# REVIEW OF TECHNOLOGY USED IN STRATEGIC ASSET MANAGEMENT: EXISTING AND FUTURE NEEDS

**REPORT TO THE**

**WATER RESEARCH COMMISSION**

**BY**

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# Executive Summary

## Introduction

Section 63 of the Local Government Municipal Financial Management Act, Act No. 56 of 2003, states that:

*(1) The accounting officer of a municipality is responsible for the management of -*

- *a) the assets of the municipality, including the safeguarding and the maintenance of those assets; and*
- *b) the liabilities of the municipality.*

*(2) The accounting officer must for the purposes of subsection ( I ) take all reasonable steps to ensure*

- *a) that the municipality has and maintains a management, accounting and information system that accounts for the assets and liabilities of the municipality;*
- *b) that the municipality's assets and liabilities are valued in accordance with standards of generally recognised accounting practice: and*
- *c) that the municipality has and maintains a system of internal control of assets*

In order to ensure that assets are effectively managed and controlled, it is important that water utilities are aware of the current condition of their assets. This will enable water utilities to conduct effective planning activities around projects and finances required to ensure that the assets remain in working order.

This study was commissioned by the Water Research Commission (WRC) primarily to determine what technologies are currently available to water utilities that can be used to determine the condition of assets deployed for water extraction, storage and distribution. The study also reviewed national and international trends in management processes with regard to condition assessment, and prediction of asset performance and asset risk determination techniques as applicable to water assets. It is envisaged that this review would serve as a useful point of reference for South African utilities as they embark on the journey towards effect management of water infrastructure assets.

## Overview of Methodology

The study commenced with a literature review of tools and techniques currently available for the water industry to conduct condition assessments perform predictive modelling of asset performance, and to determine asset risk. This document thus contains a comprehensive set of tables that summarise various condition assessment tools and techniques for water infrastructure assets. In each table, the last column indicates whether or not a tool or technique is currently available or applicable in South Africa.

In conducting the study, a questionnaire was developed and a survey conducted to gain further insight into current asset management practices in the country.

## Survey Results

Out of the 150 questionnaires distributed to water services providers, only 23 were comprehensively completed and returned. Due to the fact that the sample size was extremely small and the questions were generally of a qualitative nature, the results cannot be generalized but only used to suggest trends. The following trends are suggested from the feedback provided by the respondents:

- Visual inspection is the most common method used to determine the condition of an asset.
- There is little consistency in the frequency of condition assessment.
- Only half of the water utilities surveyed measured the reliability of their assets. The most common method employed to measure reliability was 'direct measurement'.
- Only half of the water utilities that responded to the questionnaire ranked their assets on a risk basis. The most common method employed was categorization of risks in terms of monetary value of the asset, then on a continuum and qualitative basis.
- The majority of the respondents felt that replacing assets and maintaining an asset register are two of the main activities that should be carried out as part of the asset management function. This was closely followed by carrying out risk and condition assessments of their assets, and having a maintenance management plan in place.
- The most common constraints experienced by water utilities in conducting asset management activities was a lack of technical capacity followed by financial issues and general equipment issues.

## South African Asset Management Practices

Discussions with sector experts revealed that there are a vast number of technologies available to water utilities in South Africa. There are, however, very few water utilities actually making use of these tools. In most cases these technologies are implemented in the larger water utilities and metropolitan municipalities. It is also unfortunate to note that these technologies were usually only employed in a reactive instead of a preventative mode.

Condition assessment is currently not being widely practiced as a structured activity across the country. Most condition assessment is in the form of ad hoc visual maintenance inspections or initial high level screening visual inspections for the compilation of asset registers. From the results of the survey, there does not appear to be much consistency in the visual inspection method. Predictive modelling of risk, condition and reliability for water assets is currently not widely practiced in South Africa. There appears to be a widespread awareness of the need to determine asset risks as a management practice, but there is much inconsistency in the quantification and the management of the risks.

Although guidelines have been developed to assist infrastructure managers with these technical practices, the guidelines have not yet been widely adopted and more technical detail is required to address these aspects more comprehensively.

The legislative drive for municipalities (Municipal Finance Management Act) to prepare asset registers for financial compliance has stimulated the preparation of asset registers nationwide. Most asset data that is being collected across the country is primary data that describes the location, size, nature, and value of the asset. Data useful for prediction of asset performance is not yet being widely collected. Few water service providers have computerised maintenance management systems that are operating effectively to collect secondary and tertiary asset data that can improve the confidence in condition assessments, prediction of asset performance and asset risk determination.

The future of condition assessment, prediction of asset performance and asset risk determination has great growth potential in South Africa. With asset inventories in place, which are very costly, the barriers to collecting more sophisticated data and conducting more sophisticated analysis are lowered. Service delivery failures are also focusing public attention on reliability, replacement planning, and maintenance, which will further drive the increase in data sophistication, which in turn may lead to the increase in the demand for condition assessment technology.

It should be noted that various constraints faced by the water utilities in South Africa are hampering the implementation of proper asset management practices. The most critical constraint faced by municipalities is the lack of appropriately skilled human resources with respect to management and technical staff.

## Comparison with International Trends

Around the world there are more citations of available technology, however, there are not as many citations on the application of the tools and techniques for condition in the water services sector. The impression is that no formal standards have been developed for condition assessment, predictive modelling of asset performance and asset risk determination within a specific country, whereas there is a tendency for industry regulators to put de-facto specifications in place.

Detailed data appears to be more prevalent internationally across a greater number of asset types and the major emphasis is on the adoption and institutionalisation of computerized maintenance management systems as part of the wider Enterprise Resource Planning business processes. Many developed countries have undertaken wide scale asset replacement programs, which have lead to the development of the techniques to support technical decision making. The demand for the application of these methods will grow in South Africa as we undertake more infrastructure replacement programs.

## Recommendations

The following recommendations stem from the aforementioned:

- A standard classification of assets that aligns with the accounting classification should be developed to ensure that appropriate and consistent technical data is collected when asset registers are compiled for accounting compliance purposes.
- Minimum standards for condition assessments and reporting for the different condition assessment technologies should be developed to minimise vendor influence and standardise reporting.
- Standard condition indices should be developed for water assets to enable standardised reporting across the sector.
- Research in the prediction of asset performance should be supported with the development of generic models that will make performance prediction more attainable for water providers across the country.
- A risk framework that covers the needs of small municipalities to large water service providers should be developed based on asset risk determination methods used abroad.
- More condition and risk based parameters should be included within existing benchmarking programs to raise awareness of these asset performance parameters.
- The development of technical audits as a means to stimulate technical management actions, in the same manner as financial and accounting audits, should be promoted as a means of improving the technical management of infrastructure assets.

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# 1. Introduction

Technologies applicable towards the management of physical assets have advanced rapidly and the water industry has benefited from these advancements, particularly with regard to the collection and transfer of data. The water industry in South Africa can take advantage of the worldwide technological developments towards provision of improved services.

Strategic asset management is a wide field with many tools, techniques and technologies covering the spectrum of processes exhaustively include planning, acquiring, constructing, controlling, using, operating and maintaining, disposal and re-cycling, of assets. Technology has a specific role to play in the decision making process as shown in figure 1, below.

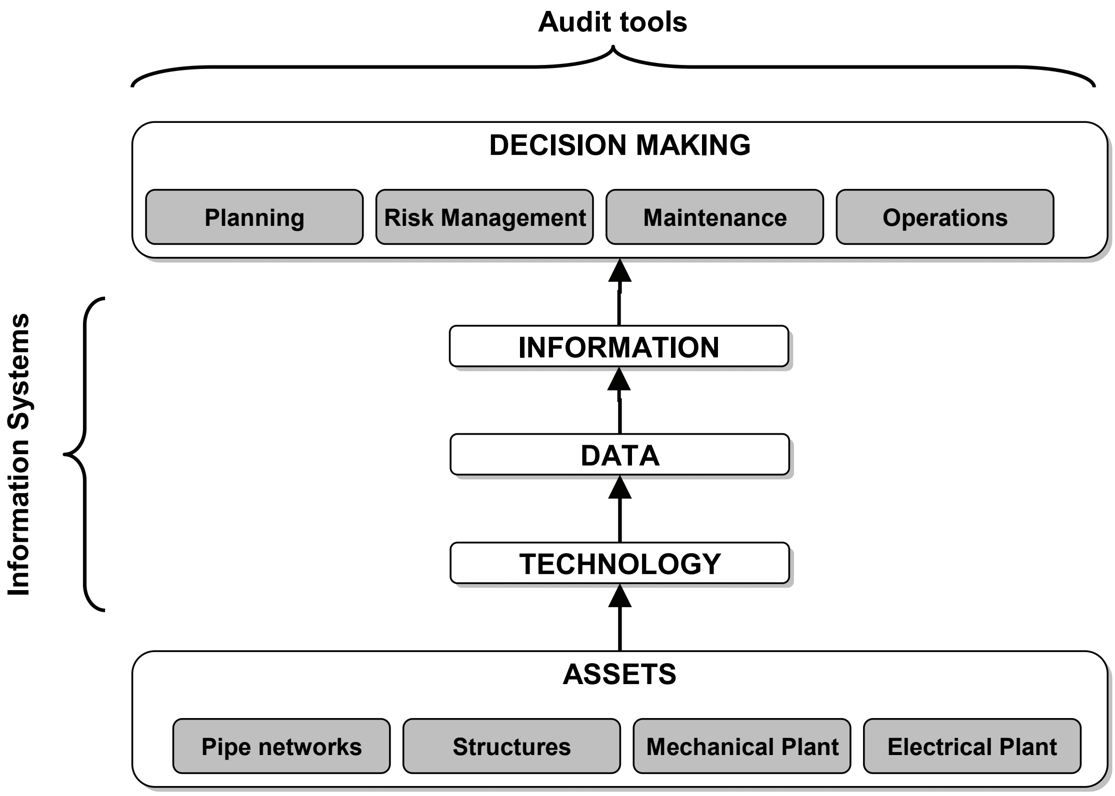


***Fig. 1.*** *Asset Management Data and Analysis Flow*

The figure above shows the connection between the assets including pipe networks, structures, mechanical and electrical plant and decision making about the management of the assets. The asset types are shown in the block at the bottom and the passage of information is shown leading up to inform the different decision making in the block at the top. Technology plays a key role in converting physical properties and performance of the assets into data, which is in turn processed into information to inform decision making. Decision making can impact on any part of the asset lifecycle and includes strategic decisions on planning, risk management, maintenance, operations, etc. Information systems include technologies and techniques that act as the conduit for the transfer and processing of data into the format useful for decision making. Audit tools evaluate the effectiveness and maturity of decision making about the assets.

The aim of this study is to review technology used in strategic asset management. Given the wide role and application of technologies in strategic asset management, the study specifically focused on the technologies used in condition assessment, prediction of asset performance, and asset risk determination.

Condition assessment entails the evaluation of the asset and its physical state relative to that of a new asset. Prediction of asset performance entails the forward prediction of the change in the performance of the asset using forecasting methods, typically over a period of greater than 10 years. Asset risk determination refers to the quantification of the risks associated with the ownership and management of individual assets. A distinction is made between individual asset risk that is associated with the non-performance of a specific asset and portfolio risks that are non-asset specific. Only the former is considered in this study.

This report begins with a literature review of tools and techniques that are available for use in the water industry for condition assessment, prediction of asset performance and asset risk determination. The application and function of these tools are summarised to provide a wide understanding of the functioning and application of different tools and techniques. Case studies of technology usage are provided where evidence of these was found. The literature review is followed by an assessment of the tools and techniques that are currently being utilised in South Africa.

A questionnaire was designed to gather information on condition assessment, prediction of asset performance, and asset risk determination and techniques that are currently being applied. The results give a snapshot of the current status of technology usage in South Africa.

The review of the available technologies and current usage in South Africa provides the basis of a gap analysis between current and potential usage of technology. Conclusions and recommendations are given to take best advantage of the tools and techniques that are available to water infrastructure managers in South Africa.

# 2. Literature Review

## 2.1 Introduction

The literature review consists of three subsections, dealing with condition assessment, prediction of asset performance and asset risk determination respectively.

## 2.2 Condition Assessments

### 2.2.1 Introduction

Condition assessment can be defined as the technical assessment of the physical condition of an asset, using a systematic method designed to produce consistent, relevant and useful information. The objective of condition assessment is to provide sufficient information on asset condition to allow informed strategic asset planning and management decisions to be made[1].

Condition assessment results, together with functionality, utilisation and cost considerations, can be used to support a wide range of asset decisions and actions, particularly in relation to the following:

- Acquisition
- Operations and Maintenance
- Risk management
- Asset valuation and Life cycle planning
- Disposal planning.

The collection of condition data is a major task and the condition assessment process for built assets should, as a minimum, rate asset condition, determine the risks associated with letting an asset remain in that condition, and identify maintenance work needed to restore to and retain an asset in its required condition[1].

### 2.2.2 Tools and Techniques

The tools and technologies used for condition assessment and performance monitoring of water and utilities assets cover all types of assets including pipelines, civil structures and mechanical and electrical plant. A comprehensive study, carried out by Marlow *et al.* (2007)[2], provides a comprehensive breakdown of a large range of condition assessment tools and techniques that can be applied to different water and wastewater service areas, including different types of asset stock. The study produced a set of inclusive tables that break down the various inspection tools and techniques, environmental surveys and condition monitoring techniques. These tables have been reproduced in this report but they have been modified to include the availability of these tools and techniques within South Africa. The tables are divided to two groups, tools and techniques for examining pipe assets and those for examining non-pipe assets.

There are eight tables on techniques for examining pipe assets, namely:

Table 1 – Physical Property Testing (Destructive and Non-destructive).

Table 2 – In-pipe (Man Entry) Inspection Techniques.

Table 3 – In-pipe (Non-man Entry) Inspection Techniques.

Table 4 – On-pipe Inspection Techniques.

Table 5 – Valve and Meter Inspection Techniques.

Table 6 – Strategic Planning for Pipes.

Table 7 – Strategic Planning and Hydraulic Assessment for Pipe Networks.

Table 8 – Environmental Survey and Network Condition for Pipe Networks.

There are three tables on techniques for examining non-pipe assets, namely:

Table 9 – Electrical Assets.

Table 10 – Mechanical Assets.

Table 11 – Civil and Building Assets.

In Tables 1 to 11 the tool or technique applicable to the asset type is listed alphabetically. then the 'Service Type' refers to whether the techniques is used for clean water (potable) or waste water (sewage); the 'Assets Covered' refers to the assets that can be appraised with the tool or technique; the 'Assessment' specifies the type of information that the tool or technique can provide on the asset inspected; the 'Material' refers to the asset material that the tool or technique is suitable for assessing or can be applied to; ‘Service Interruption’ details the service requirements in order to use the technique, from ‘NA’ which would be typically for in-service non-destructive techniques that would not result in any service interruption to ‘off line’ which would refer to the asset being investigated being taken out of service for the tool or technique to be utilised, e.g. for disruptive destructive testing; ‘Access’ states the physical requirements in order to carry out the assessment with the tool or technique; ‘Data Requirements’ lists the type of information or prior testing required to utilise the tool or technique; ‘Accuracy’ refers to the level of detail of information, from qualitative to quantitative, that could be provided by the tool or technique; ‘Integration’ indicates the tool or techniques ability to be incorporated with other systems such as GIS; ‘International Commercialisation’ is an assessment of the tool or techniques commercial availability in the countries where the research was carried out (i.e. North America, Europe and Australia); ‘Skills Required’ provides an indication of the level of skill required to operate and interpret the results of tool or technique, form ‘basic’ indicating that the tool or technique could be used by a field technician to ‘specialist skills’ which would indicate that a trained experienced specialist would be required to utilise the tool or technique; ‘Available in SA’ is an assessment, by experts in the field, of the commercial availability of the tool or technique within South Africa.

In section 2.2.3 brief summary descriptions can be found for the tools and techniques in Tables 1 to 11 that were identified as being available in South Africa.

**Table 1 – Physical Property Testing (Destructive and Non-destructive)**

| | | | Tool or technique | Service Type | Assets Covered | Material | Assessment | Service Interruption | Accuracy | International Commercialisation | Skills Required | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipeline Assets | Physical Property Testing | Non-destructive | Barcol hardness | Waste and potable | NA | Plastics and cementituous | Material hardness | NA | Semi-quantitative | Yes - widely available | Basic | - |
| | | | Carbonation testing and petrographic examination | Waste and potable | NA | Cementituous | Depth of carbonation in mm | NA | Quantitative | Yes - widely available | Basic | Yes |
| | | | Corrosion burial test | Waste and potable | NA | Ferrous | Soil corrosivity | NA | Relative | - | Basic | - |
| | | | Schmidt hammer | Waste and potable | NA | Concrete and brick | Compressive strength | NA | Quantitative | Yes - widely available | Basic | Yes |
| | | Pipe Sample Tests - Destructive | Condition assessment of plastic pipes | Waste and potable | Pipes | Plastics | Material properties | Offline an sample | Quantitative | Through Testing Labs | Specialised skills | Yes |
| | | | Core/coupon sampling | Waste and potable | Pipes | Any | | Cores can be taken under pressure | NA-dependent on test | NA-dependent on test | NA - dependent on test | Yes |
| | | | Cut-out sampling | Waste and potable | Pipes | Any | - | Off-line | NA | NA - dependent on test | NA - dependent on test | Yes |
| | | | Fracture toughness C-ring | Waste and potable | Pipes | PVC | Fracture toughness | Off line on sample | Quantitative | Through Testing Labs | Specialised skills | Yes |
| | | | Indirect tensile strength test | Waste and potable | Pipes | AC and Conc. | Tensile strength | Off line on sample | Quantitative | Through Testing Labs | Specialised skills | Yes |
| | | | Methylene chloride gelation | Waste and potable | Pipes | PVC | Level of gelation | Off line on sample | Qualitative | Through Testing Labs | Specialised skills | - |
| | | | Pit depth measurement | Waste and potable | Pipes | Ferrous | Pit depth to infer rate of corrosion | Off line on sample | Quantitative | Yes-widely available | Basic | Yes |
| | | | Phenolphthalein Indicator | Waste and potable | Any cementituous | Cementituous | Carbonation depth | Off line on sample | Qualitative | Yes-widely available | Basic | Yes |
| | | | Slow crack growth resistance | Waste and potable | Pipes | PE | Resistance to slow crack growth | Off line on sample | Quantitative | Mostly applied as research tool | Specialised skills | Yes (Research) |

**Table 2 – In-pipe (Man Entry) Inspection Techniques**

| | | | Tool or Technique | Service type | Assets Covered | Material | Assessment | Service Interruption | Access | International Commercialisation | Skills Required | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pipeline Assets** | **Inspection Technique** | **In-Pipe (Man Entry)** | Active acoustic inspection | Waste and potable | Pipes | Cementituous | Presence of defects | Man entry | Man entry | Yes - widely available | Tool training required, with confined space | Yes |
| | | | Barcol hardness | Waste and potable | Pipes | Plastics and Cementituous | Material hardness | Man entry | Man entry | Yes - widely available | Basic with confined space | - |
| | | | Carbonation testing and petrographic examination | Waste and potable | Pipes | Cementituous | Depth of carbonation in mm | Man entry | Man entry | Yes - widely available | Basic with confined space | - |
| | | | Cover meter | Waste and potable | Concrete assets | Reinforced concrete assets | Cover depth to reinforcement | Man entry | Man entry | Yes - widely available | Basic with confined space | Yes |
| | | | Electrical potential (half cell) | Waste and potable | All reinforced concrete | Reinforced concrete | Detection of corrosion | Man entry | Man entry | Yes - widely available | Basic with confined space | - |
| | | | Man entry inspection | Waste and potable | Pipes | Any | Qualitative assessment of condition | Man entry | Man entry | Yes - widely available | Basic with confined space | Yes |
| | | | Pull-off adhesion testing | Waste and potable | Coaled assets | Any coaled assets | Adhesive strength of applied coatings | Man entry | Man entry | Yes - widely available | Basic with confined space | Yes |
| | | | Schmidt hammer | Waste and potable | Pipes | Concrete and brick | Compressive strength | Man entry | Man entry | Yes - widely available | Basic with confined space | Yes |

## Table 3 – In-pipe (Non-man Entry) Inspection Techniques

| Pipeline assets | Inspection technique | In-pipe (non-man entry) | Tool or Technique | Service type | Assets Covered | Material | Assessment | Service Interruption | Access | International Commercialisation | Skills Required | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Broad band electro magnetic | Potable | Pipes | Steel, cast iron and ductile iron | Remaining wall thickness | Off line as pipe needs to be depressurized | Full bore access | Yes | Specialist service | Yes |
| | | | CCTV | Mostly waste | Pipes | Any (less useful for plastics) | Structural condition - qualitative assessment | Low flow or offline for pressurized pipes | Internal use; mostly limited to assets £90mm | Yes-widely available | Interpretation requires specialist skills | Yes |
| | | | Fiberscope inspection | Waste and potable | Pipes | Any | Qualitative assessment of condition | Online or off line | Entry point (e.g. tapping) | Yes - widely available | Interpretation requires advanced skills | Yes |
| | | | In-pipe acoustic inspection tools (sonar) | Waste and potable | Pipes | Any | Pipe defects and geometry | On line | Access to pipe interior is required | Yes-widely available | Interpretation requires specialist skills | Yes |
| | | | In-pipes hydrophones | Potable | Pipes | Any | Leak detection | On line | Large diameter mains | Yes | Specialist service | Yes |
| | | | Intelligent pigs | Potable | Pipes | More suited to steel | Geometry or corrosion | May cause water quality issues | Mostly large diameter mains specialized insertion point | Limited use in water sector | Specialist service | Yes |
| | | | Magnetic flux leakage | Waste and potable | Pipes | Iron and steel | Metal loss | Offline | Available for external and internal use direct access to pipe wall required | Yes - specialist consultants | Specialist service | - |
| | | | Multi-sensor pipe inspection robots | Mainly waste | Pipes | Any | Depends on sensors used | Depends on sensors used | Access to pipe interior | No - under development | Advanced | - |
| | | | Passive acoustic inspection | Waste and potable | Pipes | Pre-stressed concrete (PCCP) | Detect failures of pre-stressed wires | On line | Access required for hydrophone entry | Yes - tool available from commercial supplier | Training required for tool use result analysis requires expert | - |
| | | | Remote field eddy current | Waste and potable | Pipes | Iron, steel and pre-stressed concrete (PCCP) | Internal or external defects | Offline | Cut-ins required; pipes >150mm diameter | Yes - specialist consultants | Advanced skills for interpretation tool applied by specialist | Yes |
| | | | Smart Digital Sewer Pipe Diagnostic System (VTT) | Waste | Pipes | Any | Automated analysis of defects | On line | Scanner inserted - not suited to small diameter pipes | No-under development | Advanced | - |
| | | | Smoke testing | Waste | Gravity sewer | Any | Indicates illegal connections | On line | Manhole access to sewer | Yes - equipment available | Basic | - |

