.*

In this case the expected minimum operating economic life for the sewer pipeline ("Worst Case") will be 3 years.

6.2.4 Pump stations

The selected parameters which will influence the remaining useful life for a pump station is reflected in Table 6-5.

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Table 6-5: Selected critical parameters to be reviewed for a pump station

Critical Parameters/criteria	Outcome	Asset parameter value #
Installation (Aligned motor and pump, foundation, etc.)	Severe vibrations	0.5
	Some indication of	0.7
	Smooth running	1
Operating life since installation or replacement (Operating life/Design life)	1 Year	0.95
	8 Years	0.5
	More than 15	0.2
Hydraulic capacity (Pumping hours/day)	<12	0.9
	<20	0.5
	>20	0.2
Cycles per hour > 6	<6	0.95
	<12	0.6
	<18	0.25
	<24	0.1
Standby (Standby %)	200	0.95
	100	0.8
	50	0.5
	<25	0.2
Efficiency (H_s/H_{total})	0.2	0.8
	0.6	0.6
	>2	0.3
NPSH available	>5	0.9
	<3	0.3
	<2	0.2
Sufficient suction storage	>24 h	0.95
	>12 h	0.6
	<6	0.4
	<2	0.25
Abrasion (Casing/impeller failure frequency)	6 years	0.8
	3 years	0.4
	Yearly	0.15
Leakage at glands	None	1
	Slight	0.9
	Severe	0.7
Dynamic induced pressures (Del P/H_s)	0.1	0.95
	0.5	0.75
	>1	0.4
Vandalism	Every second year	0.95
	Every year	0.75
	Monthly	0.4

Note:

\# *Range of the parameters to be obtained from experience in different areas*

Table 6-6 reflects the influence on the expected useful life for the pump station.

Table 6-6: Expected useful life for the pump station

Parameters selected to determine the Remaining Operational (Useful) Life (ROL) of the asset under review	**Is the parameter applicable ? (Yes – AV = 1 and No – AV = 0) #**	**Worst case**		**Best case**	
		NEOL	**15**	**NEOL**	**15**
		Asset parameter value	**Influence on NEOL**	**Asset parameter value**	**Influence on NEOL**
Installation (Aligned motor and pump, foundation, etc.)	1	0.7	-4.5	1	0
Operating life since installation or replacement (Operating life/Design life)	1	0.9	-1.5	1	0
Hydraulic capacity (Pumping hours/day)	1	0.85	-2.25	1	0
Cycles per hour > 6	1	1	0	1	0
Standby (risk)	1	1	0	1	0
Efficiency	1	1	0	1	0
NPSH available	1	1	0	1	0
Sufficient suction storage	1	1	0	1	0
Abrasion	1	1	0	1	0
Leakage at glands	1	1	0	1	0
Dynamic induced pressures	1	1	0	1	0
Vandalism	1	0.75	-3.75	0.75	-3.75
Calculated Remaining Operational Life (ROL)			**3**		**11.25**

Note:

\# *Indication if the parameter is relevant for the infrastructure element under review – outcome of AV is either 1 or 0.*

In this case the expected minimum operating economic life for the pump station ("worst case") will be 3 years.

6.2.5 Reservoirs

The selected parameters which will influence the remaining useful life for reservoirs are reflected in **Table 6-7**.

Table 6-7: Selected critical parameters to be reviewed for a Reservoir

Critical Parameters/criteria	Outcome	Asset parameter value #
Sufficient Capacity	Volume more than 2 times the AADD	1
	Volume less than 1.5 times the AADD	0.9
	Volume more than the AADD	0.8
Foundations	Severe settlement and cracks	0.7
	Cracks and leaks	0.9
	Cracks no leaks	0.95
Wall structure	Cracks and reinforcement corroded	0.8
	Cracks with signs of leakage	0.9
	Small leakage present	0.95
Roof structure	No roof	0.8
	Cracks and corrosion	0.9
	Some corrosion	0.95
Total leakage from Reservoir	More than 50 l/min	0.85
	15 to 50 l/min	0.9
	15 l/min	0.98
Operational control	Telemetry with altitude valves	0.98
	Level operated valves	0.95
	Visual inspection and manual isolation	0.85
Dissipation of energy	Through energy dissipation valve	0.98
	Through orifice plates and control valves	0.9
	No dissipation	0.85

Note:

 # Range of the parameters to be obtained from experience in different areas

Table 6-8 reflects the influence on the expected useful life for the reservoir.

Table 6-8: Expected useful life for a Reservoir

Parameters selected to determine the Remaining Operational (Useful) Life (ROL) of the asset under review	**Is the parameter applicable ? (Yes – AV = 1 and No – AV = 0) #**	**Worst case**		**Best case**	
		NEOL	**45**	NEOL	**45**
		Asset parameter value	**Influence on NEOL**	**Asset parameter value**	**Influence on NEOL**
Sufficient Capacity	1	0.9	-4.5	1	0
Foundations	1	0.7	-13.5	1	0
Wall structure	1	0.95	-2.25	1	0
Roof structure	1	0.9	-4.5	1	0
Leakage	1	0.9	-4.5	1	0
Operational control	1	0.95	-2.25	0.7	-13.5
Dissipation of energy	0	1	0	1	0
Calculated Remaining Operational Life (ROL)			**13.5**		**31.5**

Note:

\# *Indication if the parameter is relevant for the infrastructure element under review – outcome of AV is either 1 or 0.*

\## *Values to be populated in the shaded areas.*

\### *Operational life since the time of installation.*

In this case the expected minimum operating economic life for the reservoir ("Worst Case") will be 13.5 years.

6.2.6 Channels

The selected parameters which might influence the remaining useful life for a channel are reflected in **Table 6-9**.

Table 6-9: Selected critical parameters to be reviewed for a channel

Critical Parameters/criteria	**Possible parameter values for the different cases #**	
	Worst	**Best**
Standard of construction	0.6 to 1	1 to 1.1
Assurance level & scarcity of water	0.2 to 1	1 to 1.2
Climate (Surface erosion and uplift)	0.85 to 1	1 to 1
Soil type & groundwater level	0.9 to 1	1 to 1.3
Maintenance standard	0.85 to 1	1 to 1.25
Water quality	0.85 to 1	1 to 1.2
Operating standard	0.8 to 1	1 to 1.3

Note:

\# *Range of the parameters to be obtained from experience in different areas*

Table 6-10 reflects the influence on the expected useful life for the sewer pipeline.

Table 6-10: Expected useful life for the Channel

Parameters selected to determine the Remaining Operational (Useful) Life (ROL) of the asset under review	**Is the parameter applicable ? (Yes – AV = 1 and No – AV = 0) #**	**Worst case**		**Best case**	
		NEOL	**45**	NEOL	**45**
		Asset parameter value ##	**Influence on NEOL**	**Asset parameter value ##**	**Influence on NEOL**
Standard of construction	1	0.8	-9	1.1	4.5
Assurance level & scarcity of water	1	0.9	-4.5	1.05	2.25
Climate (Surface erosion and uplift)	1	0.95	-2.25	1.05	2.25
Soil type & groundwater level	1	0.9	-4.5	1.1	4.5
Maintenance standard	1	0.85	-6.75	1	0
Water quality	1	1	0	1	0
Operating standard	1	0.85	-6.75	1.1	4.5
Scheme specific EUL of canals	`		**11.25**		**63**

Note:

\# *Indication if the parameter is relevant for the infrastructure element under review – outcome of AV is either 1 or 0.*

\## *Values to be populated in the shaded areas.*

In this case the expected minimum operating economic life for the channel (“Worst Case”) will be 11.25 years.

6.3 Software for the estimation of the remaining operating life

6.3.1 The software to determine the remaining operational life

A beta version of the software for the determination of the remaining operational life (ROL) (or estimated useful life, EUL) of water infrastructure assets can be downloaded from the WRC website: www.wrc.org/software/Asset Management Estimation of Economic Useful Life.xlsm.