## Table 4 – On-pipe Inspection Techniques

| Pipeline Assets | Inspection Technique | | Tool or Technique | Service Type | Assets Covered | Material | Assessment | Service Interruption | Access | International Commercialisation | Skills Required | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | On-Pipe | Acoustic emission | Waste and potable | Pipes | Any | Detection and location of material defects | On line | NA | Yes - available from selected vendors | Operator training is required | - |
| | | | Active acoustic inspection | Waste and potable | Pipes | Cementituous | Presence of defects | Off line and dewatered | Access to asset surface | Yes - widely available | Tool training required | Yes |
| | | | Barcol hardness | Waste and potable | Pipes | Plastics and cementituous | Material hardness | On line | Direct access to pipe surface | Yes - widely available | Basic | - |
| | | | Broad band electro magnetic | Potable | Pipes | Steel, cast iron and ductile iron | Remaining wall thickness | Off line as pipe needs to be depressurized | Exposure of pipe surface | Yes | Specialist service | Yes |
| | | | Carbonation testing and petrographic examination | Waste and potable | Pipes | Cementituous | Depth of carbonation in mm | On line | Direct contact with concrete surface | Yes - widely available | Basic | - |
| | | | Cover meter | Waste and potable | Concrete assets | Reinforced concrete assets | Cover depth to reinforcement | On line | Direct access to pipe surface | Yes - widely available | Basic | Yes |
| | | | Drop test | Waste and potable | Pipes | Any | Water loss from pipe | Offline | Access to monitoring points | General approach | Basic | Yes |
| | | | Electrical potential (half cell} | Waste and potable | All reinforced concrete | Reinforced concrete | Detection of corrosion | On line | Direct access to pipe surface | Yes - widely available | Basic | Yes |
| | | | Holiday detector | Waste and potable | Coated assets | Ferrous and concrete assets with coating for corrosion protection | Location of defects in asset coatings | Off line to test internal coating | Direct contact with coating | Yes - widely available | Basic technical skills | Yes |
| | | | Leak detection -Including acoustic, tracer gas and infrared photography | Potable | Pipes | Any- effectiveness depends on technique | Leak detection | On line | Most tests require access to pipe | Yes - tools widely available and applied | Dependent on technique used | Yes (acoustic) |
| | | | Linear polarization resistance | Waste and potable | Buried ferrous assets | Results relate to ferrous assets | Soil linear polarization resistance (LPR) | On line | Access to soil at point of interest | Equipment is widely available | Operator training required | - |
| | | | Magnetic flux leakage | Waste and potable | Pipes | Iron and steel | Metal loss | Offline | Direct access to pipe wall required | Yes - specialist consultants | Specialist service | - |
| | | | Measurement of strain | Waste and potable | Components made of homogenous material | NA | Stress and strain analysis | On line | Access lo surface | Yes - commercially available | Engineer trained in operation of tool | Yes |
| | | | On-line leak detection systems | Potable | Pipes | Any | Change in flow parameters that indicates leak | On line | NA | Developed for oil and gas sector, not yet widely applied in water sector | Automated monitoring (sophisticated tool) | Yes. |
| | | | Passive acoustic inspection | Waste and potable | Pipes | Pre-stressed concrete (PCCP) | Detect failures of pre-stressed wires | On line | Exposed surface for accelerometer | Yes - tool available from commercial supplier | Training required for tool use result analysis requires expert | - |
| | | | Pit depth measurement | Waste and potable | Pipes | Ferrous | Pit depth to infer rate of corrosion | Can be on line when done in-situ | Quantitative | Yes - widely available | Basic | Yes |
| | | | Pipe potential survey | Waste and potable | Pipes | Ferrous | Measures electrical potential between pipe and soil to infer corrosion potential | On line | Electrical contact with asset is required | Yes - available from commercial suppliers | Specialist training required | Yes |
| | | | Radiographic testing | Potable | Pipes | Ferrous, cementituous and plastics (not GRP) | Changes in material structure (inclusions, voids and corrosion) | Off line-as water absorbs radiation | Access required to both sides of pipe | Yes - tool and service commercially available | Advanced - requires specialized contractor | Yes |
| | | | Schmidt hammer | Waste and potable | Pipes | Concrete and brick | Compressive strength | On line | Direct access to pipe surface | Yes - widely available | Basic | Yes |
| | | | Ultrasonic measurement - continuous (guided wave) | Waste and potable | Pipes | Iron and steel | Level of wall thickness and corrosion pit depth | On line | Direct contact required with pipe wall | Yes | Basic - tool operation Advanced - analysis | - |
| | | | Ultrasonic measurements - discrete | Waste and potable | Pipes | Iron and steel | Level of wall thickness and corrosion pit depth | On line | Direct contact –smooth and clean surface | Yes - widely available | Trained technician | - |
| | | | Visual inspection | Waste and potable | All | Any | Qualitative visual assessment | On line | Physical access required | NA | Interpretation requires training | Yes |

## Table 5 – Valve and Meter Inspection Techniques

| Pipeline Assets | | | Tool or Technique | Service type | Assets Covered | Material | Assessment | Service Interruption | Access | International Commercialisation | Skills Required | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipeline Assets | Inspection Techniques | Meter | Visual inspection | Waste and potable | Meter | NA | Qualitative visual assessment | On line | Physical access required | NA | Interpretation requires operator training | Yes |
| | | | Volumetric X-ray or radiographic testing | Waste and potable | Welded joints, castings, electronic assets, etc. | Metal | Integrity of assets | Offline for laboratory testing or when meter interior is assessed | Direct access required to asset | Yes- commercially available from selected vendors | Advanced - requires specialized contractor | Yes |
| | | Valve | CCTV | Mostly waste | Valves | Any | Structural condition - qualitative assessment | Low flow or off line for pressurized pipes | Internal use; mostly limited to assets >90mm | Yes-widely available | Interpretation requires training | Yes |
| | | | Fibrescope inspection | Waste and potable | Valves | Any | Qualitative assessment of condition | On line or off line | Entry point (e.g. tapping) | Yes - widely available | Interpretation requires training | Yes |
| | | | Radiographic testing | Potable | Valves | Ferrous, cementituous and plastics (not GRP) | Integrity of assets | Off line-as water absorbs radiation | Direct access required to asset | Yes - tool and service commercially available | Advanced - requires specialized contractor | Yes |
| | | | Valve exercising | Potable | Valves | NA | Valve condition and operability | On line | Physical access required | Equipment required widely available | Basic-operator needs training | Yes |
| | | | Visual inspection | Waste and potable | Valves | NA | Qualitative visual assessment | On line | Physical access required | NA | Interpretation requires operator training | Yes |

## Table 6 – Strategic Planning for Pipes

| | | Tool or Technique | Service Type | Assessment | Data Requirements | International Commercialisation | Integration | Skills Required | Asset Management Sophistication | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|
| Pipeline Assets | Strategic Planning | AQUA-Selekt | Waste | Sewer condition | CCTV inspection data | Yes - has had limited application in Europe | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | AQUA-WertMin | Waste | Planning of CCTV inspection, rehabilitation and construction for sewer networks | Requires CCTV data | Yes - available from Germany; limited application | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | CARE-S | Waste | Service levels, budget setting, life cycle cost and rehabilitation planning | Dependent on models applied | No - research applications only | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | CARE-W | Potable | Service levels, budget setting, life cycle cost and rehabilitation planning | Dependent on models applied | No - some application in European cities | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | FailNet-Stat | Potable | Failure forecasting model for water pipelines | Good asset and failure data needed | No - only research application in Europe | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | KANEW | Potable | Strategic tool that estimates length of water mains to replace or repair each year | Good asset and failure data desirable | Yes - basic version available through AwwaRF | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | KureCAD | Waste | Applies GIS analysis for prioritisation of sewer rehabilitation | Good GIS data required | Yes | Links to GIS | Professional engineering skills | Basic to advanced | - |
| | | PARMS Planning | Potable | Long term asset management planning using asset failure curves developed from utility data | Good asset and failure data needed | Yes - used by a number of Australian utilities | No - standalone tool | Professional engineering skills | Basic to advanced | - |

**Table 7 – Strategic Planning and Hydraulic Assessment for Pipe Networks**

| | | | Tool or Technique | Service Type | Assessment | Data Requirements | International Commercialisation | Integration | Skills Required | Asset Management Sophistication | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipeline Assets | Network Assessment | Strategic Planning | PARMS Priority | Potable | Decision support system to assist in asset renewal decisions | Good asset and failure data needed | Yes - used by a number of Australian utilities | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | | PiReP/PiReM | Potable | Decision support system for rehabilitation planning of water networks | Good asset and failure data needed | No - under development with commercial release planned | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | | SCRAPS | Waste | Expert systems that prioritizes sewer inspections | Information on critical assets | Yes - available from WERF | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | | UtilNets | Potable | Reliability based decision support system for managing pipeline maintenance | Good asset and failure data needed | No - currently at prototype stage | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | | WARP | Potable | Long term asset management planning using asset failure curves | Good asset and failure data needed | Yes - planned release in 2006 | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | Hydraulic Assessment | FailNet-Reliab | Potable | Hydraulic reliability | Good asset and failure data needed | No-only limited research application | No - standalone tool | Professional engineering skills | Basic to advanced | - |
| | | | Hydraulic modelling | Potable and waste | Relationships between flow, pressure, roughness, capacity and service | High - good quality asset data needed | Yes - many commercial and public domain software available | Can link to GIS | Professional engineering skills | Basic - generic approach | Yes |
| | | | Inflow and Infiltration - sewer flow survey | Waste | Inflow and infiltration to sewers | High | NA - framework approach | Potential to link with GIS and hydraulic models | Professional engineering skills | Basic-generic approach | Yes |
| | | | Leak detection | Potable | Detection of leaks | NA | Tools widely available | NA | Operator training required | Basic-generic approach | Yes |

**Table 8 – Environmental Survey and Network Condition for Pipe Networks**

| | | | Tool or Technique | Service Type | Assessment | Data Requirements | International Commercialisation | Integration | Skills Required | Asset Management Sophistication | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pipeline Assets | Network Assessment | Network Condition | Leak detection | Potable | Detection of leaks | NA | Tools widely available | NA | Operator training required | Moderate | Yes |
| | | | WRc sewer rehabilitation man | Waste | Cost effective management of assets; identify service problems in drainage areas | High-but can be customized to be affordable | Framework available as manual | NA | High-professional engineering skills | Basic - generic approach | - |
| | | | WRc trunk main structural condition assessment | Potable | Current structural condition and remaining service life of water transmission pipes | Moderate | Framework available as manual | NA | High-professional engineering skills | Basic - generic approach | - |
| | | Environmental Survey | Ground penetrating radar | Waste and potable | Location of buried assets | Minimal data requirements | Yes- available from commercial suppliers | NA | Requires trained operator | Basic-generic approach | Yes |
| | | | Linear polarization resistance | Waste and potable | LPR gives indication of soil corrosion rate for buried ferrous assets | NA | Yes- equipment available from commercial suppliers | Results can be input to GIS | Requires trained operator | Basic - generic approach | - |
| | | | Pipe potential survey | Waste and potable | Measures electrical potential between ferrous pipe and soil to Infer corrosion potential | NA | Yes- available from commercial suppliers | Results can be input to GIS | Specialist training required | Basic-generic approach | Yes |
| | | | Soil characterization | Waste and potable | Soil parameters relevant to deterioration of buried assets | NA | Equipment and testing services widely available | Results can be input to GIS | Operator training; interpretation requires expert | Basic - generic approach | Yes |
| | | | Soil corrosivity | Waste and potable | Predicts corrosion rate for ferrous assets from soil characteristics | Pipe characteristics | Testing services widely available | Results can be input to GIS | Requires trained operator | Basic - generic approach | Yes |
| | | | Soil resistivity survey | Waste and potable | Indication of soil corrosion potential for buried ferrous pipeline assets | NA | Equipment and testing services widely available | Results can be input to GIS | Requires trained operator | Basic - generic approach | Yes |

## Table 9 – Electrical Assets

| | | Tool or Technique | Service Type | Assets Covered | Assessment | Access Requirements | Service Interruption | Accuracy | International Commercialisation | Skills Required | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Non-Pipeline Assets | Electrical Assets | AwwaRF's Manager Software | Potable | Water treatment works | Treatment work condition and value | NA | NA | NA | Available from AwwaRF | Professional asset manager/ engineer | - |
| | | Current monitoring | Waste and potable | Electric motors | Measurement of current in a circuit and comparison with design loads | No | On-line with safety precautions in place | Good- comparison with historical recordings can be used to identify onset of faults | Yes | Electrician required | Yes |
| | | Ductor testing | Waste and potable | Electrical connections, bus bars and contacts | Determines the contact resistance In draw-out contacts such as circuit breakers | Access to normally live parts | Off-line | Good | Yes-widely available | Trained electrical technicians or engineers | Yes |
| | | Insulation test | Waste and potable | Motor winding, cables, switchboards and motor control centres | Electrical insulation performance | Access to conductor and insulation | Off-line - Equipment needs to be isolated | Good accuracy | Yes - widely available | Trained electrical technicians or engineers | Yes |
| | | Load rejection test | Waste and potable | Power generation systems | Performance of power generation systems under these sudden load changes | Site specific | On-line | Dependent on approach | Widely available in other sectors | High - team of engineers | Yes |
| | | Motor circuit analysis | Waste and potable | Electric motors | Detection and monitoring of electrical motors and circuits | No - portable hand-held equipment | Off-line | Good accuracy | Yes - widely available | Trained electrical technicians or engineers | Yes |
| | | Oil testing | Waste and potable | Mechanical assets with oil as lubricant or coolant | Impurities and dielectric strength of oil, which may indicate asset condition | Sample of oil required | Dependent on equipment | Oil analysis is accurate, but only indicative of asset condition | Yes- commercially available | Laboratory analysis | Yes |
| | | Process control system (Integrated) | Waste and potable | Networked instrumentation or electrical equipment | Monitors assets and provides preventive maintenance data | Assets connected to field bus network | On line | Dependent on measured variable | Yes-widely available | Trained operator can assess condition data | Yes |
| | | Thermographic testing | Waste and potable | All electrical assets | Infrared imagery to locate defects and potential failures by scanning for thermal abnormalities | Direct access to live assets | On line | Qualitative | Yes | Held service engineer | Yes |
| | | Transformer circuit protection coordination | Waste and potable | High value electrical assets | Testing of electrical protective systems | Access to high voltage areas | Off line-power supply disruptions | Indicative tool | Yes | Field service engineer | Yes |
| | | Transient earth voltage | Waste and potable | All electrical assets | Detects discharges to earth through voids or insulation breakdown | No requirement for direct contact | On line | Qualitative inspection tool | Yes | Field service engineer | Yes |
| | | Ultrasonic emission inspection | Waste and potable | Electrical assets such as switchboards | Identify ultrasound waves that can indicate defects or failures | Physical contact required to outer casing | On line | Qualitative inspection tool | Yes | Field service engineer | - |
| | | Visual Inspection | Waste and potable | Electrical assets | Qualitative visual assessment; can include grading system. | Physical access required | On line | Qualitative | NA | Operator training required | Yes |

## Table 10 – Mechanical Assets

| | | Tool or Technique | Service Type | Assets Covered | Assessment | Access Requirements | Service Interruption | Accuracy | International Commercialisation | Skills Required | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Non-Pipeline Assets | Mechanical Assets | AwwaRF's Manager" Software | Potable | Water treatment works | Treatment work condition and value | NA | NA | NA | Available from AwwaRF | Professional asset manager/ engineer | - |
| | | Measurement of strain | Waste and potable | Any component made of homogenous material - e.g. motor shaft | Measurement of strain | No specific requirements | On line | Accurate | Yes- commercially available | Engineer trained in operation of tool | Yes |
| | | Oil testing | Waste and potable | Mechanical assets with oil as lubricant or coolant | Impurities and dielectric strength of oil, which may indicate asset condition | Sample of oil required | Dependent on equipment | Oil analysis is accurate, but only indicative of asset condition | Yes- commercially available | Laboratory analysis | Yes |
| | | Performance testing of rotating machinery | Waste and potable | Pumps, fans, motors, air blowers, mixers, etc. | Performance of rotating machinery, such as head, pressure, noise and vibration | No specific requirements | On line | Dependant on the accuracy of measuring device | Yes | Operator requires training for interpretation of results | Yes |
| | | Process control system (integrated) | Waste and potable | Networked instrumentation or electrical equipment | Monitors assets and provides preventive maintenance data | Assets connected to field bus network | On line | Dependent on measured variable | Yes - widely available | Trained operator can assess condition data | Yes |
| | | Thermographic testing | Waste and potable | All electrical assets | Infrared imagery to locate defects and potential failures by scanning for thermal abnormalities | Direct access to live assets | On line | Qualitative | Yes | Field service engineer | Yes |
| | | Ultrasonic emission inspection | Waste and potable | Electrical assets such as switchboards | Identify ultrasound waves that can indicate defects or failures | Physical contact required to outer casing | On line | Qualitative inspection tool | Yes | Field service engineer | - |
| | | Vibration analysis | Waste and potable | Rotating machinery, such as pumps, electric motors and fans | Condition fault diagnosis by measurement and analysis of vibration | Fixed point testing to ensure consistent measuring point | On line | Qualitative - assessment based on comparison with previous tests | Yes-fully developed and commercially available | Field service engineer | Yes |
| | | Visual Inspection | Waste and potable | Electrical assets | Qualitative visual assessment; can include grading system | Physical access required | On line | Qualitative | NA | Operator training required | Yes |
| | | Volumetric X-ray or radiographic testing | Waste and potable | Welded joints, castings, electronic assets etc. | Non-destructive method used for checking the integrity of metal assets | Unobstructed view of area of interest | Off-line for laboratory testing | Accuracy dependent on operator expertise | Yes- commercially available from selected vendors | Operator requires training for image interpretation | Yes |

## Table 11 – Civil and Building Assets

| | | Tool or Technique | Service Type | Assets Covered | Assessment | Material | Service Interruption | Accuracy | International Commercialisation | Skills Required | Available in SA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Non-Pipeline Assets | Civil and Building Assets | Acoustic emission- | Waste and potable | Storage tanks, pressure vessels, aerial lift devices, welded joints | Detection and location of material defects | Any | On-line | Qualitative estimates of material damage | Yes - available from selected vendors | Operator training is required | - |
| | | Air permeability | Waste and potable | Concrete elements with flat surfaces (slabs, walls, pavements, etc.) | Permeability, quality class and capillary suction of concrete | Concrete | On line | Excellent measure of resistance of concrete against aggressive media | Yes - limited use in water sector | Basic technical skills | - |
| | | AwwaRF's Manager Software | Potable | Water treatment works | Representing asset and condition data within a consistent framework | NA | NA | NA | Available from AwwaRF | Professional asset manager/ Engineer | - |
| | | Barcol hardness | Waste and potable | Pipes | Material hardness | Plastics and cementituous | On line | Semi-quantitative | Yes - widely available | Basic | - |
| | | Carbonation testing and petrographic examination | Waste and potable | Tanks, walls, buildings, dams, etc. | Presence of carbonation to determine concrete quality and protection of steel reinforcement | Reinforced concrete assets | On line | Qualitative | Yes | Basic | Yes |
| | | Concrete electrical resistance | Waste and potable | Tanks, walls, buildings, dams, etc. | Corrosion rate of reinforcement bars in concrete | Reinforced concrete assets | On line | Indicative of asset condition | Yes - available from selected vendors | Basic technical skills | Yes |
| | | Core sampling | Waste and potable | Civil assets | Sample core taken for analysis and testing | Reinforced concrete assets | NA | NA- dependent on test | NA-dependent on test | NA - dependent on test | Yes |
| | | Cover meter | Waste and potable | Concrete assets - tunnels, walls, dams, beams, etc. | Cover depth to reinforcement | Reinforced concrete assets | On line | Accurate survey of reinforcements in concrete assets | Yes-widely available | Basic | Yes |
| | | Crack measurement | Waste and potable | Concrete assets - tunnels, walls, dams, beams, etc. | Measuring linear deformations, cracks, settlements and shrinkage coefficients | Reinforced concrete assets | On line | Quantitative | Yes-widely available | Basic | Yes |
| | | Electrical potential (half cell) | Waste and potable | All reinforced concrete assets | Detection of corrosion | Reinforced concrete | On line | Up to 95% | Yes - widely available | Basic | - |
| | | Holiday detector | Waste and potable | Coated assets | Location of defects in asset coatings | Coated ferrous and concrete assets for corrosion protection | Off line - to test internal coating | Qualitative | Yes - widely available | Basic technical skills | Yes |
| | | Impact echo method | Waste and potable | Concrete assets - tunnels, walls, dams, beams, etc. | Determine concrete thickness or location of internal defects | Concrete | On line | Good accuracy for thickness measurements | Yes-available from commercial suppliers | Basic - operation; Expert - defect categorization | - |
| | | LPR for corrosion monitoring | Waste and potable | Concrete assets - tunnels, walls, dams, beams, etc. | Concrete temperature that allows structure's long-term performance to be determined | Reinforced concrete | On line | Results are indicative only | Yes - available from selected vendors | Basic | |
| | | Magnetic flux leakage | Waste and potable | Metal assets-tanks, etc. | Metal loss | Iran and steel | Offline | Quantitative assessment | Yes- specialist consultants | Specialist skills | - |
| | | Measurement of strain | Waste and potable | Any component made of homogenous material, dams | Measurement of strain | No specific requirements | On line | Accurate | Yes- commercially available | Engineer trained in operation of tool | - |
| | | Phenolphthalein indicator | Waste and potable | Any cementituous civil assets | Carbonation depth | Cementituous | On line | Qualitative | Yes - widely available | Basic | - |
| | | Pull-off adhesion testing | Waste and potable | Coated tanks, etc. | Adhesive strength of applied coatings | Any coated assets | On line | Quantitative | Yes-widely available | Basic | Yes |
| | | Schmidt hammer | Waste and potable | Any cementituous civil assets | Compressive strength | Concrete and brick | On line | Quantitative | Yes-widely available | Basic | Yes |
| | | Discrete Ultrasonic measurements | Waste and potable | Steel civil assets | Level of wall thickness and corrosion pit depth | Steel | On line | Quantitative | Yes - widely available | Trained technician | - |
| | | Visual Inspection | Waste and potable | Civil assets | Qualitative visual assessment; can include grading system | Any | On line | Qualitative | NA | Operator training required | Yes |

### 2.2.3 Summary Descriptions of Tools and Techniques

#### 2.2.3.1 Introduction

A brief summary of the descriptions of the tools and techniques found in Tables 1 to 11, which have been identified as being available in South Africa, have been provided in alphabetical order (to assist the reader). Comprehensive descriptions of all the tools and techniques can be found in the other references provided or in Marlow *et al.* (2007)[2].