6.3.2 Procedure for using the software titled: Asset Management – Determination of the estimated useful life

The Excel spreadsheet can be accessed from the accompanying compact disc. Open the spread sheet titled: *Asset Management – Determination of the estimated useful Life*. The macros feature must be enabled in Microsoft Excel for the spread sheet to function automatically as designed. Accept the user agreement to proceed to the program (**Figure 6-1**). The user will be forced to full screen mode in Microsoft Excel whilst zooming to 100%. Click on the OK button in the window titled: *Screen size*, the user will be automatically directed to the Pipe Line Assessment spreadsheet (**Figure 6-2**).

Figure 6-1: Accept the user agreement

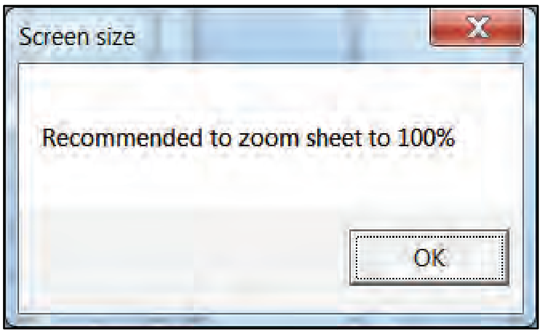

Figure 6-2: Screen size

In the case for the condition assessment of a pipeline the pipe material can be selected from the dropdown menu (This is still a beta version of the software, thus only steel pipeline parameters are available).

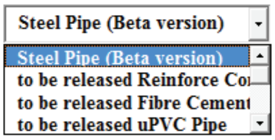

Figure 6-3: Selection of pipe material

Set the generic estimated useful life (EUL) of the project by adjusting the provided scrollbar. The EUL can also be defined as the design life time for a new project.

The applicable assessment parameters can then be selected or deselected if the parameters are not applicable to the specific project or scenario. Should a parameter be deselected a purple box will hided the *Adjustment in Years* column applicable for the specific parameter.

Additional parameters can also be included at the bottom of the list of parameters. When selecting an additional parameter the window titled: *Attention* will appear onscreen, follow the instructions (**Figure 6-4**). A description for the additional parameters can be entered in the provided space. These additional parameters' minimum and maximum range values can be manually set in the provided text box at the bottom of the page.

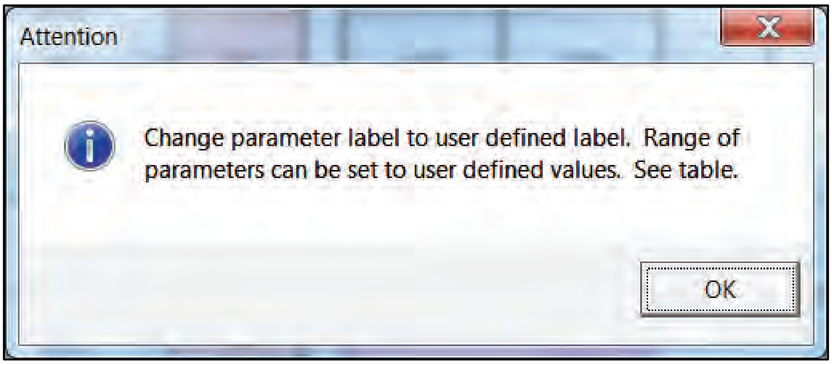

Figure 6-4: Additional parameters included

The values for each parameter may be adjusted for both the worst case scenario and the best case scenario independently with the provided scrollbar. In the case that a user may find that the provided parameter ranges of values insufficient the user may select the tick box titled: *Tick to select user defined parameters*. The selected parameter will be highlighted in red with a warning box appearing as indicated below in **Figure 6-5**. The user may now specify a lower and upper value for the Worst Case Scenario as well as the Best Case Scenario.