#### 2.2.3.2 Active Acoustic Inspection

This non-destructive technique uses the transmission of sound to assess defects in the structure of pipes; generally of cementituous materials. A known force is imparted to the asset and sensors measure the response. Cracks, delaminations and other discontinuities affect the transmission of sound. Generally damaged pipes will display lower wave speeds and thus propagate less energy to the sensors. Depending on the response, the assessor can identify whether the asset has cracks and/or other defects.

The active acoustic inspection tool consists of a means of imparting sound energy and sensors to detect that energy. An impact, generally from a steel ball, is used to impart sound energy which propagates along the asset's length. Sensors are placed to detect the propagated sound. Assets with defects such as crack or voids will experience some reflection of the sound reducing the energy that reaches the sensors.

Acoustic techniques rely on the propagation of sound waves travelling through the component and can be divided in two main classes namely acoustic monitoring and ultrasonic testing. In acoustic monitoring, an active crack is required for detection. When an incremental crack extension occurs, the energy release causes a mechanical wave to propagate through the structure. The mechanical wave can then be detected by the sensor (which is normally a piezoelectric crystal)[3].

#### 2.2.3.3 Broadband Electromagnetic

The broadband electro magnetic (BBEM) technique is an eddy current based technique. In eddy current methods the thickness of a pipe wall is determined by measuring induced magnetic fields in ferromagnetic material (typically steel and ductile iron). While conventional eddy current inspection techniques use a single frequency, BBEM induction techniques record data over a broad range of frequencies. As the depth of penetration is dependent on the frequency of excitation, this thus allows information from a range of depths to be obtained by utilising a range of frequencies.

The BBEM technique works by passing an alternating current through a transmitter coil at the surface of the pipe, which generates an alternating magnetic field. Flux lines from this magnetic field pass through the metallic pipe wall, generating a potential difference across it. This voltage produces eddy currents in the pipe wall that produce their own, secondary magnetic field. By measuring the strength of these magnetic fields or the eddy current that produces it, the remaining metallic wall thickness can be determined.

The technique is non-destructive and commercial suppliers of BBEM state that signal can be received through all forms of external coating, and in all ferrous materials.

#### 2.2.3.4 Carbonation Testing and Petrographic Examination

In normal high quality reinforced concrete, the steel reinforcement is chemically protected from corrosion by the alkaline nature of the concrete. Carbonation testing measures the depth of carbonation and can be determined using onsite or laboratory based techniques. The depth of carbonation can be measured on a freshly exposed core section of concrete by spraying with a phenolphthalein indicator spray solution. The indicator will also highlight the distribution of fine cracks and micro-cracks. Micro-crack frequency is measured along lines of traverse across the surface. Carbonation testing is commonly undertaken on structures constructed from concrete materials, to determine the existence and depth of carbonation.

The practical considerations are that the more complex assessment techniques conducted in the laboratory require skilled laboratory staff to prepare samples from cores, for the analysis and the interpretation of the experimental results. Analysis techniques conducted onsite using phenolphthalein have the advantage, that in some applications, that they can be undertaken without the need to take core samples. A limitation to this effect is components that contain carbonation along micro-cracks and diffusion paths in poorly compacted concrete, which may not be readily revealed by the phenolphthalein analysis technique.

#### 2.2.3.5 CCTV Inspection

CCTV inspection methods were introduced in the 1960s and provided an inexpensive and safer option to direct inspection methods. CCTV inspection is a simple approach for pipe interior inspection. The CCTV consists of a camera that is mounted on a wheeled platform capable of travelling along the pipe. The inner surface of the pipe is videotaped during the inspection and recorded images are transmitted to a remote station located above ground and reviewed by an engineer off-line. The engineer detects, classifies and rates the severity of defects against documented criteria. The manual assessment procedure is labour intensive and time consuming and therefore increases the overall inspection costs. Computer software is widely available for interpreting CCTV results.

CCTV condition assessments are made by professionals, either during inspection or at a later time using the recording images. For wastewater pipelines, standards are available for qualitative and quantitative grading of defects and a system for ‘condition grading’, which is commonly used as the base for rehabilitation decisions. A condition grade is allocated to represent the range of conditions from a “like new” to a “collapsed” or “collapse imminent” main. The accuracy of the condition grading depends on the inspector's experience. CCTV inspections can only provide an assessment of the internal surface of the main, but can provide the base information on which further inspection tools can be used to provide specific information on the pipe wall.

Other complementary technologies, such as Germany Karoo System, TRI-Scan, the Japanese Pipe Sewer Scanner and Evaluation Technology (SSET), and the Laser Based Scanning technique and the PIRAT system developed by an Australian research agency CSIRO are being used extensively in various geographical environments. CCTV has also been used in combination with other technologies to obtain improved condition data. CCTV has been used in conjunction with GIS and sonar equipment. In South Africa, a few large water utilities use CCTV for pipeline inspections, e.g. Joburg Water.

The main advantage of CCTV technology is that it provides visual examination of the entire length of the pipeline and there is considerable body of knowledge available to aid interpretation of results.

A disadvantage is that defects hidden from the camera by obstructions may not be detected thus, dewatering of the pipeline is usually required before inspection.

**Case Studies**

Below are some examples of case studies where CCTV has been used to collect condition data for assessing sewer systems for asset management.

- The City of San Diego in California, USA implemented a CCTV program to address sewage spills. The purpose of the CCTV inspections was to develop a rehabilitation and replacement program for sewer pipes. Pearpoint tractor equipment was used for the inspections and the CCTV data was assessed by qualified engineers who made recommendations to the city for rehabilitation and replacement[4].
- The City of Fort Worth in Texas, USA has expanded its sewer maintenance group to include a CCTV inspection division. The CCTV division was set up to address numerous problems experienced in the sewer system. The cost of the CCTV inspections in 1998 was $1.28/meter[5].
- El Toro Water District (ETWD) also utilised CCTV inspections for assessing the condition of its water and sanitary sewer collection network. ETWD used a custom-built mainline inspection vehicle for surveying its entire system and documenting its integrity. The agency utilised flexidata (PipeLogix, www.pipelogix.com) for its data collection and creation of survey reports. The collected information was transferred from the field computer directly to CDs or DVDs[6].

Some countries have produced CCTV technology specifications and guidelines that are legally binding, whenever a contractor is hired for the collection of CCTV data for pipeline condition assessment. Examples are the Launceston City Council in Australia (*General specifications for CCTV Survey Pipeline Inspection*, S*ection X, July 2005*)[7] and the City of Ukiah and Ukiah Valley Sanitation District (*Requirements and Standards for Closed Circuit Television Sewer Lateral Inspections*)[8].

### 2.2.3.6 Concrete Electrical Resistance (Resistivity)

Resistivity meters are used for measuring the electrical potential fields to evaluate the corrosion rate of the reinforcing bars in the concrete. The electrical resistance of the concrete is measured according to the Wenner four-point method. Resistivity measurements can be performed by measuring the permeability of seal coats on concrete. Resistivity meters can be used to investigate the influence of various concrete components on the electrical resistance of reinforcement. After completing permeability testing an additional resistivity test can give the saturated (worst case) resistivity of the concrete. Resistivity meters provide immediate on-site measurement of concrete resistivity.

#### 2.2.3.7 Condition Assessment of Plastic Pipes

Condition assessment for plastic pipes is often difficult because they do not lose material from the pipe wall, instead, fracture in plastic pipes occurs by crack initiation from defects either inherent in the pipe wall or from damage sites on the pipe's outer surface. Currently there are no non-destructive techniques available to locate cracks in plastic pipes before failure occurs. However, destructive condition assessment techniques can be used to assess the level of resistance to this kind of failure. These destructive approaches available can only provide a relative measure of pipe's quality.

The remaining lifespan of a specific asset can only be estimated based on the expected size of inherent defects within the pipe wall and damage at the pipe's outer surface (i.e. by comparing the material properties of the pipe sample in comparison to industry benchmarks).

#### 2.2.3.8 Core/Coupon Sampling

Core/Coupon sampling is a method for obtaining small samples on which to conduct testing. The samples obtained by this method are small enough so that pipes can be repaired using standard repair clamps. Sampling can be conducted on any pipe type and material with the exception of vitrified clay pipes due to its brittle nature.

Core and coupon sampling are similar with the exception that core samples are generally removed using a drill, whilst coupons are cut from the pipe wall and can be any size without being fully circumferential. These samples can be used for phenolphthalein testing, carbonation testing, pit depth measurements and other tests depending on the pipe material.

Core and coupon sampling is widely used and relatively simple to carry out. Samples can be obtained during normal work practice, such as when a new connection is made to a water pipe or when a section is removed. Due to the small sample sizes, samples may not be representative of the entire pipe circumference nor provide an assessment of the condition along the whole pipeline.

#### 2.2.3.9 Cover Meter – Reinforcement Location and Measurement

Cover meters are a non-destructive means for determining the depth to concrete reinforcement, the location of reinforcement at different depths up to 360mm, bar spacing and anchor setting points in concrete assets. Cover meters use the eddy current testing method. Along with concrete quality, cover thickness is the single most important durability parameter for concrete structures. The pulse current method can be combined with a scan car that measures the position of the measuring head relative to the concrete surface.

Cover meters can be sophisticated tools and some digital versions can calculate and display the location of reinforcement instantaneously. Generally logged data is date and time stamped and the results can be downloaded to PC. Some cover meters have a built-in facility to measure half-cell potential measurements as well as the Eddy current method. The combination of both methods results in accurate surveys of reinforcement in concrete structures. BS1881:242 stipulates accuracy requirements for cover meters when measuring at different ranges. Advanced cover meters can have an accuracy of ±1 mm. Cover meters can be used on concrete slabs, walls, columns, pipes and spiral mesh. Cover meters lose accuracy at greater depths.

#### 2.2.3.10 Crack Measurement Tools

Cracks in concrete structures can be measured with a range of tools such as Deformation Meters, Measuring Magnifier, Crack Width Meter and Crack Monitor. These crack measurement tools are used for different applications and thus have different measuring ranges and accuracies.

Deformation Meters are used for measuring linear deformations, cracks, settlements and shrinkage coefficients. The Deformation Device references two base plates in the structure and can accurately measure the change in length of structure over time. Measuring Magnifiers typically have a magnification of 8× and can measure cracks with widths limited to 0.2-0.3 mm in concrete structures. The Measuring Magnifier enables accurate determination of whether cracks exceed these limits. The Crack Width Meter is used as a comparator to provide an approximate crack size during visual surveys. The Crack Monitor is used on structures where the rotation at cracks is also significant. The crack monitor gauge is specifically designed to measure rotation, transverse and longitudinal movement and special fittings are available to allow the measurement of external and internal corners.

Crack measurement tools can be applied to a wide range of structures and substrates, including steel (ASTM El 457-00 Standard Test Method for Measurement of Creep Crack Growth Rates in Metals). Crack measurement tools are widely used for the condition assessment of concrete structures and are commercial available.

#### 2.2.3.11 Current Monitoring

By monitoring variations in current flow the onset of electrical faults can be identified before equipment breakdown occurs. Current monitoring analysis can be used to detect electric motor problems such as broken rotor bars. This technique can be used on electrical induction motors, synchronous motors, compressors, pumps and motor operated valves to determine changes in the level of performance that occurs over time and enable repair or replacement prior to electrical faults or equipment breakdowns occurring.

Clamp-on ammeters are widely available from numerous suppliers; older units can only be used on AC equipment while newer equipment can measure both AC and DC. The sensitivity of portable clamp-on ammeters is often dependant on the cost, however most units can measure current flow with a high degree of accuracy. Monitoring can be undertaken whilst the equipment is on-line with minimal disruption. Routine current monitoring enables the determination of equipment-electrical faults prior to failure.

#### 2.2.3.12 Cut-out Sampling

Cut-out sampling is a method for obtaining a short pipe ring samples on which a range of tests can be undertaken. It’s a destructive technique that can be carried out on pipes made from any material. However, due to the disruption and costs involved it is generally used on smaller diameters pipes. It is also unlikely for this sampling method to be conducted on re-enforced concrete pipes and vitrified clay pipes due to their brittle nature.

If the sample required is not a ring sample and is small enough so that the area could be using a clamp type repair, then core or coupon sample would be a better alternative. Samples obtained can be used for tensile or compressive strength testing, pit depth measurement, fracture toughness testing and other tests depending on the pipe material.

#### 2.2.3.13 Drop Test

Drop tests are a simple non-destructive method for identifying areas of a network containing significant leakage. A drop test can be undertaken for individual pipelines both new and old, small pipe network areas and larger areas. Drop tests work by isolating the area of interest and observing either the level of water in a reservoir or water pressure. Loss of water head/height indicates that either the pipe(s) or valve(s) are leaking. Similar testing has also been used to measure exfiltration in sewers. Leak detection provides both an indication of condition and the performance of the asset, depending on the amount of leakage detected on a section of pipe. However, it does not provide details regarding the actual condition of the pipe or pipe network.

As a general approach to assessing water tightness, drop testing can be undertaken by any utility. The simple nature of the test has allowed this technique to be widely used in the water and other industries. It has been used in the U.K. water sector as a low technology approach to assessing leaks in transmission mains. It has also been used in research to assess the level of exfiltration from sewers. The accuracy of drop testing is limited by the type of method used to assess leakage (level or pressure drop) and the size of the area being tested. The drop test can be used to gain a quantitative measure of leakage for a pipe or area of pipe network.

#### 2.2.3.14 Ductor (Micro Ohm Resistance) Testing.

The Ductor (proprietary name) test is a non-destructive assessment to determine the contact resistance in draw-out contacts on high current devices and bus bar interconnections located in electrical power distribution boards and switchboards. The two current leads are connected across the joint to be tested. The resistance is calculated from the test current and sense voltage, with the resistance measured in micro Ohms. The Ductor assessment method is commonly undertaken to determine the condition of electrical circuit breaker contacts, switchgear contacts, cable joints and bus bars joints where high currents are encountered.

Auxiliary supply voltage to the test unit is typically 100-250 V AC. Test equipment with downloadable facilities are available. Ductor test assessments are sensitive and provide measurements of micro Ohms. Prior to undertaking Ductor testing the equipment being assessed must be isolated and previous test results are required in order to assess the condition of the asset.

#### 2.2.3.15 Electrical Potential (Half Cell) Measurement of Concrete Reinforcement

Electrical potential measurement is a non-destructive technique that can be used to identify areas of reinforced concrete in need of repair or protective treatment before corrosion causes cracking and spalling. To measure the electrical potential, an electrical connection is made to the steel reinforcement of the asset that is being assessed (see figure 2). Electrical potential measurement is used to assess the corrosion potential of the steel reinforcement in civil reinforced concrete assets. ASTM Standard C876 provides guidelines for evaluating corrosion in concrete structures. Electrical potential measurement is also referenced in BS 1881: Part 201. Electrical potential measurement is a safe, rapid, cost-effective and non-destructive method of condition assessment, which offers key information on the evaluation of corrosion. It is the simplest way to assess the severity of steel corrosion, as it measures corrosion potential, which is qualitatively associated with steel corrosion rate. Confidence in electrical potential measurement as an indication of corrosion potential has developed greatly as a result of bridge deck corrosion surveys.

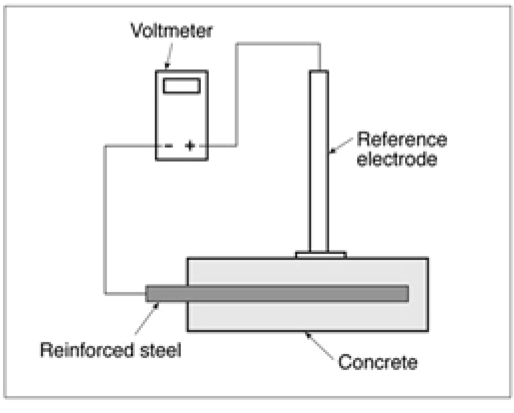


***Fig. 2.*** *Schematic Illustration of Electrical Potential Measurement Technique*

Electrical potential measurement does not directly indicate the rate of corrosion. The factors influencing the electrical potential measurements are affected by: the resistivity of the concrete, the pH of the pore solution (carbonation), the concrete cover depth, any coatings and sealers, and concrete patch repairs.

Electrical potential measurement cannot be used on structures with active cathodic protection systems. Electrical potential measurement should never be used as an assessment of condition in isolation.

### 2.2.3.16 Fiberscope Inspection

Fiberscope inspection works similar to CCTV inspection but relies on optical fibres to gather images, which can be observed using an eyepiece. This technique can be used to inspect small diameter pipes and valves. One important feature is that the fiberscope allows internal inspection of charged water mains. Fiberscopes are generally used for visual inspections of mains for corrosion or sediment build-up. A camera can be attached to the eye piece of the fiberscope to record the inspection.

Fiberscope inspection is suitable for capturing visual images of the internal surface of water mains, primarily small diameter mains, and can be used to assess the condition of internal linings, the build up of corrosion products, and other features of interest. This technique can also be used for in-service inspection of valves.

### 2.2.3.17 Fracture Toughness (C-Ring) Testing

Fracture toughness testing is a destructive test where a specimen is statically loaded and the time to failure measured (see figure 3). It is generally used for quality control testing, but it can be used to test samples taken from in service PVC pipes. Fracture toughness testing gives an indication of the materials resistance to cracks and fast fracture. C-Ring fracture toughness is used to determine if a section of PVC pressure pipe exceeds a minimum fracture toughness set by the relevant standard or water utility.

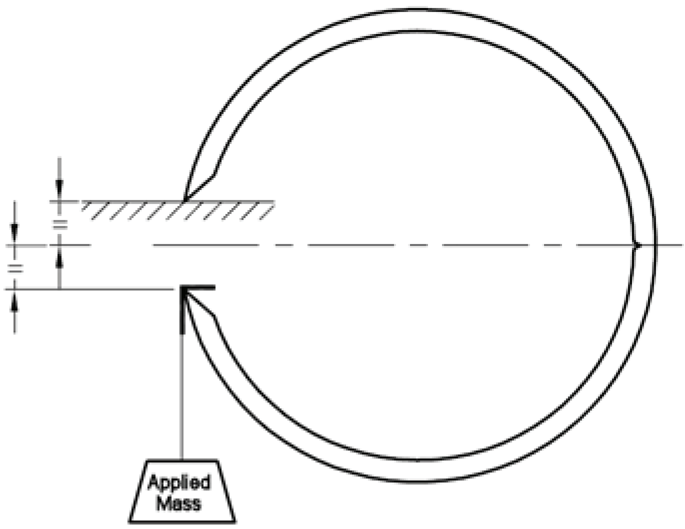


***Fig. 3.*** *Schematic of C-Ring Fracture Toughness Testing*

This test is widely used in the plastic pipe industry by both manufacturers and utilities and should only be conducted in a laboratory by qualified personnel. If the notch is not located at the point of lowest gelation (the point of greatest attack during Methylene chloride testing) the test results cannot be considered reliable. The test gives an indication of the pipe susceptibility to failure by fast fracture; the test can be extended to obtain information about the probable lifetime of a pipe section.

### 2.2.3.18 Ground Penetrating Radar (GPR)

Ground Penetrating Radar (GPR) is a technique for acquiring subsurface information. GPR works by emitting short bursts of electromagnetic radiation into the ground and recording the radiation reflected to locate buried assets of any material. The amplitude of each emitted pulse received by the GPR unit is recorded on a time scale or distance (if wave velocity is known) providing a vertical plot or 'trace' for each pulse. As the unit is moved along the ground, a series of traces are taken and colours or grey scale allocated to the amplitudes of each. The 'coloured' traces are then placed along a distance scale and the 2D profile created.

The depth of penetration is also dependant on soil type, with low electrical conductivity soils providing the deepest penetration. Whilst the penetration, in soils with a high electrical conductivity is limited by the attenuation of the wave pulse due to its conversion into thermal energy. Also, soils with large numbers of discontinuities will cause signal scattering, reducing the penetration of the pulse deeper into the subsurface. The location of assets is achieved quickly in the field, though accurate interpretation of the results requires a skilled operator

The repeatability of measurements is very high when there has been no change in soil conditions; variations in soil conditions will affect the results due to the change in the soil's wave pulse velocity and signal attenuation. Unlike other location techniques GPR is able to locate polymer and clay assets. Penetration into soils with high electrical conductivity, like mineralogical clays, can be limited to less than one meter. The ability to detect an asset below the water table is reduced by signal loss due to scattering at water table boundary and signal attenuation due to the high electrical conductivity below the water table.

#### 2.2.3.19 Holiday Detector

Holiday detectors are commonly known as porosity detectors, spark testers or jeepers. Holiday detectors can be used on any asset which has a conductive substrate and non-conducting (insulating) coating, from ductile iron pipes to tanks. Holiday detectors work by applying a constant current source to the coating substrate, which results in an applied test voltage. A typical DC detector delivers a stabilized DC output of up to 30kV with a resolution of 10V. Flaws are located by moving the detector over the coated surface; when the detector moves over a flaw, the applied potential 'jumps' from the substrate to the detector. A visual and/or audible alarm indicates when a fault is found. Some holiday detectors use the wet sponge method to detect pinholes in coatings. This method is recommended for thin film porosity testing (coatings under 150 um), or in favour of high voltage testing, particularly when working with coatings in corrosive environments.

Holiday detectors are handheld and come in a variety of types for the inspection of a wide range of asset types and can be obtained from a number of suppliers. They are used widely in industries where the integrity of coating is important and can detect cracks, blow holes, burrs, air bubbles and inclusions. Holiday detectors can only be used to find flaws in coatings whose substrate is made from a conductive material such as metal and concrete. Holiday detectors can be used to rapidly test the quality of a coating, including defects that cannot be detected by visual inspection.

### 2.2.3.20 Hydraulic Modelling

Hydraulic models represent mathematically the relationships between flow parameters such as pressure, diameter, roughness and slope, and service demand. There are many commercially available software packages that model the hydraulic behaviour of pressure and gravity pipelines or networks. Hydraulic modelling enable network design, simulation and optimisation. Hydraulic models are calibrated against measured values of pressure and/or flow. Once calibrated, the hydraulic model can be used to identify hydraulic issues (such as surge or water hammer) within the pipeline or network. When identified, asset inspections and other survey techniques can be used to investigate further.

Hydraulic modelling is used for the analysis and design of pressure and gravity pipelines and networks. Model calibrations through adjustment of friction factors can provide some indication of the pipe's internal condition.

### 2.2.3.21 Indirect Tensile Strength Testing

The tensile strength of cylindrical cores taken from concrete or asbestos cement pipes are used as a measure of residual tensile strength of the pipe. Once extracted, the cores are compressed to failure. The comprehensive stress at failure can be used to indirectly obtain the residual tensile strength of the pipe from which the core was taken. By measuring the current tensile strength of the core and comparing that to values for virgin pipe, the rate of deterioration of the cement matrix can be estimated and applied to predict the time to failure of the pipe under known operating and installation conditions.

The testing of the core itself is destructive. Since only cores are taken, the pipe itself must be repaired. If only one core is extracted, the pipe can be clamped. However, a common practice is to remove a section of a pipe from which multiple cores are then taken. In this case, the pipe section must be replaced. This is a new test that is not widely used. The pipe must be exhumed for removal of test sample, and the pipe repaired or pipe section replaced. Testing of asbestos cement pipe samples is subject to health and safety considerations.

#### 2.2.3.22 Infiltration and Inflow – Sewer Flow Survey

Sewer flow surveys are often used to calibrate hydraulic models (see Section 2.2.3.20 Hydraulic Modelling review), but they can also be used to determine where infiltration of groundwater or inflow of water (other than infiltrated groundwater such as rain water) into the system is a problem. The aim of a flow survey is to obtain actual flows in the sewer system during both dry and wet weather conditions.

Flow surveys can be used to identify parts of the system where infiltration and inflow flows originate and estimate their magnitude. Flows to these key manholes are monitored and compared to the expected sewer flows from the subsystems. Once data is collected it is analyzed to provide several flow parameters including average dry-day flow, maximum and minimum diurnal flow, inflow, rainfall-induced infiltration, seasonal infiltration, etc. Infiltration and inflow flow surveys allow the detection of excessive flows and the targeting of capital investment to solve operational issues in sewer networks and treatment plants.

#### 2.2.3.23 In-Pipe Acoustic Inspection Tools (Sonar)

CCTV inspection is the industry standard technology for measuring the internal condition of sewers and storm water pipes. However, this technique is limited in that it only allows inspection above the flow line – interpretable CCTV images can not be obtained below the flow line due to the turbidity of sewage (see Section 2.2.3.5 CCTV Visual Inspection review). An alternative technique, sonar, also provides pictorial evidence of sewer condition. Unlike CCTV, sonar can be used in full sewers, or to inspect the sewer beneath the flow line. Sonar can also be used to give an image of the sewer above the flow line. However, different transducers and electronics are required for operation in air and water. As such, sonar suitable for below the flow line can not give an image of the sewer above the flow and vice versa.

Sonar inspection has been utilized mainly in sewer pipelines. In water mains, the resolution of the inspection technique is not sufficient to detect small defects that are significant in pressure applications. Furthermore, other competing inspection technologies (including leakage detection) can provide the required information. Nevertheless, the principle of sonar inspection can still be used to measure the distance to the pipe wall. Acoustic systems for flow detection are also available that are based on detecting vibrations and other phenomena caused by the spreading of mechanical sound waves, and are suitable for detecting cracks and for determining the state of connections and pipe bedding.

**Combined Sonar and CCTV**

CCTV has been combined with other technologies to enhance condition data collection. Underwater Sonar equipment has been combined with CCTV in Canada and large diameter sewer condition assessments have been successfully conducted.

Sonar technology involves the emission of an acoustic pulse from a transducer and the subsequent reception of the pulse echo reflected from some surface. The time delay from the instant of transmission to the instant of reception can be used to determine the distance from the transducer to the surface which reflected the pulse[9].

In the case of sewer inspection, the Sonar transducer is mounted in an appropriate housing and towed through the sewer. The acoustic signal, or pulse, is transmitted radially toward the sewer wall using a rotating transducer and by analyzing the received echo the distance from the transducer to the wall can be calculated and the shape of the interior wetted perimeter determined. The on-board computer generates images of the interior perimeter in real time and produces a display. The Sonar equipment is deployed similarly to camera inspection equipment. That is, the equipment is placed in a rig configured to the size of the sewer, a tow cable is used to advance the rig and Sonar through the sewer and an umbilical cable provides communication with the control and monitoring computer at the surface. When used in conjunction with CCTV equipment the Sonar unit is suspended below the rig.

The inspection record sheets contain coded information which identifies all observations made during inspection of a particular reach of sewer. Information recorded includes, among other things, noted defects (such as cracks, encrustation, missing bricks, open joints, etc.), alignment changes, changes in cross-section or pipe material, sediment deposits, and connection sizes and locations[9].

**Case Study**

Combined Sonar and CCTV equipment has been used in the past two years to inspect over 50,000 meters of trunk sanitary sewers and combined sewer interceptors in Canada. Two of these sewers are:

- The high level interceptor in Toronto, Canada was inspected using sonar technology combined with CCTV technology. The sonar technology was used for very deep pipelines (depth cover of 10 meters), with very large diameter sizes approximately 1,825 mm to 2,600 mm and also where there where rapid cross section transitions. The purpose of the inspection was to assess the condition of the linings for the various pipes types constituting the interceptors. The linings were found to be in good to very good condition[9].

- The western sanitary interceptor sewer in Hamilton, Canada. The sewers conveyed industrial effluent which was suspected to be corrosive thereby corroding the pipe invert. Sonar images indicated significant chemical corrosion had not occurred in the sewer. However, this review did indicate that some structural distortion had occurred subsequent to construction which is likely due to inherent weaknesses in the unreinforced concrete tunnel lining. Observations of isolated longitudinal cracks in the pipe with the CCTV equipment were confirmed by the Sonar findings[9].

## 2.2.3.24 In-Pipe Hydrophones

Hydrophones are used to detect leaks due to the noise created by the water as it is forced out under pressure, through the pipe wall. Leaks generally make three sounds; a medium frequency sound (500-800 Hz) which is associated with the water passing through the leak orifice; and two low frequency noises (20-300 Hz) which are associated with the water stream impacting the soil and circulating around the outside of the pipe[10]. The sound of the leak can also provide an indication of the magnitude of the leak. In in-pipe hydrophones an underwater microphone is inserted into a pipe and moves along the pipe with the flow. The hydrophone is introduced to the pipe via a valve or tapping made for the purpose of the inspection. There is also potential to utilise existing access points provided by hydrants or fittings (e.g. air valves and scour valves). In-pipe hydrophones are generally tethered systems, although some free swimming technologies are also available.

Water loss control programs are widely used throughout the water industry and a major phase of these programs is leak detection. Leak detection with in-pipe hydrophones, is used to determine the exact location of a leak. Repairing of these leaks saves the utility revenue, conserves water supply and energy. Leaks are located by first identifying or detecting a leak and then it can be located by moving the hydrophone to the position where the noise is clearest, then determining the location of the hydrophone at this point. This provides a very precise leak detection and location for main of any material.

### 2.2.3.25 Insulation Test

Deteriorated insulation allows a steady flow of electricity to escape from the electrical circuit during operation. As part of an electrical and conditioning monitoring program, electrical insulation testing is commonly undertaken to determine the insulation resistance of electrical circuits, since the efficiency and running costs of equipment are increased when electrical circuits exhibit poor insulation properties. In order to assess an electrical circuit for its electrical insulation performance, a hand held mega-ohmmeter is used to test the insulation resistance by applying a known voltage (500V or 1000V DC for low voltage systems) to the circuit being assessed and measuring the current flow to ground. The DC test voltage is applicable to both AC and DC circuits.

Electrical insulation testing is a commonly used and recognized technique for assessing electrical circuits and equipment insulation performance in motor windings, cables, switchboards and motor control centres. Insulation testing to determine the condition of electrical equipment and circuits should be undertaken by trained electrical technicians and engineers, since knowledge and experience of electrical circuits and interpretation of the readings obtained from the analysis is required. Insulation testing is common practice, inexpensive and easy to carry out.

### 2.2.3.26 Intelligent Pigs

A pig is a device inserted into a pipeline that travels freely, driven by the flowing media to do a specific task within the pipe, such as cleaning. An intelligent pig carries complex monitoring technologies that provide information on the condition of the pipe and/or its contents. With a few exceptions, intelligent pigs simply gather data, which is then analyzed by engineers to determine and report on the condition of the pipe. Intelligent pigs are inserted into the pipeline at a location that has a special configuration of pipes and valves where the tool can be loaded into a receiver. The receiver can then be closed, sealed, and the flow of the pipeline product directed to launch the tool into the main line of the pipeline.

Intelligent pigs use different technologies to locate defects or gather condition and other information about large diameter pipelines. Several non-destructive inspection technologies can be integrated into these intelligent pigs:

- The *Magnetic Flux Leakage technique,* used to detect corrosion or thin walls.
- *Ultrasonic sensors,* used to detect corrosion, coating delaminations, cracks, dents and gouges.

- *Global Positioning System* (GPS) technology is being adapted to obtain the exact location of any problem in the pipe or to map the pipe.
- *Geometry tools,* which use mechanical arms or electro-mechanical means to measure the bore of pipe. In doing so, the tool identifies dents, deformations, and pipe ovality. It can also sense changes in girth welds and wall thickness. In some cases, these tools can also detect bends in pipelines.

The two most common requirements are for tools that can undertake geometry/diameter measurement and detect metal-loss/corrosion. However, the information that can be provided by these tools covers a much wider range of inspection and troubleshooting needs, including:

- Diameter/geometry measurements
- Curvature monitoring
- Pipeline profile
- Temperature/pressure recording
- Bend measurement
- Metal-loss/corrosion detection
- Photographic inspection
- Crack detection
- Wax deposition measurement
- Leak detection
- Product sampling
- Mapping

High resolution intelligent pigs can accurately detect and locate corrosion or any other anomalies in pipelines. Once the problem is detected the information can be used to develop a pipeline repair, rehabilitation or replacement program. However, intelligent pigs are expensive devices that need specialised insertion and retrieval structures. Traditionally they have been used in the gas and oil industry and with only a limited application in the water and wastewater industry.

### 2.2.3.27 Leak Detection

Leak detection is currently undertaken using a number of techniques, including acoustic techniques, tracer gas and infrared photography. Drop tests and in-pipe hydrophones are also used and are discussed in separate reviews (see Section 2.2.3.13 Drop Test and Section 2.2.3.24 In-Pipe

Hydrophones reviews). Noise correlators are computer controlled systems that measure noise at either side of the suspected leak location and locate the leak automatically. While leak detection by this method can be conducted regardless of the pipe material, plastic pipe materials tend to be "quieter" than metallic or cementituous materials and so make it harder to detect leaks using acoustic methods. Data logging techniques can be used in conjunction with noise correlators, installed at various locations in a network for extended periods to focus the search for leaks. Infrared photography technique or infrared thermography can be used to detect ground water anomalies caused by water escaping from the main which create 'wet' patches in the ground. Other techniques, such as the tracer gas, are not yet widely used in the water industry. The tracer gas technique involves the introduction of a non-toxic water-insoluble lighter-than-air gas such as hydrogen or helium into the pipe system. These tracer gases escape at leaks and permeate through the cover soil and pavement to be detected and thus located by specialised gas detectors.

Large leaks in water distribution networks can be identified quickly as the amount of water flowing from the pipe can have noticeable affects at ground level. However, pipe assets which contain small leaks do not release enough water for surface affects to be detectable at ground level and leak detection techniques are required to locate these leaks.

### 2.2.3.28 Load Rejection Test

Load rejection tests or models are intended to analyze and predict the performance of power generation systems under sudden load changes. Either full load rejection tests or partial load rejection tests can be conducted. Load rejection tests are most commonly applied to power generation systems such as hydro-power plants, wind turbines and steam turbine power plants. When undertaking load rejection assessment, analysis may either be carried out on the actual plant or modelled using commonly available computer software programs developed for undertaking load rejection analysis.

By undertaking load rejection tests, the risks and consequences associated with the event of sudden load rejections of power generation systems can be determined. When modelling load rejection events using computer simulation programs, the time in setting up a computer model is often time consuming and trained and experienced technical staff are required to undertake, assess and simulating load rejection events.

### 2.2.3.29 Man Entry Inspection

While CCTV is now the industry standard approach for inspecting the internal condition of sewers, in larger diameter sewers it becomes more economical to carry out man entry inspections. In this approach, the internal condition of the asset is assessed using a walk-through inspection. This requires a team of operatives to enter the pipeline and assess the condition of the manhole and the sewer walls above the flow line.

Defects are assessed visually and recorded along with distance using a standard coding system. Photographs of features of interest can also be taken. When this is done, the picture reference should ideally be cross-referenced with the survey distance. Hand held videos can also be used to provide a permanent record of the inspection. The safety implications of man-entry inspections should be given appropriate consideration. In particular, when entering a manhole in a sewer line, it is very important to observe the appropriate confined space regulations.

Acoustic tests can also be performed by striking the crown, sidewalls, and invert of the sewer with a hammer and noting whether the generated sound is dull or solid. This can provide qualitative information regarding the sewer structure and can indicate the presence of voids in the sewer wall (depending on the construction).

### 2.2.3.30 Measurement of Strain

Several techniques are used to measure strain of assets. Two techniques are examined here: electrical resistance and photoelastic strain gauges.

The electrical resistance strain gauge is the most common type of strain gauge used today. This simple strain gauge consists of a very fine wire filament (resistor) arranged in a long zig-zag pattern, with the long lengths parallel to the direction of the measured strain. The fine wire is bonded to the strained surface by a thin layer of epoxy resin. As the surface and hence the wire filament is strained, the wire will become elongated and it diameter will reduce. The reduction in the diameter of the resistor will cause the resistivity of the wire to increase and an electrical signal passing through the filament will thus vary depending on the strain. The 'Gauge Factor' is a parameter equal to the fractional change in electrical resistance divided by the actual strain. Since the magnitude of strain rarely exceeds the order of $10^{-3}$ and the Gauge Factor is often about 2, the fractional change in electrical resistance can be extremely small. This means that the measurements need to be extremely accurate to avoid errors. To improve the accuracy of the measurements, the strain gauge is inserted into an electric circuit such as the Wheatstone bridge.

A photoelastic material is a material that only exhibits the property of birefringence when the material is under stress. A polarized light beam travelling through a stressed photoelastic material will be resolved into two components, such that the electric field vector in each component is aligned with one of the two principal stress axes in the material. Each component of the light beam will experience a different refractive index, causing the two components to travel at different speeds and thus be out of phase with each other when they exit the photoelastic material. The two diffracted components of light emerging from either the model or the coating are then bought together in a polariscope, which determines the relative phase shifts by analyzing the interference "fringe" patterns created. Areas of high stress concentration are identified by thinner fringes, as stress concentration decreases the fringes become wider. Photoelastic strain analysis equipment thus consists of a polarized light source, a model made of a photoelastic material or the actual component covered in a photoelastic coating and a polariscope to detect the refracted or reflected light.

Electrical resistance strain gauges are relatively inexpensive and photoelastic strain gauges can measure residual stresses in materials.

### 2.2.3.31 Methylene Chloride Gelation Assessment

The methylene chloride test is a destructive test used to give an indication of the degree of gelation in a PVC pipe. A short section of chamfered pipe is immersed in a bath of methylene chloride for at least 15 minutes and the chamfered surface then inspected for attack. The degree and location of attack gives an indication of the degree of gelation around the pipe circumference. Areas of the pipe which have been attacked will become whitened or bleached. The chamfered surface will also become rough where attack has occurred.

Gelation is the process by which particulate PVC is formed into a homogeneous material. The degree of gelation achieved during the extrusion of a PVC pipe is related to the toughness of the material produced. A low level of gelation results in a material with reduced toughness and pressure pipes made from a low level of gelation material will fail before a pipe with a high level of gelation under the same operating conditions. Thus the methylene chloride gelation test is a good test of the condition of PVC pipes as low gelation indicates low fracture toughness and thus more likely to fail.

### 2.2.3.32 Motor Circuit Analysis

Motor circuit analysis is a non-destructive low voltage method for testing electric motor cables, connections, windings and rotors for developing faults, to reduce the likelihood of electrical failure occurring during operation. The test can also indicate motor efficiency losses over time. When undertaking motor circuit analysis, a low voltage is applied to enable the testing of electric motor cables, connections, rotor and windings for the onset of equipment breakdown or faults. An insulation resistance test to earth is performed at either 500V or 1000V DC. The measurements which are typically undertaken when conducting motor circuit analysis include: DC resistance, impedance, inductance, phase angle, multiple current/frequency response and insulation to ground.

Motor circuit analysis is applicable to all types of plant that contain electrical motors and circuits. Analysis of electrical motors and circuits using motor circuit analysis is widely used throughout the manufacturing industry. Motor circuit analysis allows for changes in electric motors and associated circuits to be trended. All tests are conducted using portable hand held non-specialized equipment, which enables assessment to be conducted by non electrical trained personnel. During the assessment, the electrical motor must be electrically isolated.

### 2.2.3.33 Oil Testing

A number of tests can be conducted on oil samples that can identify component wear, fatigue and corrosion. The analysis can also give an indication of oil contamination and deterioration, which can indicate when oil should be changed.

In many different types of equipment (petrol/diesel motors, gearboxes, compressors and hydraulic systems), analysis of the lubricating oil for the presence of sediment particles, corrosion, fatigue and changes in the properties of the oil (such as density and viscosity) can often provide an indication of the equipment's current state of operation and internal condition. Over time the level of oil and the changes in the oil properties have an influence on the rate of wear and deterioration of moving internal components, with the formation of ferrous particles in the lubricating oil providing an indication of the rate of wear of internal plant components. Laboratory-based assessments undertaken to gain an indication of the condition of equipment through analysis of its lubricating oil, are:

- Ferrographic analysis – a technique that can be used to determine the density and size of particles that have formed in the lubricating oil as a direct result of wear, fatigue and/or corrosion.

- Particle counter analysis – a method undertaken to monitor particles in lubricating and hydraulic oils caused by corrosion, wear and contamination.
- Atomic emissions spectroscopy – can be used to determine the presence of corrosion and wear products, contaminants and additives in hydraulic and lubricating oils.
- Kinematic viscosity assessment – provides an indication of the deterioration of oil over time as well as an indication of the contamination of the oil by fuel and other oils.

In transformers, oil is used primarily as a cooling medium to transfer heat from the core and coils to the external radiator banks, while also forming part of the insulation system. Oil filled transformers have the core and coil assembly placed in a tank filled with dielectric cooling oil. The primary insulation system used in an oil-filled transformer is Kraft paper, wood, porcelain and oil. Over time, the insulating properties of the oil may deteriorate as a result of contamination and the formation of moisture leading to transformer break down. In order to reduce the likely hood of transformer break down and to determine the condition of the oil as a heat transfer and electrical insulating medium, the following laboratory based tests are commonly undertaken:

- Sediment tests – to determine the properties of sediment that has formed in the oil due to contamination and or deterioration over time.
- Karl Fisher titration test – can be used to determine the amount of moisture in an oil sample by measuring the electrical current flow between two electrodes immersed in the sample solution with the result reported as the amount of water in parts per million.
- Dielectric strength tests – are used to measure the insulating properties of electrical insulating oils.