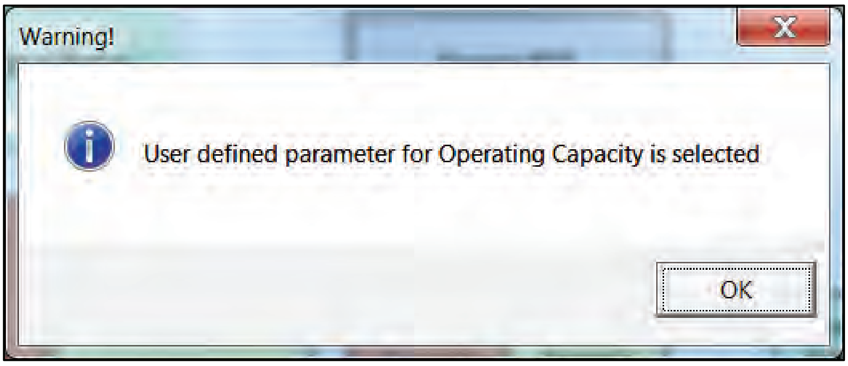

Figure 6-5: User defined parameter values selected

On condition that user is satisfied with all the selected parameters and has adjusted the values accordingly the user may select the *Analyze* button.

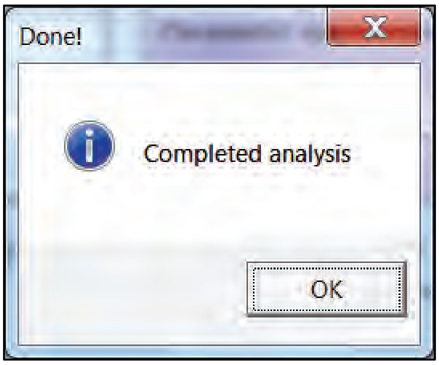

Figure 6-6: Analysis completed

The Estimated Remaining Operational Life for both the worst case and best case scenario will be reflected in the provided space. Should a user define unrealistic values for the selected assessment parameters that may cause the project to have a negative estimated remaining useful life, an *Error* message will appear warning the user to reassess the project (**Figure 6-7**).

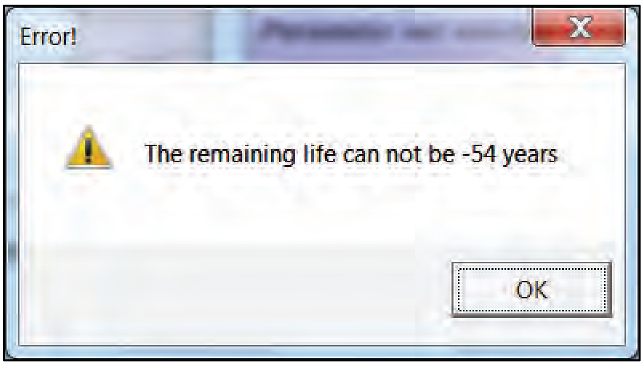

Figure 6-7: Unrealistic remaining useful operating life

If the assessment is completed the user may close the window or perform another assessment of a new project by clinking on the *Set to default* button. The window will now be set as when opened initially. A print screen of the provided condition assessment spreadsheet is reflected in **Figure 6-8**.

NOTE:

The early closure of this project (K5/1950) resulted that only a *beta version* of the condition assessment program is available. Future refinement of individual parameters for different scenarios and upgrades of the software is possible.

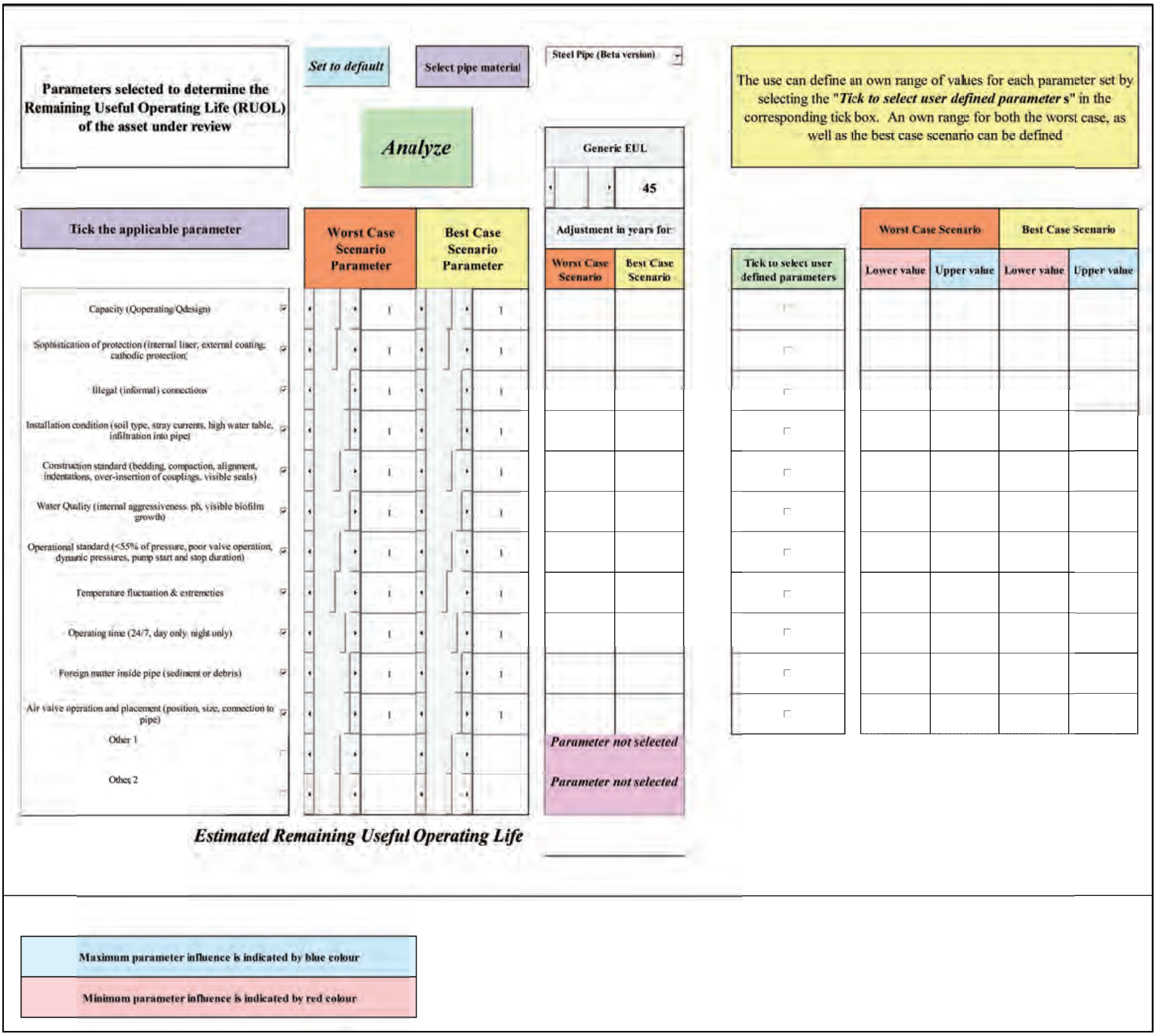

Figure 6-8: Print screen of Excel spreadsheet for the estimation of the remaining operating life for a pipeline

6.4 Verification of the key parameters

The selected key parameters should be evaluated by experienced asset managers and the parameter values reviewed. The potential influence of the key parameters on the expected useful life of different asset types should be investigated by incorporating historic operational data.

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APPENDIX A – Material associated with this project which can be downloaded from the WRC website.

The following information could be obtained from the WRC website: www.wrc.org.za. (Click on knowledge hub and enter 1950 in the search box to gain access to these files.)

- Supporting Material (Different Reports from EPA and other Relevant Articles);
- Legislation (Copies of the applicable Legislation); and
- Software (Software for the determination of the remaining estimated useful life) – www.wrc.org.za/software/Asset Management Estimation of Economic Useful Life.xlsm.