The majority of the assessments used in determining the type of contaminants and particles present in oil samples are laboratory based assessments, and as a result require trained technical staff to undertake these assessments and interpret test results. Oil testing can be used to optimise the frequency of oil changes in plant equipment, preventing premature oil changes and indicating when an oil change is due.

### 2.2.3.34 Performance Testing of Rotating Machinery

Performance testing of rotating machinery is a non-destructive method used to assess whether equipment is operating as per the original specifications or manufacturer's data. Ideally performance tests should also be carried out periodically to ensure that equipment continues to operate satisfactorily. To undertake a performance test, a rotating machine needs to be run under a range of operating conditions. The test results are compared to the specification or manufacturer's data to determine if the equipment is operating as specified. Performance testing is particularly common for on-site testing of pumps. Performance testing of pumps can help diagnose pump problems such as cavitation, impeller damage and case damage. Noise, temperature and vibrations may also be measured as part of the pump performance test.

In order to undertake a performance test the rotating machinery needs to be operated under a full range of operating conditions. As the performance of equipment can degrade significantly with time, performance testing can highlight inefficiencies and the need for the repair or replacement of components, which can lead to cost and time savings. On-site performance tests will be limited by the equipment available to take measurements.

### 2.2.3.35 Phenolphthalein Indicator (Carbonation Testing)

The phenolphthalein indicator test is a quick method used to indicate the presence of free lime in cementatious materials. Samples are removed from the structure being tested, such as a pipe section, and stained with the indicator. Areas with low or no free lime content remain colourless, while areas with free lime remaining turn pink. Cementituous materials become carbonated due to the action of carbon dioxide; carbon dioxide reacts with moisture in the cement/concrete to form carbonic acid. This then reacts with the free lime to form calcium carbonate. The rate of carbonation is dependent on the permeability and moisture content of the concrete. Over time, the depth of carbonation will increase.

The service life of concrete assets with steel reinforcement depends on the ability of the concrete to protect the reinforcement from corrosion. In good quality reinforced concrete, the steel reinforcement is chemically protected from corrosion by the alkaline nature of the concrete. The lack of free lime at the surface of the steel reinforcement reduces the alkalinity to the point where the passive protection layer cannot be maintained. The steel reinforcement is therefore free to corrode in the presence of moisture and oxygen. This will eventually lead to spalling of the concrete and failure of the asset.

### 2.2.3.36 Pipe Potential Surveys

Pipe potential surveys are used to gain an understanding of the electrochemical interaction between ferrous pipes and the surrounding soil. The pipe-to-soil potential is measured using a voltmeter and a reference electrode. The pipe-to-soil potential measured during testing is useful for identifying areas for further analysis, including areas where coatings have deteriorated or been damaged.

There are two main types of pipe potential survey. The first is Direct Current Voltage Gradient (DCVG) that is used for pipelines with a high quality external protective coating. The DCVG survey can be used to determine the location of gaps in the pipes coating. The technique involves imposing a direct current on the pipe and measuring the difference in the pipe-to-soil voltage between two reference electrodes, which are gradually moved along the whole length of the main. At gaps in the coating, the imposed electrical current leaks to earth and there is a significant increase in the voltage gradient compared to sections of the main where the coating is complete.

The second survey technique determines the pipe-to-soil potential along the length of the main using a single reference electrode and without an imposed current. This approach is most useful for mains that have either a low quality or no external coating and where the pipeline's electrical continuity is created by lead-run joints.

Pipe potential surveys measure the voltage between ferrous pipes and the surrounding soil. Other techniques are also available which rely on similar techniques, including the Pearson Survey, the Current Attenuation Survey and the Close Interval Potential Survey. The Pearson Survey and the Current Attenuation Survey are used to assess the condition of pipe external linings. When in contact with the ground, the electrodes complete the electrical circuit and allow the pipe-to-soil potential to be read from the voltmeter. Pipe potential readings are generally taken periodically along the pipeline. Varying moisture contents in soils over time (wet seasons to dry seasons) will cause variation in results. The results of pipe potential surveys will be affected by the presence of stray currents and these techniques may miss very small isolated areas of corrosion.

### 2.2.3.37 Pit Depth Measurement

Pit depth measurement is a manual technique to infer corrosion rates of ferrous materials. Samples are sand blasted and inspected for pitting; the depths of pits are measured using a pointed micrometer or needle-point depth gauge. The corrosion rate is then estimated, with care taken not to underestimate results due to corrosion products remaining in the pits. Pit depth measurements can be undertaken as a non-destructive technique in the field, or a pipe section can be removed for testing in a laboratory.

Pit depth alone does not give an indication of asset condition; knowledge of original wall thickness, general corrosion depth and age are also required to estimate the corrosion rate and thus remaining life of the asset. More advanced pit depth measurements and those for small pits require laboratory facilities. Detailed knowledge of the original wall thickness and general corrosion depth is sometimes difficult to obtain. The age of the pipe may not always be relevant in calculating corrosion rate, as in the case of coated pipelines, since corrosion begins only after failure/removal of this coaling. For these reasons, corrosion rate estimates should be considered relatively uncertain and this uncertainty should be considered in decision making.

Dempsey and Manook (1986)[11], proposed an alternative approach to determine the condition of water mains based on determining the 'remaining metal wall thickness' as opposed to determining a corrosion rate. This is a standard UK Water Industry method of determining the condition of water mains. The depths of corrosion pits on pipe walls and average wall thickness are measured and the remaining metal wall thickness is calculated. While the overall approach is consistent across the UK Water Industry, the equations used and assumptions applied to determine the 'remaining metal wall thickness' and thus condition, varies.

## 2.2.3.38 Process Control Systems (Integrated)

An overall Distributed Control System (DCS) network monitors/controls assets and provides preventative maintenance data. Intelligent field devices provide a lot of diagnostic information. Usually field devices offer two kinds of diagnostic information: "on-line" (cyclically retrieved) diagnostic information and "off-line" (a-cyclically) retrieved information. Off-line information includes more detailed information about the device. Field devices can be tested, commissioned and configured on-line through the network. Not readily applied to existing plant as requires substantial infrastructure changes and associated costs. Ideal for green field sites or where major new plant is being installed.

### 2.2.3.39 Pull-off Adhesion Testing

Pull-off adhesion testing measures the adhesive strength of applied coatings to metal, concrete, masonry, plastic and wood. The strength of epoxies, mortars, plasters, bituminous coats, paint finishes and metal coatings can be measured. The surface strength of concrete and other materials can also be tested directly. The mechanical tensile strength is tested by applying a perpendicular force, either to destruction or until the applied force reaches a prescribed value. For this reason the test may be fully non-destructive in certain situations.

Pull-off adhesion testing involves measuring the mechanical tensile strength of a coating by applying an increasing stress to the test surface until the weakest path through the material fractures. During testing, the test dolly is attached to the coating surface with an adhesive. Force is then applied perpendicular to the surface to maximize tensile stress as compared to the shear stress (see figure 4). Failure will occur along the weakest path within the system comprised of the test fixture, adhesive, coating system and substrate. The weakest path could be along an interface between the test fixture and the coating, the coating and the substrate, a cohesive fracture within the coating, a cohesive fracture of the substrate (e.g. concrete) or a combination of these. Test results are generally given as a pressure (MPa) and can be related to the strength of adhesion to the substrate.

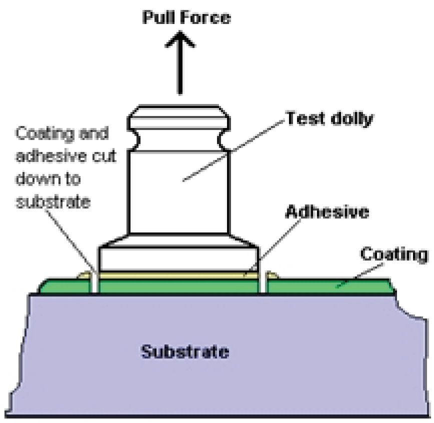


***Fig. 4.*** *Schematic of a Basic Pull-off Test Setup*

Pull-off adhesion testing can be used to test the surface strength of any asset. This primarily applies to assets to which coatings have been applied, but the surface strength of materials such a concrete can also be tested.

### 2.2.3.40 Radiographic Testing

Radiography is the use of radiation to obtain a picture (radiograph) of an object. The intensity of radiation transmitted through the object is recorded, using a photosensitive film or digital recorder. The process is very similar to x-ray radiography in a hospital. Radiography is a non-destructive technique that has been used to examine ferrous, cementituous, and plastic pipes. The radiograph shows variations in material and structure, including changes in density, inclusion of material ingredients, and changes in thickness. It can also be used for inspection of valves.

In the water sector, the techniques have been used to examine the condition of pipes and valves *in-situ*. In process industries, radiography has been proven to be very useful in detecting different kinds of internal deposits in pipes.

### 2.2.3.41 Remote Field Eddy Current (RFEC and RFEC/TC Tools)

The Remote Field Eddy Current (RFEC) inspection technique is a non-destructive method that uses low frequency AC and through-wall transmission to inspect ferrous pipes and tubes from inside the pipe. The through-wall nature of the technique allows external and internal defects to be detected with approximately equal sensitivity. RFEC probes have been successfully adapted for inspection of cast iron and steel water mains, as well as pre-stressed concrete cylinder pipes.

The RFEC tool uses a relatively large internal solenoid exciter coil, which is driven with low frequency AC. A detector, or circumferential array of detector coils, is placed near the inside of the pipe wall, but axially displaced from the exciter. Two distinct coupling paths exist between the exciter and the detector coils. The direct path, inside the pipe, is attenuated rapidly by circumferential eddy currents induced in the wall. The indirect coupling path originates in the exciter fields, which diffuse radially outward through the wall. At the outer wall, the field spreads rapidly along the pipe with little further attenuation. These fields re-diffuse back through the pipe wall and are the dominant field inside the pipe at remote field spacing. A receiver coil that is placed in the remote field zone of the exciter picks up the field. Because the pipe wall attenuates the through-wall field, the strength of the field is very sensitive to the wall thickness. Anomalies anywhere in the indirect path cause changes in the magnitude and phase of the received signal, and can therefore be used to detect defects such as cracks, pits or wall thinning produced by corrosion.

Although the RFEC tools are commercially available (though specialized contractors), the pipe first requires internal cleaning prior to inspection. This create drinking water quality issues for use of this technique in potable water mains.

### 2.2.3.42 SCADA

The term **SCADA** stands for **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition. A SCADA system is a common process automation system which is used to gather data from sensors and instruments located at remote sites and to transmit and display this data at a central site for either control or monitoring purposes. The collected data is usually viewed on one or more SCADA host computers located at the central or master site. SCADA can be expanded to basic *telemetry*, i.e. satellite telemetry, radio telemetry, cell phone telemetry or landline telemetry. *Telemetry* refers to accessing data and controlling the system by remote means. Vast SCADA products have been developed and SCADA has found extensive use in the water sector internationally and in South Africa.

In order to provide a safe, reliable water supply, water utilities must continually track and manage filters, pumps, valves, and other mission-critical equipment that purifies and transports water to customers. The interrelated nature of a water delivery system makes prolonged down time or failure unacceptable. Ensuring that these systems are functioning properly is crucial to maintaining public safety. The advantages of SCADA technology are:

- Water users do not have to manually read and record meter readings at regular intervals because the data on water use is collected automatically.
- Can be rigged for telemetry access by radio, satellite, cell phone, or telephone landline and allow the user to remotely control the water system and access instantly.
- Instant control over canal and pressurized flows
- Low capital investment for components
- Easy to install and maintain

**Case Studies**

Some of the practical applications of SCADA in the water sector are:

- The City of Holliston, Massachusetts has upgraded its SCADA system from their old control technology which lacked both remote monitoring capability and centrally located alarming to a more reliable and functional system. The SCADA system is used control and monitor four well pump stations, four tanks and a water treatment plant[12].

- The City of San Diego Water Department embarked upon a long term strategic view of its water infrastructure control system. The purpose of this evaluation was to find where improvements could be made in water distribution and maintenance through the use of technology. The evaluation focused on improving the speed and effectiveness of in-the-field repairs to the system, increasing the speed of discovering and responding to system failures, and integrating the data collection and monitoring into a single system-wide control centre. The City Council authorized the Water Department to replace the existing operating system with the radio-based SCADA telemetry system. This new data management system integrates the data collection and monitoring into a single system-wide control centre for more streamlined data utilization. The estimated project cost was $4 million[13].

It should be noted that SCADA technology is mainly used for the monitoring and control of the processes at water utilities. It has found limited use for the collection of data for condition assessments. SCADA is widely used in most of the water utilities in South Africa for monitoring and control. SCADA technology has tremendously advanced with the development of transponders, data loggers, cellular and internet based monitoring and control systems

### 2.2.3.43 Schmidt Hammer

The Schmidt hammer is a simple hand held device that allows non-destructive assessment of materials such as bricks and concrete. The tool gives an inferred measure of comprehensive strength by assessment of surface hardness and can provide valuable comparative data between different parts of the sample depending on surface conditions.

In use, the Schmidt hammer is ideally aligned perpendicular to the surface being tested. A spring loaded mass is then fired at a sample. The distance the mass rebounds from the surface of the sample is related empirically to the comprehensive strength of the sample. Results obtained from the manual version of the tool are converted to comprehensive strength using calibration curves while some digital versions can give comprehensive strength readouts directly.

### 2.2.3.44 Slow Crack Growth Resistance of PE Pipes

The Notched Tensile Test is a destructive test that can be used to quantity the resistance to slow crack growth of a polyethylene (PE) pipe material. The test involves deliberately introducing a razor notch onto a test coupon, which is then subjected to a pre-defined tensile stress. The time to failure is recorded, which correlates with the resistance to slow crack growth exhibited by a particular pipe material. Traditionally used to assess performance of new PE materials, this test has also been used to measure slow crack growth resistance of pipes currently in-service.

Results from notched tensile tests can be used to determine the material classification of the pipe under inspection. Furthermore, results from notched tensile tests on a wide range of PE materials have also been published in the literature. This provides a basis for comparison in terms of slow crack growth resistance.

### 2.2.3.45 Soil Characterisation

Soil characterisation involves analysing soil parameters relevant to the deterioration of buried assets. Soil characteristics interact with buried assets of all types of materials. Characterization of soil parameters relevant to buried assets allows suitable material types to be chosen and effective preventative measures to be taken to minimise the degradation of the asset. Soil characterisation can also be used with pipe specific information to predict the working life of the pipe.

Soil parameters of interest include:

**Soil resistivity** – is relevant to the corrosion of ferrous materials. Soils with low resistivity are more likely to have high corrosion rates, while high resistivities are likely to indicate low corrosion rates.

**pH** – Low pH values are associated with corrosion of ferrous assets and deterioration of cementituous assets.

**RedOx potential** – of soil is a measure of soil aeration and gives an indication of the suitability of conditions for sulphate reducing bacteria.

**Sulphates** – react with cementituous materials forming gypsum and ettringite, which have significantly higher volumes than the materials they replace causing swelling and cracking of the pipe wall. Sulphate attack will only occur in soils where sulphate salts are in solution.

**Chloride content** – chloride ions permeate into cementituous materials and attack any steel reinforcement. Corrosion of the reinforcement results in a volume increase applying stress to the cementituous asset resulting in spalling.

**Moisture content** – of the soil acts as the electrolyte in electro-chemical corrosion of ferrous assets. Flowing water can leach free lime from cementituous assets[14]. Soil moisture content will also define the degree of saturation of the soil.

**Shrink/Swell capacity** – of soil is related to the soil moisture reactivity, as clayey soils change volume depending on their water content. As the moisture content of the soils reduces due to uptake by plant root systems, percolation through soil matrix and evaporation, the soil will shrink. Assets within soils with high shrink/swell capacities are known to have an increased failure rate, due to the stresses imparted by the soil during the shrink/swell cycle.

**Buffering capacity** – of clay soils and soils high in organic matter is high while sandy soils and soils low in organic matter have low buffering capacity.

**Linear polarization resistance** – can been used to predict the corrosion rate of buried ferrous assets; where high LPR would indicate a low corrosion rate.

**Contaminants** – soil contaminants such as organic compounds can have negative effects on polymeric materials. Organic compounds such as petrol can migrate through the polymeric pipes both impacting water quality and remaining in the polymer matrix causing it to swell and lose strength. Highly levels of acidic contaminants can also cause environment stress cracking of polymers dramatically reducing lifetime.

Integration of soil characteristics into a GIS system can provide a good picture of soil conditions. Soil information, asset characteristics and depth, and groundwater levels can be overlaid within a GIS to identify likely interactions between soil, groundwater and buried assets. Soil tests are often conducted at failure locations, however, it should be noted that this may provide a skewed picture of soil conditions. Samples can be obtained without exposing buried assets.

## 2.2.3.46 Soil Corrosivity

The predominant deterioration mechanism for ferrous pipes is electro-chemical corrosion. Soil corrosivity tests use one or more soil characteristics to predict the likely rate of corrosion. There are different methods to determine soil corrosivity that incorporates multiple soil characteristics, they are:

**The 10-point DIPRA method** – uses soil resistivity, pH, RedOx potential, sulphide content and moisture content to classify soils as either corrosive or non-corrosive.

**The Metalogic method** – uses twelve soil factors; soil type, soil resistivity, water content, pH, buffering capacity, chloride and sulphide concentrations, ground water level, horizontal and vertical homogeneities and electro-chemical potential to rate corrosivity at four levels from highly corrosive to virtually non-corrosive.

**The Spickelmire method** – uses a twenty-five point method and includes soil properties as in the DIPRA method and pipe factors such as pipe location, size, maximum surge pressure, design life, and leak repair difficulty.

**Linear Polarization Resistance** (LPR) – is a soil characteristic used to predict the corrosion rate of buried ferrous assets. LPR has a negative correlation with corrosion rate in ferrous assets, meaning that soils with high LPR values will exhibit low corrosion rates.

Soil corrosivity provides an indication of the likelihood that corrosion will occur. Soil corrosivity tests are relevant for buried ferrous assets. Soils can be categorized into broad corrosivity categories that identify areas where corrosion potential is highest. Prediction of pipe condition requires additional information such as pipe age and wall thickness. Techniques used in predicting soil corrosivity can be conducted prior to lying pipe allowing appropriate corrosion control measures to be undertaken. Most techniques can only provide a qualitative indication of the likely corrosion rate.

### 2.2.3.47 Soil Electrical Resistivity

The predominant deterioration mechanism for ferrous pipes is electro-chemical corrosion. Soils with low resistivity are more likely to have high corrosion rates, while high resistivities are likely to exhibit lower corrosion rates. As such, measuring soil resistivity gives an indication of the likely rate at which corrosion will occur. Soil resistivity can be measured *in-situ* or in the lab using a number of techniques. Resistivity varies with changes in soil moisture and salt content, lower moisture content resulting in higher resistivity; lower salt content resulting in higher resistivity.

Field measurements of soil resistivity are conducted using the Wenner technique. This involves inserting four equally spaced electrodes into the soil. An electrical potential is then impressed between the outermost electrodes, and the potential drop between the two central electrodes is measured. Several measurements are taken and used to calculate the soil resistivity.

Soil resistivity is a cost effective and widely used environmental indicator of the likely corrosivity of soils. Soil resistivity is only indicative of corrosion rate for buried ferrous assets; further detailed analysis is required to determine the actual corrosion rate and asset condition.

### 2.2.3.48 Thermographic Testing

Thermographic testing uses infrared imagery to locate defects and potential failures in electrical equipment by scanning for thermal abnormalities. Thermographic testing detects thermal properties using infra red imaging. Thermographic testing is an effective method of locating problems in all electrical equipment that carries a current. Thermographic testing is potentially applicable to the following: Substations, Switchgear, Motor Control Centres, Motors, Bearings, Transformers, Circuit Breakers, Cables, Terminators, Bus Bars, Bus Plugs, Overhead Distribution Lines, Starters Contactors, Transmission Lines, Power Panels, Lighting Panels, High Voltage Equipment, Switches, Controls and Low Voltage Equipment.

Thermographic testing is widely applied for the testing of electrical systems; there are numerous commercial organizations that provide these specialist skills. Thermographic testing allows rapid scanning of electrical equipment and the results are repeatable. The equipment must be under load conditions during testing. As most thermographic testing is performed on "live front" energized equipment precautions must be taken to ensure no direct contact with live parts.

### 2.2.3.49 Transformer Circuit Protection Coordination and Protection Relays

Transformer circuit protection coordination and protection relays are designed to prevent damage to valuable electrical equipment from short circuits or other faults. The testing and analysis of electrical protection systems should be undertaken, to ensure adequate protection and reliable performance of protection relays. This type of protective device co-ordination reviews should be carried out every five years as part of any comprehensive maintenance programme.

A review of transformer circuit protection coordination and protection relays should include analysis of fault levels, equipment ratings, protection installed and protection settings to ensure faults such as short circuits will not cause damage to electrical equipment. Tests include primary and secondary injection tests sets for high and medium voltage distribution switchboards and motor control centres to establish that the protection operates at the right settings and includes motor protection relays.

Testing of electrical protective systems is standard, particularly in organizations such as power and water utilities. The design and testing of electrical protection systems is critical in preventing damage to important and expensive electrical equipment.

### 2.2.3.50 Transient Earth Voltage (TEV)

The detection of transient earth voltage is an indicator of partial discharge that can occur upon insulation breakdown due to aging, damage or contamination. The pulse or discharge only partially bridges the gap between the phase to ground insulation.

If a partial discharge occurs in the phase to earth insulation of an item of high voltage plant, a small quantity of charge is transferred capacitively to the earthed metal cladding. An electromagnetic wave is generated at the discharge site which propagates away in all directions. By escaping through an opening in the metal cladding (e.g. at a gasketed joint) this can be detected on the outer surface as a transient earth voltage. The transient earth voltage has a nanosecond rise time and amplitude that varies widely from millivolts to volts.

Transient earth voltage can be used to inspect high voltage switchgear, transformer cable boxes and tappings for the detection of electrical insulation breakdown. Only personnel authorised to use high voltage can undertake the testing of high voltage electrical equipment.

### 2.2.3.51 Ultrasonic Testing

Ultrasonic inspection is a non-destructive test conducted by sending high frequency sound into an asset and evaluating any echoes detected. Scatter, diffraction, reflection or other wave phenomenon modifies the wave when it encounters anomalies. A suitably placed piezoelectric crystal in turn receives the sound wave and interpretations can be made about anomalies in the structure. Ultrasonic testing has the advantage that it can interrogate a volume of material rather than just a surface area. Ultrasonic examination procedures are widely used for thickness measurement, corrosion monitoring, delamination checks and flaw detection in welds, forgings, castings and pipes.

In recent years much work has gone into the development of ultrasonic techniques for the rapid screening of pipes for corrosion/erosion. This has resulted in systems that make use of low frequency guided waves. Systems were originally designed for use on above-ground exposed or insulated pipes, but are now used on buried pipes, though the range of inspection can be shorter.

During testing a unit using piezoelectric transducers is clamped around the pipe and ultrasound is sent simultaneously in both directions along the pipe. The signal obtained is similar to a conventional ultrasonic A-scan, where the horizontal axis represents distance along the pipe and the vertical axis represents signal amplitude, which is indicative of the severity of the corrosion. Unlike conventional A-scans, the signals are displayed from three different wave modes, namely symmetrical, horizontal flexural and vertical flexural. The relative intensities and characteristics of these three signals are important in identifying different distributions of corrosion.

Continuous ultrasonic measurement is used to obtain an understanding of corrosion along a pipeline, with the ability to asses both above and below ground pipes.

**Case Study**

Olson Engineering, Colorado, USA has undertaken extensive research and development on non destructive techniques and has undertaken a number of projects where they have implemented various technologies. One project involving ultrasonic testing was at Lake Logan Dam North Carolina, USA, where ultrasonic tests were performed between 1974 and 1986 to determine the condition of the mass concrete of the dam. Acoustic Tomography tests throughout the dam concrete (downstream to upstream) were performed at 28 stations along the dam. Acoustic Tomography was used to measure the velocity of acoustic waves through concrete, which provided an indication of concrete condition in the interior of the dam, with the velocity of sound through concrete providing an indication of condition. The higher the velocity of sound through the concrete; the better the quality and condition of the concrete being tested[15].

### 2.2.3.52 Valve Exercising

Valve exercising is a non-destructive test used to ensure the function of valves by moving them through their full range of motion. Periodic operation gives a measure of operability, which in turn can be used as an indicator of condition. A valve exercising program is thereby used as a means of identifying faulty or broken valves needing replacement.

When conducting a valve exercising program, each valve should be operated through a full cycle and returned to its original position on a regular basis. The time frame can vary between authorities, depending on local experience, but should be often enough to prevent a build-up of corrosion products and any other deposits that could render the valve inoperable or prevent full closing. The time interval between valve exercising for more critical valves should be shorter than for other less important valves. When conducting the program, a detailed record of valves should be maintained including the number of turns required to close or open the valve, torque required to operate valve (if possible), valve location, valve condition, maintenance required etc. This data should be compared with previous records to identify any changes to valve operation

### 2.2.3.53 Vibration Analysis

Vibration analysis is used to monitor the condition of assets and for fault diagnosis. Vibration is typically measured using hand-held or permanently positioned accelerometers placed on the equipment at key measurement points, with portable data collectors and software for vibration analysis. In its simplest form if the number increases, each time the asset is tested, the condition of the asset is deemed to have deteriorated. More complex forms include installing a sensor directly on the machine where the collected signal is processed in real-time. Once abnormal vibration signal is detected an alarm is generated, allowing the operator or controller to take action to preventing further damage from occurring. This type of vibration analysis is normally found on machinery with rotating parts like pumps and motors[16].

Vibration analysis is thus a preventative maintenance technique that uses instruments to monitor and analyze machine vibration to determine if the machine is in good working order and therefore condition.

### 2.2.3.54 Visual Inspection (Pipes)

Visual inspection is a low-tech inspection method of structural condition assessment that requires no specialized equipment and can provide a great deal of useful information about buried assets. Visual inspection can be carried out as an opportunistic approach to condition assessment when assets are unearthed for operational reasons. Visual inspection is also undertaken as a precursor to other condition assessment techniques. Exposing buried assets also allows the quality and condition of back fill to be assessed.

Visual inspection of the external surface of a buried asset requires the asset to be exposed. Unearthing the asset also allows the quality and condition of backfill to be assessed. Especially for polymeric materials (e.g. PVC) which can be subject to fracture from resulting point loads. For this reason the presence of stones and other similar materials in the surround media should be noted. When undertaken as an opportunistic inspection it has a relatively low associated cost. Results can be used to indicate any further tests which might be useful. Results are qualitative only; depending on operator experience and detail included in inspection reports and limited to the section observed.

#### 2.2.3.55 Volumetric X-Ray or Radiographic Testing

Volumetric X-ray testing uses multiple X-ray images taken from different angles to enable reconstruction of any horizontal or vertical X-ray image plane (see figure 5). The reconstructed X-ray image planes have the capacity to provide precise dimensional measurements. Horizontal and vertical X-ray reconstructed images can provide excellent location information about weld defects and discontinuities.

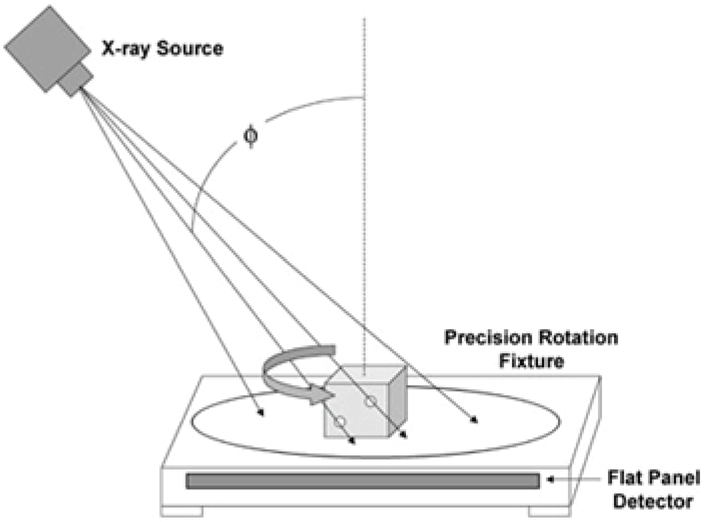


***Fig. 5.*** *Schematic of Volumetric X-Ray Testing*

Volumetric X-ray testing is a commonly used non-destructive testing method used outside of the water industry. Volumetric X-ray imaging can provide high level of condition detail but it is relatively time consuming and expensive.

#### 2.2.3.56 Case Studies of Combined Techniques

In practice several techniques are used to determine or monitor the condition of infrastructure assets. In this section two case studies are examined.

**Case Study A**

Non-destructive technologies have continually are used to assess the dam structures in Canada. Electrical and acoustical tests were used for assessing the reliability of existing anchor installations at Loch Alva and Log Falls dams. The technologies applied were:

**Spread Spectrum Reflectometry** – a coded electrical signal is sent down a conductor, where it reflects from any significant change of impedance (such as the end of the conductor) along the travel path. For accuracy and noise reduction, a coded series of pulses is used. The reflected signal still retains the code, which can compared to the original signal to determine the travel time and hence the distance to and from the point of different impedance[17].

**Half-Cell Potential Measurement** – this is an electrochemical type test. The potential along the surface of each tendon is measured with respect to a reference electrode (copper/copper sulphate half cell in this case). Access holes (approximately 50 mm diameter and 600 mm deep) are drilled to allow for proper placement of the reference electrode. Interpretation of half-cell potential measurements is used to assess whether the presence of corrosion along the surface of the ground anchor is "likely", "uncertain", or "not likely". This test will not indicate the severity of corrosion, nor whether or not there has been any loss of anchor capacity.

**Polarization Resistance Measurement** – this is another electrochemical test. Placement of a reference electrode is necessary as described for the half-cell potential measurement. In this case the change in potential along the surface of an element is monitored in response to an impressed current. Results from this test may yield information about the surface area of the element in contact with grout (i.e. an assessment of grout cover/quality), and it may also be possible to measure instantaneous corrosion rate. Since the measurement only renders corrosion rate at an instant in time, it does not reveal loss of section without extrapolation of the results. Another limitation is that the measurement represents an average over the surface area. It does not directly indicate the presence of localized corrosion that may be many times higher than the average. However, it can indicate whether the observed rate of corrosion is "severe", "moderate", "average" or "below average" compared to observations that have been made at other sites.

**Sonic Echo Test** – this is a mechanical, wave propagation type test in which seismic waves are propagated along the length of the anchor. Results from the test are useful to assess grout quality, loss of cross section greater than 20%, and a qualitative estimate of remaining pre-stress (i.e. ‘significant loss of pre-stress’ or ‘element appears to sustain a relatively high level of pre-stress’)[17].

**Ultrasonic Test** – this is another mechanical, wave propagation type test that employs high frequency sound waves (see Section 2.2.3.51). Results are useful to assess loss of anchor section within a short distance from the head of the anchors.

From the testing it was determined that a limited amount of additional anchoring was required at both structures in order to conform to the acceptance criteria for stability required in the latest Dam Safety Guidelines published by the Canadian Dam Association. Eight additional anchors were installed at Log Falls Dam and three additional anchors were installed at Loch Alva Dam in 2006.

**Case Study B**

The Water Supplies Department of the Government of Hong Kong Special Administrative Region contracted several companies to conduct assessments for water mains in its approximately 7,300km network. In 2002 Black & Veatch were commissioned to carry out condition surveys of the Dongjiang water mains system[18]. The original survey included stray current measurements in the vicinity, and wall thickness measurements over a limited length of pipeline using a hand held 'Remote Field Technology' called 'Mainscan'[18].

Remote Field Technology, Mainscan uses the response of a single frequency in the remote field region to determine the thickness of remaining sound metal. The Mainscan equipment consists of a 16-channel CPU unit, a laptop computer, and a scanning head. Data is gathered as the scanning head is moved across the pipe surface, and is stored on the laptop for subsequent analysis.

In 2003, the Water Supplies Department carried out a condition survey of the Lion Rock Tunnels and developed a rehabilitation and replacement plan for them. EGS (Asia) Ltd., of Hong Kong was engaged as a specialist condition survey contractor in partnership with Rock Solid Pty. of Australia. They used another electromagnetic technology called 'Near Field Technology' also known as Broadband Electronic Methodology[18].

This technique uses the equivalent of a continuous range of electromagnetic frequencies to measure the wall thickness of a pipe by sensing the attenuation and phase delay of the signal passed through the pipe wall. In this case six exciter coils were used to generate the signal. Measurements were taken at the nodes of a 50mm square grid and averaged to provide a mean value for each 50mm x 50mm square of the grid.

Research and development is still in progress for the electromagnetic technologies. The "Surface Wave-Time Domain Reflectometry' technology developed by Supreme Instruments Ltd of Hong Kong is still an unvalidated technique, but it has been utilised for the condition assessment of submarine pipes between Lantau and Hong Kong Island. The technique is capable of obtaining information about wall thickness as well as coating defects along a substantial length of main by accessing only a limited number of locations (provided there is an electrical continuity and a return path).

### 2.2.3.57 Concluding Remarks

These brief summaries of the various techniques provide an outline of how the technique or tool works and what information it can provide about the asset being investigated. If the technique or tool is applicable for the asset being investigated and it is feasible to use the technique or tool a cost benefit analysis should be carried out to deem if the condition information that will be obtained by employing the technique or tool is worth the costs required to obtain that information. In order to carry out a cost-benefit analysis, cost information will be required from service providers of these techniques and tools (Appendix A – provides details of vendors of various technologies available in South Africa).

However, it is again stressed, that this analysis should be undertaken within a risk-informed framework (see Section 2.4) which balances cost of inspection/monitoring against the risks of failure. This section has provided a framework for the selection of the tool or techniques for assessing the condition of infrastructure assets.

## 2.3 Prediction of Asset Performance

### 2.3.1 Introduction

Infrastructure assets deteriorate over time as they age. This leads to degradation in condition, the reduction of performance and an increase in the probability of failure. The maintenance needs of assets also vary over time, with assets requiring mainly planned maintenance in their early life and increased unplanned maintenance and refurbishment nearer the end of their lives.

The deterioration of assets over time leads to a drop in level of service delivered to the customer. The quality of service may include criteria such as pressure, flow, water quality, fire fighting provisions, and reliability of supply [19]. In practice, due to built-in redundancy and storage, minimum pressure is the overriding criterion of concern. Maintenance is required throughout the life of the asset to ensure the quality of service that is expected from customers and by the water utility.

The prediction of asset performance addresses two primary needs; accurate budgeting to maintain service quality over the long term; and the identification and prioritization of intervention strategies in the short-term. The cycle of infrastructure management forms the basic analysis methodology that is common to the infrastructure of all services (see figure 6).

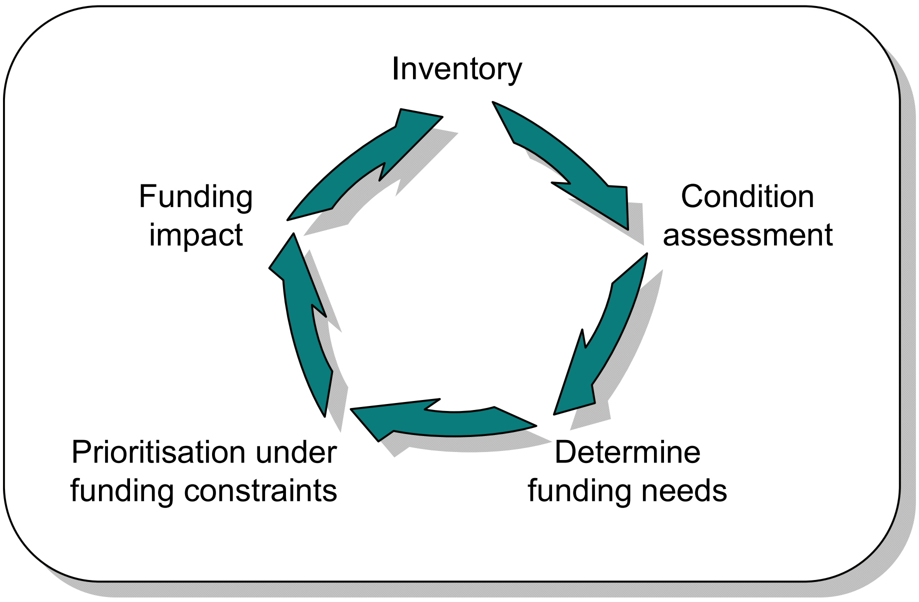


***Fig. 6.*** *Infrastructure Management Cycle*

The cycle begins with the development of an inventory of assets, which may also serve as an asset register. A condition assessment is then undertaken to assess the funding needs of the infrastructure.

If the asset performance can be predicted over time, the immediate and long-term needs can be determined. If not, only the immediate needs can be determined. The needs are then tempered with the reality of constrained budgets, which implies a subset of needs which need to be addressed. The impact of this intervention is then determined to understand the consequences of action or inaction. If performance prediction is undertaken, the long-term impact can be assessed, otherwise only the immediate impact can be determined.

### 2.3.2 Performance Prediction Methods

The performance prediction of entire infrastructure networks requires the development of prediction models based on limited performance data. This is a different method from the performance prediction of individual pipes inspected in detail at the project level, such as large mains. The most common methods of performance prediction of networks are described in the next section.

### 2.3.3 Direct Assessment

The direct assessment method entails an assessment of the current state of the individual assets and their maintenance needs. This is often includes a field inspection by an experienced assessor who scores the current condition on a rating scale, estimates the immediate maintenance needs and sometimes estimates the time to failure (remaining useful life) of the asset. The condition distribution is used to assess the condition backlog (i.e. the extent of assets in poor condition). The immediate maintenance needs are used for estimating budgets and prioritising treatments. The time to failure estimates are used to estimate the medium term capital maintenance needs for the refurbishment or replacement of assets.

This method provides a snapshot of the current asset situation and is useful for setting budgets and prioritising immediate needs. The assessed time to failure profile gives an indication of the future refurbishment requirements.

The benefit of this method is that it is simple, robust and requires no predictive modelling capability. A disadvantage of this method is that it can only provide a very rough indication of future needs and the consequences of different budgets on long-term performance cannot be determined.

This method is widely used and can be determined from typical asset register data. The method is recommended in the International Infrastructure Management Manual[20].

### 2.3.4 Survivor Curves

The survivor curve method is used to incorporate uncertainty in asset groups with similar characteristics, such as construction age and material type. This is typically utilised for pipe networks. With this method, the time to failure of a group of assets is determined and then distributed about a mean that is represented by the expected time to failure. The distribution accounts for the variance of time to failure within the group. The time to failure curve therefore represents the expected replacement profile of the asset group. The mean expected lives and variances of different asset material types are determined to calibrate the model.

This method is useful for dealing with hidden assets, such as pipe networks where the assets are often grouped in groups of similar age and material type. The advantages are that the method is simple and provides a robust indication of the future refurbishment needs. The disadvantages are that the outputs cannot be used for prioritising individual projects and the consequences of different budgets on long-term performance cannot be determined.

KANEW software model developed by Karlsruhe University and AWWARF software developed by Dresden University of Technology use the survivor curve concept to represent the remaining life profiles of pipes based on date of installation and type of pipe[21].

### 2.3.5 Deterministic Models

Deterministic models are models which represent the change in asset performance on an incremental basis over time. Advanced models may predict the development of individual distresses using mechanistic-empirical models over time. Simpler models may predict the change in a performance index over time on a purely empirical basis. Models of this nature are developed by assuming a theoretical form and then calibrating the model using regression methods on a set of empirical data.

The effectiveness of deterministic models is dependent on the ability to model the underlying failure mechanism and the subsequent distress propagation, which is very difficult to achieve for water assets. The advantages are that the future performance of the asset can be estimated and impact of budgets on long-term asset performance can be determined. The disadvantages are the difficulty in developing and calibrating the performance models.

UtilNets is a decision-support system funded by the European Union for rehabilitation planning and optimisation of the maintenance of underground pipe networks of water utilities[21]. The system performs reliability predictions of the pipes and determines the consequences of maintenance and neglect over time in order to optimise the rehabilitation policy. The software has several modules that perform the following key functions:

- Structural reliability module – that models corrosion, internal and external loads.
- Hydraulic reliability module – that models current state in terms of maximum and minimum pressure to required for hydraulic reliability.
- Water quality reliability module – that models the effect of corrosion on water quality.
- Service reliability module – that incorporates the structural, hydraulic and water quality outputs.
- Rehabilitation module – based on the development of feasible options.
- Non-quantifiable consequences of failure model (risk model) – based on the combination of several potential outcomes into one hazard score.
- Prioritisation module – to prioritise projects.
- Network reliability hydraulic module – to model demand point connectivity (extent of redundancy) and adequacy of flows at demand points.

### 2.3.6 Probabilistic Models (Failure Models)

Probabilistic failure models have been developed to model the probability of failure of an asset over time. The failure models do not model condition or distress development, but merely the chance of failure in any given period. Most models are developed on a theoretic basis using an underlying failure distribution for the asset group and are then calibrated using long-term failure records.

The effectiveness of developing and calibrating these models depends on the availability of long-term failure records, which are rarely available. The advantages are that the failure risk of the asset portfolio can be estimated and the impact of budgets on long-term asset performance can be determined. The disadvantages are lack of asset performance data on which to calibrate the performance models.

EPAREL developed by the Norwegian Research Institute, SINTEF, is used to calculate the failure probability for individual assets based on material type, construction year, water quality, surrounding soil and diameter. A non-homogenous Poisson process and a Weibull function are used to calculate the failure probability. This model also has an integrated water quality module used to calculate water age and chemical concentration. The system has been applied at several water services in France[21].

The estimation of the probability functions related to the failure of the individual assets has been further developed by the University of Auckland, New Zealand by incorporating a Bayesian approach to define the models based on failure experiences. This method is useful when dealing with poor and missing data when historic records are not available[22].

### 2.3.7 Probabilistic Models (Markov Processes)

Markov processes have been used to model the probability of changing state from one condition category to another, typically on a multi-point condition rating scale. The likelihood of changing state is represented in a transition matrix and calibrated with empirical data. The transition can be stepped through multiple transition periods (typically years) to determine the future performance of the asset portfolio.

The advantages are that the long-term performance of the asset portfolio can be determined with the impact of different budgets. The disadvantages are that the future performance of individual assets cannot be determined and prioritised.

AQUA-Wertmin 4.0 is a model developed in Germany that uses a Markov type transition method from one condition state to another, coupled with survivor curves for the asset group in each state. The model utilises inputs from CCTV inspections. Individual forecast-based sewer rehabilitation strategies are developed per reach in consideration of the constructional and hydraulic conditions and as well as for the calculation of market value and inspection intervals for sewers[23].

### 2.3.8 Concluding Remarks

The application of prediction models for water networks appears to have followed the development of prediction models for road networks. Although the prediction methods are similar, water networks generally have less data available. This is due to the hidden nature of the pipe networks and the high cost of collecting distress data. The distress mechanisms are also not well described so the models tend to be more empirically based than mechanistic. To counter these shortcomings the use of Bayesian updating models are beneficial for modelling pipe networks.

The drive for asset management implementation and the compilation of asset registers in South Africa and abroad will increase the availability of water assets data. It is expected that the availability of data will in turn stimulate the use of the data to support decision making and therefore present opportunities for the development of improved prediction models that are locally calibrated.

## *2.4 Asset Risk Determination*

### 2.4.1 Introduction

Risk management is concerned with the control and mitigation of the consequences of risk events. The risk exposure of an organisation is dependent on the probability of the risk events occurring and the consequences of the risk events. The focus of risk management is to minimise the risk exposure through proactive intervention.

In asset management, risk management helps organisations understand their risk exposure, identify critical assets and then formulate plans which are used to manage risks to acceptable levels. Risk management is more and more being viewed as a core business driver that influences all decision making, rather than an activity undertaken in isolation[20].

In asset management, risk management can be addressed on two different levels. At a portfolio level, events should be identified that could impact on the performance of the service including key corporate risks. At an asset level, the risk exposure of the asset is determined by identifying the most significant events that could cause critical assets to fail or cease to function adequately[24]. This study is focused on methods dealing with asset risk only.

The risk management process defined in the International Infrastructure Management Manual[20] includes the following steps:

1. Risk management context
2. Risk identification
3. Risk analysis
4. Risk treatment
5. Monitor and review

### 2.4.2 Risk Management Context

The risk context includes establishing the goals, objectives and scope of the risk assessment. The organisation also needs to define the processes to ensure the risk management plan is implemented.

### 2.4.3 Risk Identification

Risk identification is the process of identifying the risk events that the organization is exposed to. This can be done by checklists that list the risks that are found to occur regularly with similar components or by brainstorming with stakeholders based on their collective experience and expertise[24].

### 2.4.4 Risk Analysis

#### 2.4.4.1 Introduction

Risk analysis includes quantifying the risk exposure in order to prioritise the risks in terms of their severity with the most potentially damaging and likely risks at the top of the priority ranking. Risk exposure is quantified as follows:

Risk Exposure **=** Probability of Occurrence **x** Impact

There four common ways of quantifying risk using the product of probability and impact of occurrence. These are summarised in the Table 12.

**Table 12 Methods of Risk Quantification**

| Method | Probability | Impact | Risk Exposure |
|---|---|---|---|
| Rating on continuum | Rating (0-10) | Rating (0-10) | Relative risk rating (0-100) from product. |
| Qualitative categorization | Qualitative category (High, Medium, Low) | Qualitative category (High, Medium, Low) | Risk category (High, Medium, Low) using risk matrix. |
| Monetary value | Probability | Monetary value | Monetary value from product. |
| Criticality score | - | Rating (0-10) | Relative criticality score (0-10). |

Each of the methods listed in Table 12 are discussed in greater detail in the following sections.

#### 2.4.4.2 Rating on Continuum

The use of ratings is useful when dealing with risk events where the probability is not easily determined and the impact not easily defined. The assessment enables the rating of the risk on a relative continuum based on the perceived probability and impact of experienced practitioners and stakeholders. The product of the scores for probability and impact give a relative risk rating between 0 and 100 that enables the ranking of the risks. Presented in Table 13 is an example of the use of subjective ratings at a portfolio level.

**Table 13 Example of Use of Subjective Ratings**

| Hazard | Probability | Impact | Risk Exposure |
|---|---|---|---|
| Electricity supply failure | 8 | 8 | 64 |
| Extreme weather | 2 | 10 | 20 |
| Cost of materials | 5 | 6 | 30 |
| Skills shortage | 10 | 5 | 50 |

This method can be improved by replacing the ratings of probability with direct probability assessments. The resultant rating is the product of the probability and the scaled impact (0 to10), which results in a ranking between 0 and 10.

The impact score method can also be expanded to include weighted contributions from multiple criteria. In this case several criteria such as impact on service delivery, financial loss and environmental impact can be individually scored and the summarised into one weighted impact score with differing weight contributions from each impact criteria.

#### 2.4.4.3 Qualitative Categorization

Qualitative categorisation uses qualitative descriptions of the possible probability and impact of each risk. The use of well defined categories is useful to guide inexperienced risk assessors and to ensure consistency is scoring. However, the definition of the categories requires careful thought and consideration. To facilitate the consistency between assessors, each qualitative category has a clear definition. Examples of the probability and impact categories are presented in Tables 14 and 15 respectively.

**Table 14  Example of Probability Categories**

| Probability category | Definition |
|---|---|
| High | Very likely (Greater than 60% chance of happening) |
| Significant | Likely (30-60% chance of happening) |
| Moderate | Unlikely (10-30% chance of happening) |
| Low | Very unlikely (Less than 10% chance of happening) |

**Table 15  Example of Impact Categories**

| Impact category | Definition |
|---|---|
| High | Direct revenue loss & cost of service > R500,000 |
| Significant | Direct revenue loss & cost of service R200,000-R500,000 |
| Moderate | Direct revenue loss & cost of service R10,000-R200,000 |
| Low | Direct revenue loss & cost of service < R10,000 |

Where the potential impact and probability of a risk are defined by qualitative descriptors, the risk exposure cannot be calculated by multiplying the two factors together.  In this case, the risk exposure is indicated by the position of the risk in a matrix.  These matrices have been called probability impact grids or summary risk profiles, an example of which is presented in figure 7.  A tolerance line can be used on the diagram (as is indicated by the red line in figure 7) to differentiate between the overall risk categories.  In the example in figure 7 there are four resultant categories of risk with the high risk (H) being the most severe, low risk (L) being the least severe and significant (S) and moderate (M) risk in-between.

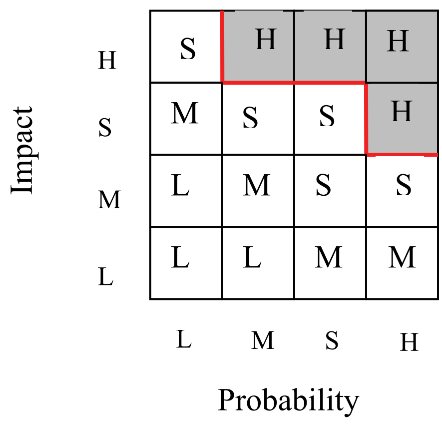


*__Fig. 7.__ Example of a Probability Impact Grid*

#### 2.4.4.4 Monetary Value

The use of monetary value is the most rigorous approach to estimating risk exposure and has the greatest flexibility in computation and analysis[21]. The quantification of the probabilities and the costing of the impact are the greatest challenge when using this method. The calculation of the inputs may require substantial calculation and are reliant on the availability of information.

There are several methods that can be used to quantify probabilities, including the following:

- Expert opinion
- Fault tree analysis
- Decision tree analysis
- Probability theory

Opinions of probability are subject to several biases and risk tolerance of the individual doing the assessment. Experts therefore need to be guided by an understanding of the biases and risk tolerance effects so that reasonably objective assessments of probability can be made. These assessments should be done by inexperienced risk assessors.

Fault trees are useful for understanding complex failure problems with interdependencies between failure events. Fault tree analysis begins with the identification of an undesired effect as the root or top event of a tree of logic. There is only one top event and all concerns must tree down from it. Each situation that could cause the effect is added to the tree as a series of logic expressions. When fault trees are labelled with actual numbers about failure probabilities, computer programs can be used to calculate the failure probabilities from fault trees[25].

Decision trees can be used to determine conditional probabilities of failure based on a number of uncertainties that are not necessarily related by cause and effect. Each uncertainty is assigned a probability function which has an influence on the final probability of failure.

Probability theory can be used to develop probability functions of failure based on historic data. If historic data is not available the probability functions can be theoretically developed by selecting an appropriate model form and using experts to estimate representative model parameters. The Weibull distribution has been widely used as a failure or hazard model in maintenance management applications. Asset properties such as material type, age, soil type, etc. have an impact on the failure probability distributions.

The determination of the monetary value of risk impact is often a major challenge. Several impacts are not easily quantifiable in monetary terms including inconvenience, unhappiness, loss of image, and the value of life. For this reason monetary value determination may need to either exclude some of the factors for simplification or provide rough estimates for the difficult aspects. Advanced analyses may include utility and risk attitude assessments to determine the value of the less tangible influences.

#### 2.4.4.5 Criticality Score

In some cases when dealing with individual assets, only the impact score is assessed and stated as a criticality score. This score enables the ranking of assets in terms of their criticality. Candidates for treatment, i.e. assets in poor condition, can then be prioritised with the most critical receiving treatment first in a constrained budget. Several factors can be assessed and weighted to contribute to the criticality score[21].

### 2.4.5 Risk Management

Once all the major risks have been identified and prioritised, the risks need to be dealt with. The management options may include:

- Risk acceptance
- Risk avoidance
- Risk reduction and mitigation
- Risk transfer

Whatever the countermeasures are considered, they must be cost-effective. If the risk exposure value can be calculated as a financial value, the cost-effectiveness of a risk reduction action can be assessed by calculating the Risk Reduction Leverage[26]. The Risk Reduction Leverage can be defined by:

$$\text{Risk Reduction Leverage} = (\text{Risk}_{\text{Before}} - \text{Risk}_{\text{After}}) \,/\, (\text{Cost of Risk Reduction})$$

Where, $\text{Risk}_{\text{Before}}$, is the risk exposure before risk reduction actions have been taken; and $\text{Risk}_{\text{After}}$, is the risk exposure after taking the risk reduction action. A Risk Reduction Leverage above 1.00 indicates that the reduction in risk exposure achieved is greater than its cost.

### 2.4.6 Monitor and Review

A key aspect of risk management that often results in unsuccessful management is the allocation of responsibility for the risk management actions that have resulted from the risk analysis. Risk mitigation measures should be monitored and reviewed annually to ensure that the major risks are being mitigated and that new risks have not been inadvertently been introduced or omitted.

### 2.4.7 Risk Management Practices

A wide variety of asset risk determination methods are used by different authorities, with several different combinations of the methods described above. The method chosen is often dependent on the availability of reliability data, with the more detailed probability methods requiring more detailed performance data. A review of asset management plans in New Zealand revealed that many of the local councils only utilise risk management at the portfolio level, using the qualitative categorisation methods. Those that were found to implement risk management at the asset level used either the rating of risk on a continuum or the criticality score for their risk analysis.

The asset management guidelines released by Department, Provincial and Local Government, South Africa recommend the use of the qualitative categorisation for the portfolio level risks and the criticality score for the asset levels risk analysis[24].

# 3. South African Review

## *3.1 Introduction*

The main focus of the review was to identify the current condition assessment, prediction of asset performance and asset risk determination techniques that are being implemented and utilised by water suppliers in South Africa. A questionnaire was developed to gain an understanding of these specific asset management practices. In the next section the questionnaire and the questionnaire methodology used are discussed and the results are presented and examined.

## *3.2 Water Service Providers Survey*

### 3.2.1 Introduction

In order to determine the current practices being implemented in infrastructure asset management by South African water suppliers a questionnaire was prepared. The questionnaire was titled 'Review of Technology used in Strategic Asset Management' and prepared in collaboration with stakeholders.

The questionnaire was the means of collecting data from the South African water sector to review technologies applicable to asset management practices. The questionnaire was designed to address four issues namely; condition assessment, reliability measurement, risk analysis and tools/techniques or technologies utilised.

A copy of the questionnaire used for this study can be found in Appendix B – Questionnaire.

### 3.2.2 Methodology

The initial approach was to utilise an interview process to capture the information of what infrastructure asset management practices were being employed by South African water services providers. A questionnaire was developed to initially provide structure to the interviews which were going to be carried out telephonically. The telephonic interview questionnaire was discussed with the client, where it was changed from a telephonic interview to a standalone questionnaire, as it would be too costly to interview all the major water service providers in South Africa.

The questionnaire was reviewed during the second reference group meeting on the 6th November 2008. During this meeting with the stakeholders it was agreed that a number of the questions on the questionnaire were to be changed and that the focus would be expanded to include waste water assets. These significant changes were made to the questionnaire, which then had to be re-submitted. The revised standalone questionnaire was then resent out to water service providers in South Africa in November 2008. A list of all the water service providers who were surveyed with the questionnaire is presented in Table 16.

After the revised questionnaire was sent out to the water service providers, daily follow-up calls were conducted to try ensure that the questionnaires were completed. This also provided an opportunity to check how the municipalities had progressed with completing the questionnaire and to enquire if any problems had been experienced when filling in the questionnaire. Presented in Appendix C is a record of the daily tracking undertaken by Aurecon to receive filled-in questionnaires from the water service providers.

As can be seen in Appendix C the response received from the water service providers was poor. Majority of the municipalities did not fill-in and return the questionnaire; most claimed to be too busy, others felt that the questionnaire was not applicable to them (for example Xhariep District Municipality), and with some it was not possible to contact the appropriate responsible person. Unfortunately there was no real incentive for the technical managers at the water service providers to complete the questionnaires. This resulted in the poor response received with only 23 of the 150 water service providers fully completing the questionnaire and contributing to the survey. An assumption made in the survey was that the recipient would have an adequate understanding of strategic asset management in order to provide meaningful responses to the questionnaire.

### 3.2.3 Questions

The questionnaire (a copy of which is presented in Appendix C) comprised of the following issues, namely:

1. What water assets are you responsible for?
2. How often do you perform condition assessment on water assets?
3. What technologies do you use for condition assessment?
4. Do you measure reliability of water assets?
5. What methods are used to measure reliability of water assets?

6. Do you rank water assets based on risk?
7. What methods are used to quantify the risks?
8. How do you mitigate the risks in water assets?
9. Does your organization maintain a risk register for water assets?
10. Briefly comment on:
    a. What you believe the top three asset management activities you should be doing?
    b. What are the three current constraints that prevent you from doing this?
    c. Any other comments you'd like to make on you current asset management practices.

Presented in Appendix D is a database of all the answers received from the organisations that participated in this study.

**Table 16 – List of Water Service Providers Surveyed**

| Eastern Cape | Western Cape | Northern Cape | Free-State | Kwazulu-Natal | North West | Gauteng | Mpumalanga | Limpopo | Water Boards & Mines |
|---|---|---|---|---|---|---|---|---|---|
| Cacadu DM | City of Cape Town Metro | Kgalagadi DM | Xhariep DM | Ugu DM | Bojanala DM | Emfuleni LM | Albert Luthuli LM | Mopani DM | Amatola Water |
| Camdeboo LM | West Coast DM | Moshaweng LM | Letsemeng LM | Umgungundlovu DM | Moretele LM | Midvaal LM | Msukaligwa LM | Vhembe DM | BiWater |
| Blue Crane Route LM | Matzikama LM | Ga-Segonyana LM | Kopanong LM | Msunduzi LM | Madibeng LM | Lesedi LM | Mkhondo LM | Capricorn DM | Utukela Water |
| Ikwezi LM | Cederberg LM | Gamagara LM | Naledi LM | Uthukela DM | Rustenburg LM | Nokeng tsa Taemane LM | Pixley Ka Seme LM | Polokwane LM | Randwater |
| Makana LM | Bergrivier LM | Namakwa DM | Mangaung LM | Umzinyathi DM | Moses Kotane LM | Kungwini LM | Lekwa LM | Thabazimbi LM | Exxaro Grootegeluk Coal |
| Sunday's River Valley LM | Saldanha Bay LM | Richterveld LM | Mantsopa LM | Amajuba DM | Central DM | West Rand DM | Dipaleseng LM | Lephalale LM | |
| Baviaans LM | Swartland LM | Nama Khoi LM | Masilonyana LM | Newcastle LM | Bophirima DM | Mogale City LM | Govan Mbeki LM | Modimolle LM | |
| Kouga LM | Cape Winelands DM | Kamiesberg LM | Tokologo LM | Zululand DM | Ventersdorp LM | Randfontein LM | Nkangala DM | Bela-Bela LM | |
| Amatole DM | Witzenberg LM | Hantam LM | Tswelopele LM | Uthungulu DM | Potchefstroom LM | Westonaria LM | Delmas LM | Mogolakwena LM | |
| Buffalo City LM | Drakenstein LM | Karoo Hoogland LM | Matjhabeng LM | Umhlathuze LM | Merafong City LM | Ekurhuleni Metro | Emalahleni LM | Greater Sekhukhune DM | |
| Chris Hani DM | Stellenbosch LM | Khai-Ma LM | Nala LM | iLembe DM | | City of Jhb Metro | Steve Tshwete LM | | |
| Ukhahlamba DM | Breede Valley LM | Ubuntu LM | Thabo Mofutsanyane DM | Sisonke DM | | City of Tshwane Metro | Highlands Local LM | | |
| O.R Thambo DM | Breede River / Winelands LM | Umsobomvu LM | Setsoto LM | eThekwini Metro | | | Dr JS Moroka LM | | |
| Alfred Nzo DM | Overberg DM | Kareeberg LM | Dihlabeng LM | | | | Thaba Chweu LM | | |
| Nelson Mandela Metro | Overstrand LM | Renosterberg LM | Phumelela LM | | | | Mbombela LM | | |
| | Cape Aghulhas LM | Thembelihle LM | Moqhaka LM | | | | Nkomazi LM | | |
| | Swellendam LM | Mier LM | Mafube LM | | | | | | |
| | Eden DM | Khai Garib LM | | | | | | | |
| | Kannaland LM | Frances Baard DM | | | | | | | |
| | Hessequa LM | Sol Plaatjie LM | | | | | | | |
| | Mosselbay LM | Dikgatlong LM | | | | | | | |
| | George LM | Magareng LM | | | | | | | |
| | Oudtshoorn LM | Phokwane LM | | | | | | | |
| | Bitou LM | | | | | | | | |
| | Knysna LM | | | | | | | | |
| | Centrel Karoo DM | | | | | | | | |
| | Laingsburg LM | | | | | | | | |
| | Prince Albert LM | | | | | | | | |
| | Beaufort West LM | | | | | | | | |

### 3.2.4 Results & Findings

#### 3.2.4.1 Introduction

In this section the results received from the water service providers that filled in the questionnaire are presented and discussed. The composition of the organisations that contributed to this survey are examined before the analysis for each of the question is considered. The questionnaire was sent to Metropolitans, District Municipalities, Local Municipalities, Water Service Authorities (WSA) and Mines/Private companies. Presented in figure 8 is a graphical breakdown of the respondent types who returned answered questionnaires. From figure 8a it can be seen that unfortunately only one of the Metropolitans surveyed responded to the survey. From figure 8b it can be seen that 83% of the respondent were WSA. The provincial breakdown of the water service provider that responded and took part in this study is presented in figure 9. From figure 9 it can be seen that none of the municipalities in Mpumalanga and North West province returned questionnaires and thus did not contribute to this study.

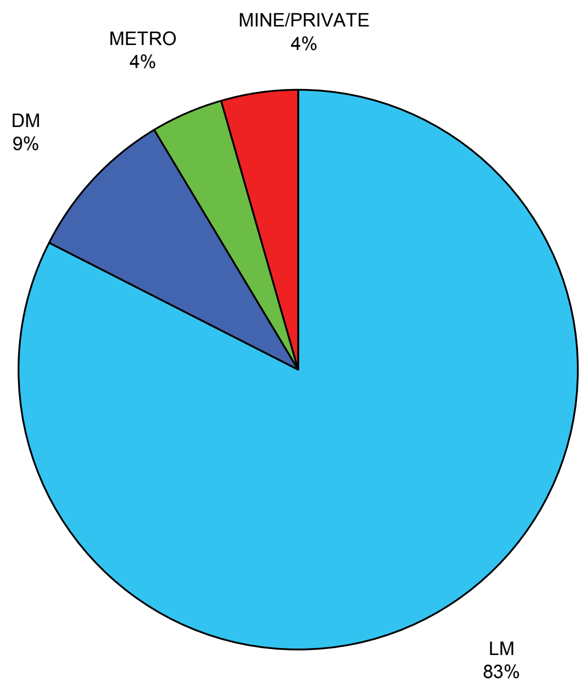


***Fig. 8a.*** *Types of the Organisations that Took Part in This Study.*

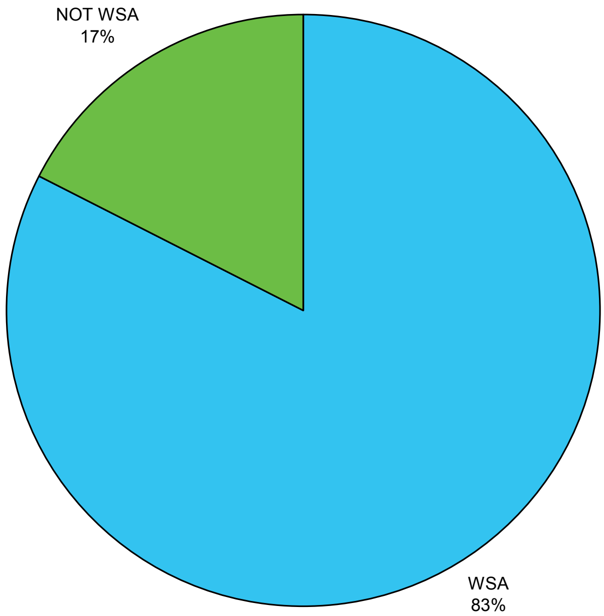


***Fig. 8b.*** *Breakdown of the WSA's that Took Part in This Study.*

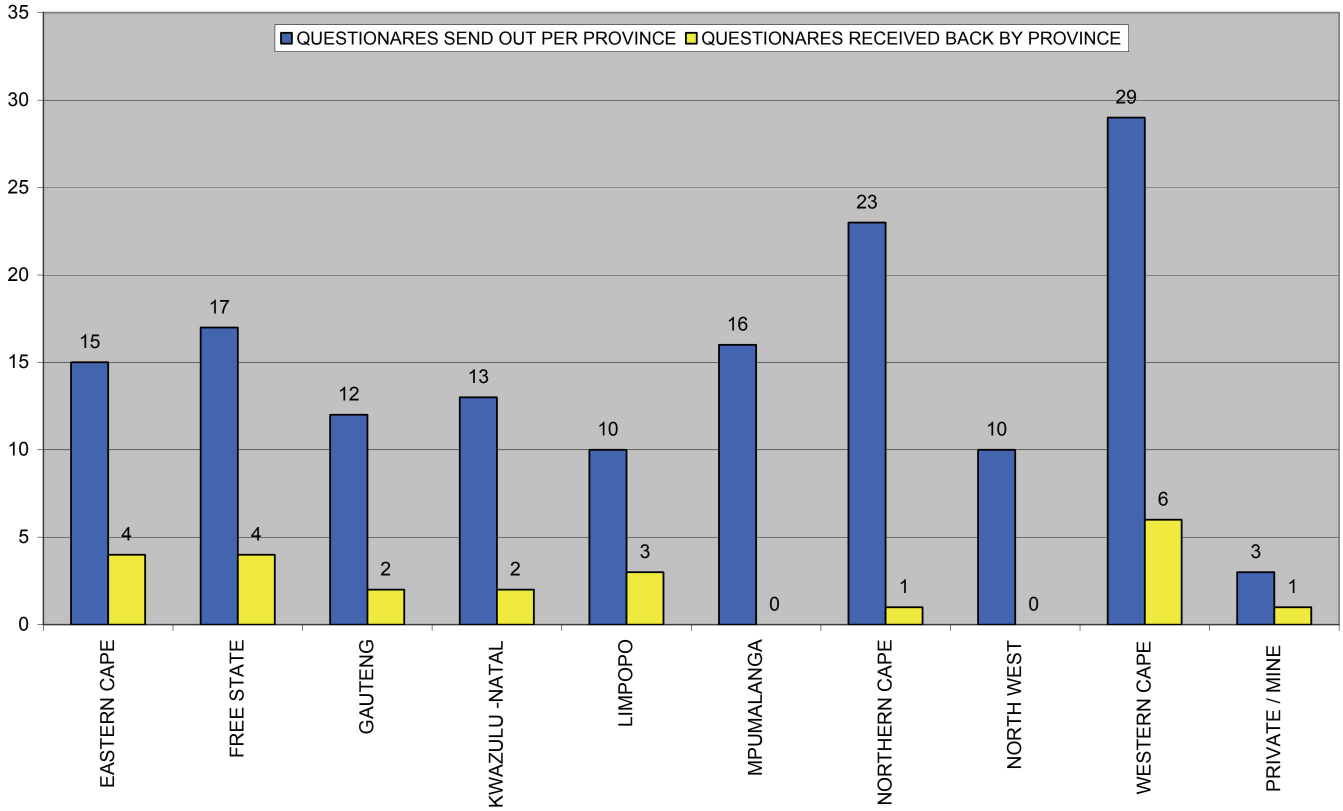


***Fig. 9.*** *Provincial Division of the Organisations that Took Part in This Study.*

### 3.2.4.2 Types of Infrastructure

The first question in the questionnaire was to establish the type of infrastructure assets that the respondent's organisation is responsible for, the results of which are presented in figure 10. From figure 10 it can be seen that all the respondents were responsible for clean (potable) water pipelines and valves. The only category where the majority of the respondents did not have a responsibility for was Spring Protection (where only 26% of the respondents were responsible) and the second lowest was Dams (where about 65% of were responsible). Overall majority of the organisations that participated in this study had responsibility for most if not all of the infrastructure assets listed in the first question of the survey.

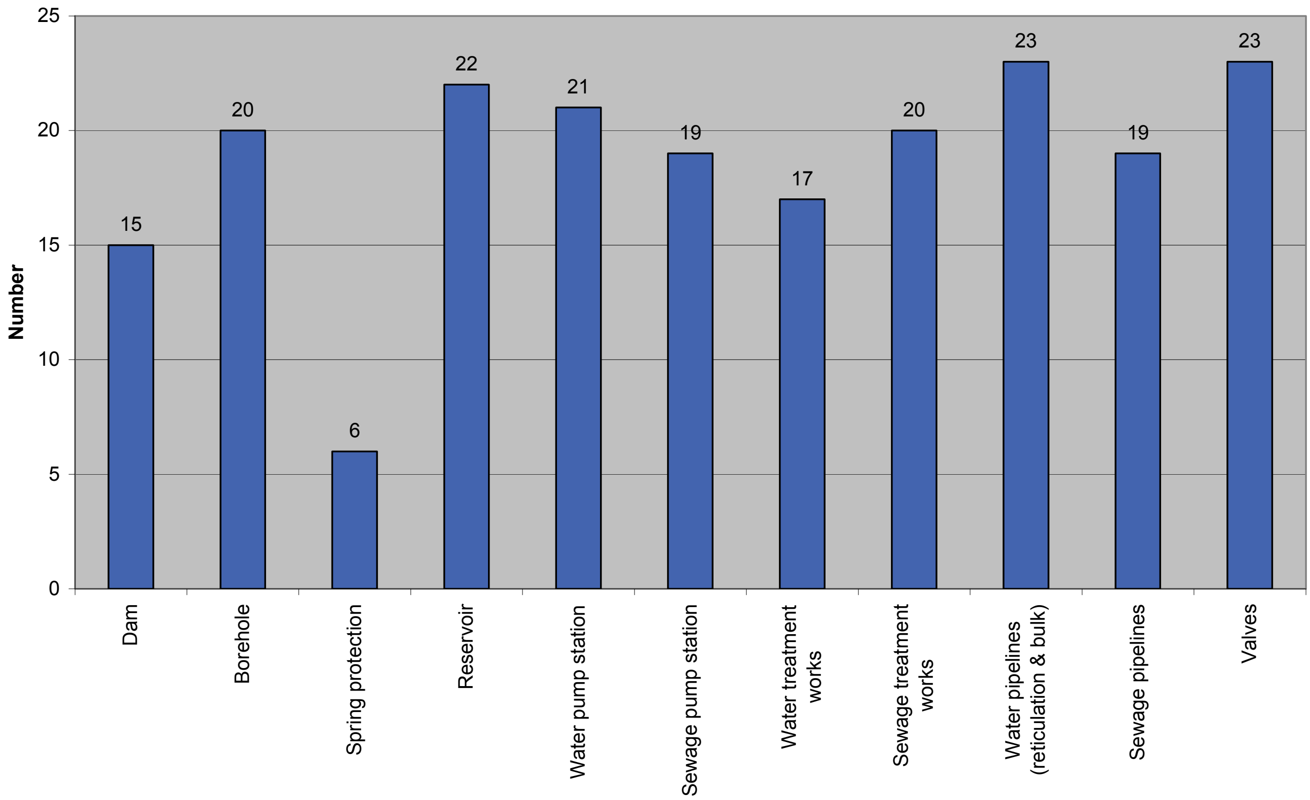


***Fig. 10.*** *Infrastructure Assets the Respondent's Organisation Had Responsibility For.*

### 3.2.4.3 Condition Assessments Utilised

The second question in the survey was to determine what condition assessments were carried out on the various infrastructure assets and the frequency of the assessments. The types of actions that respondents replied as being carried out are presented in figure 11 and the frequency that the assessments are carried out is presented in figure 12. From figure 11 it can be seen that visual inspection is the most common method utilised by the respondents for determining the condition of infrastructure assets. From figure 12 it is evident that there is no consensus amongst the organisations that took part, regarding the frequency of carrying out condition assessments. The two most common frequencies stated were daily and annually. This represents the two opposite ends of the spectrum for frequency of carrying out assessments. For some of infrastructure assets listed, daily inspections are highly recommended (e.g. dams) but for other infrastructure types like pipelines an annual assessment would be ideal, but daily inspections of kilometres of buried pipeline would not be feasible or practical.

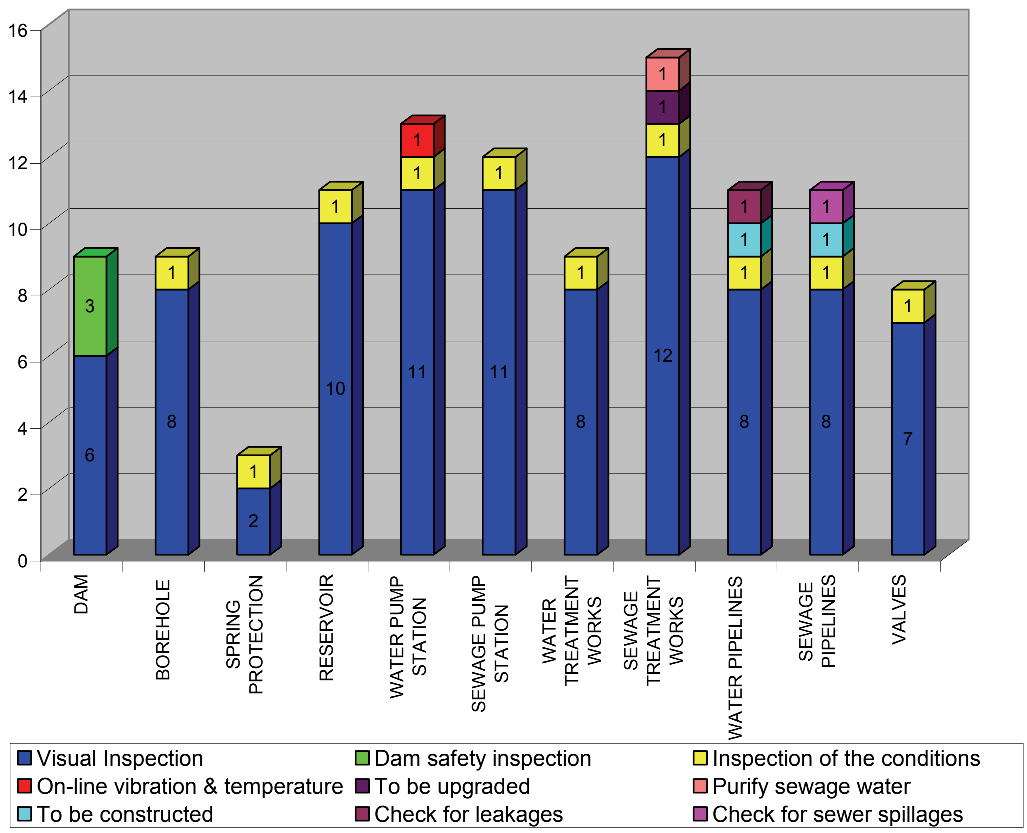


***Fig. 11.*** *Types for Condition Assessments of Infrastructure Assets.*

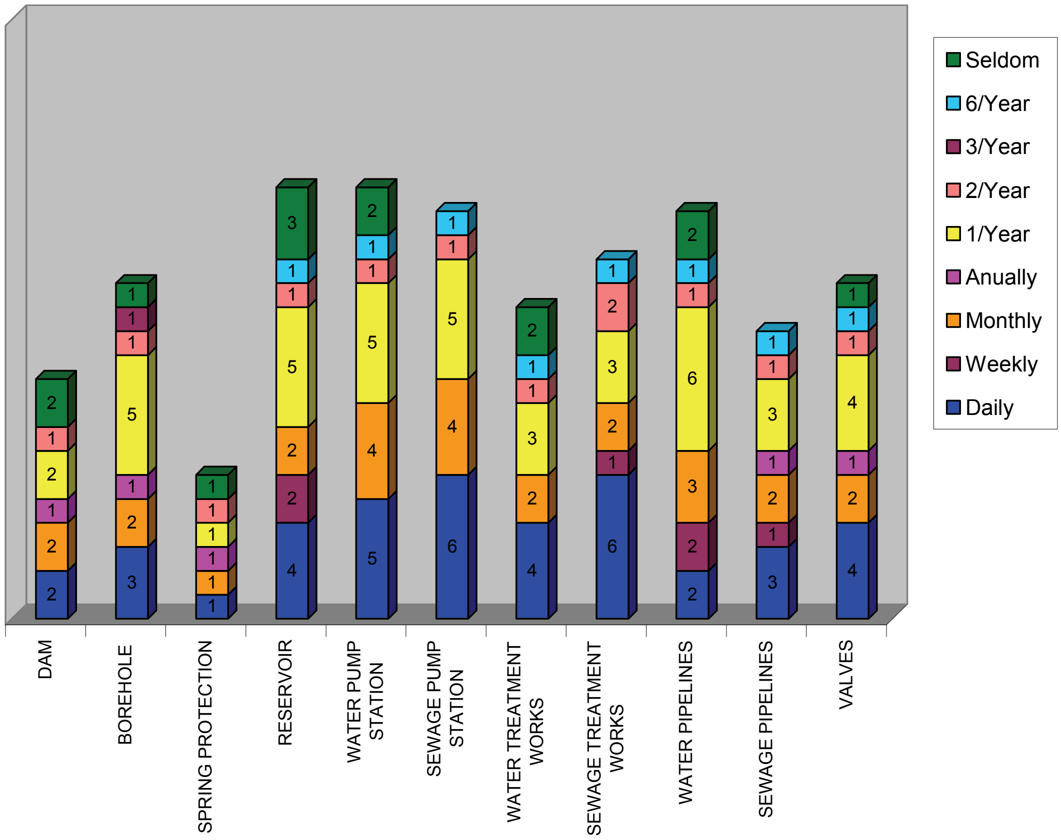


***Fig. 12.*** *Frequency of Condition Assessments Carried Out on Infrastructure Assets.*

### 3.2.4.4 Technologies Utilised for Condition Assessments

The third question was to determine what techniques are currently being utilised by water service providers to determine the condition of their infrastructure assets. Presented in figure 13 is a summary of all the techniques utilised for condition assessment across all the infrastructure asset types. From figure 13 it is clearly evident that visual inspection is by far the most commonly method utilised for determining condition assessment of water and waste water infrastructure assets in South Africa. Presented in Appendix E Section E1 are all the detailed resultant charts for each of the individual infrastructure assets types.

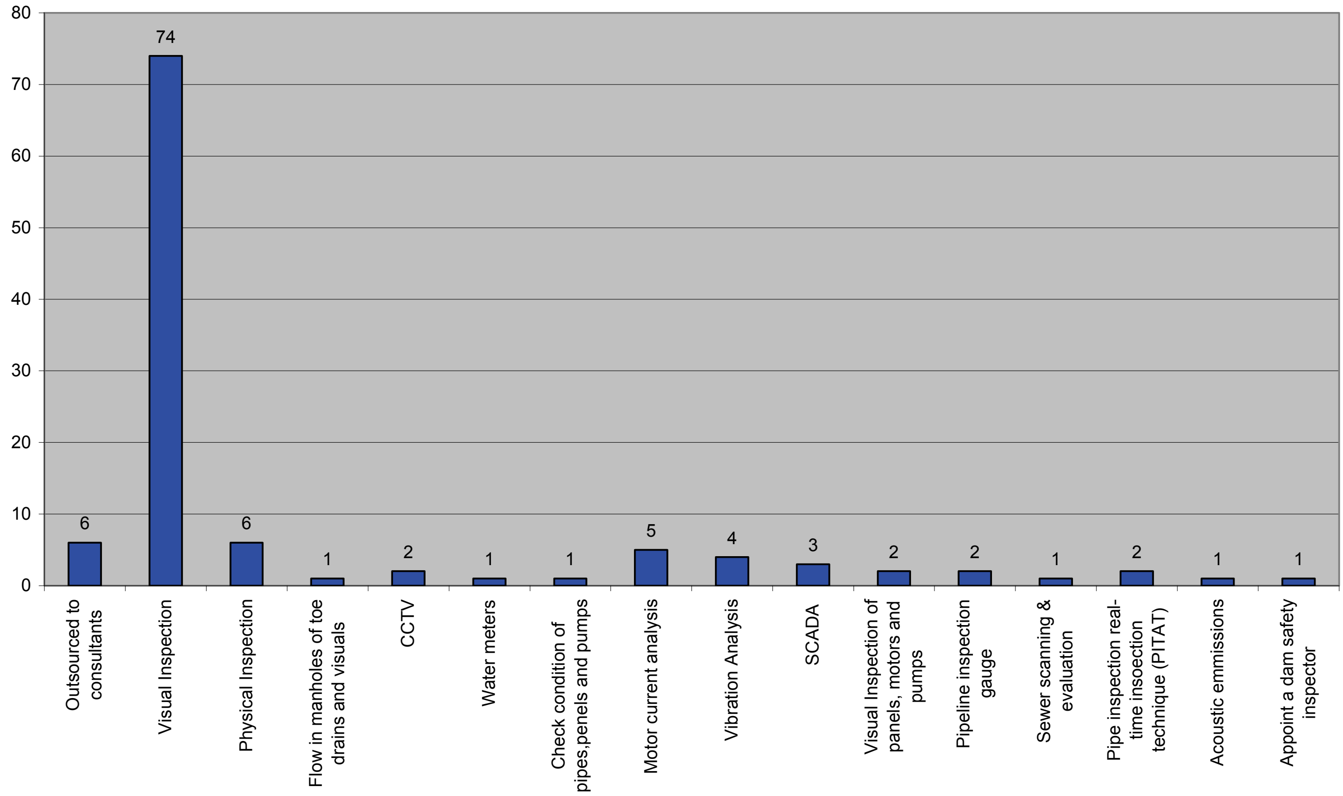


***Fig. 13.*** *Types of Technologies Utilised for Condition Assessments.*

### 3.2.4.5 Measuring Reliability

The fourth question in the questionnaire was to determine if the organisation measured the reliability of the infrastructure assets they were responsible for, the results of which are presented in figure 14. From figure 25 it is apparent that in general for each infrastructure asset type approximately half of the organisations that responded to the questionnaire claimed to carry out reliability measurements on their water and waste water infrastructure. It would be interesting to investigate what each of these organisations understands by 'Reliability'.

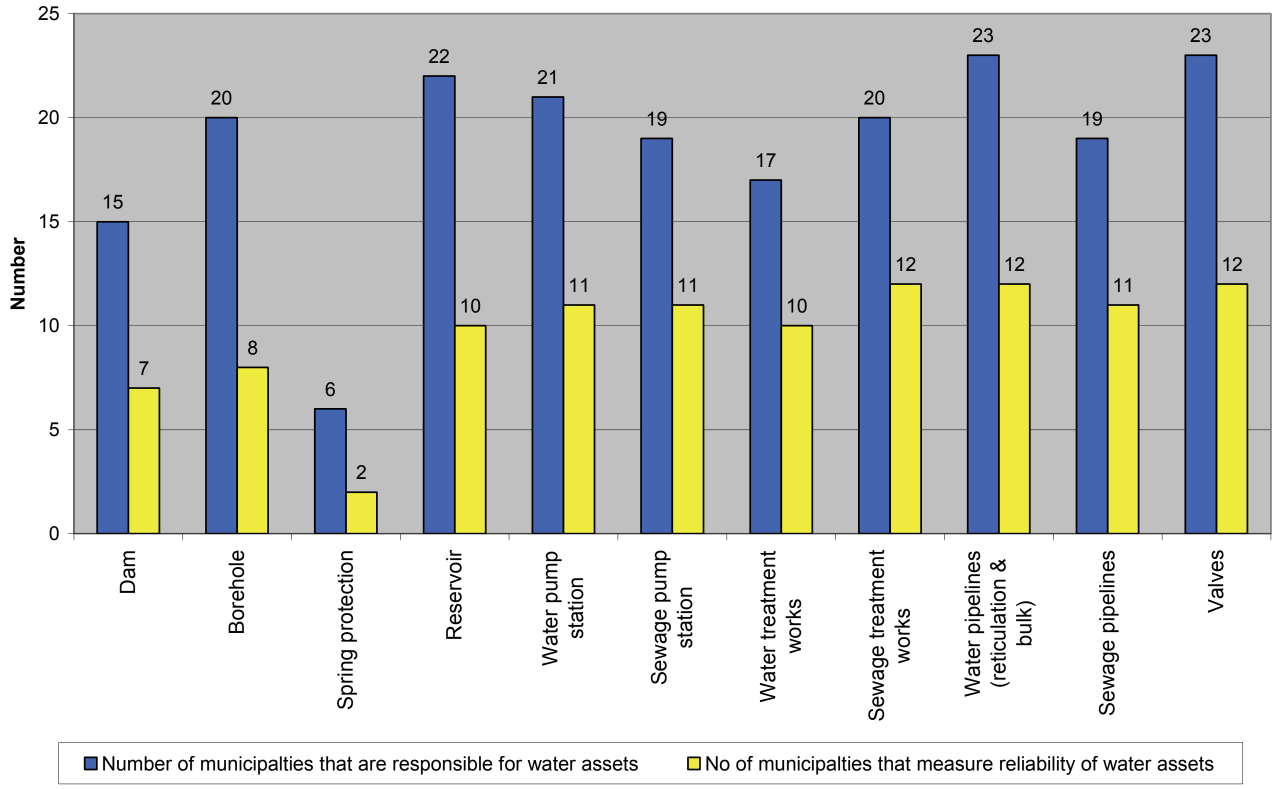


***Fig. 14.*** *Proportion of Organisations that Measure Reliability of Infrastructure Assets.*

### 3.2.4.6 Methods Utilised for Measuring Reliability

The fifth question in the survey is to determine what methods the organisations utilise to measure the reliability of their infrastructure assets. Presented in figure 15 is a summary of all the methods utilised for measuring reliability across all the infrastructure asset types. From figure 15 it is obvious that 'direct assessment' is the most common method for measuring reliability of water and waste water assets, according to the results received from the participants of the questionnaire. The second most common method for measuring reliability amongst respondents was visual inspection. It is perhaps a limitation that the questionnaire could not investigate further into what the organisations that responded to the questionnaire understood by "direct measurement" and what activities they undertake when they use direct measurement to determine the reliability of their assets. Presented in Appendix E Section E2 are all the detailed result charts for the methods utilised for each of the infrastructure asset types.

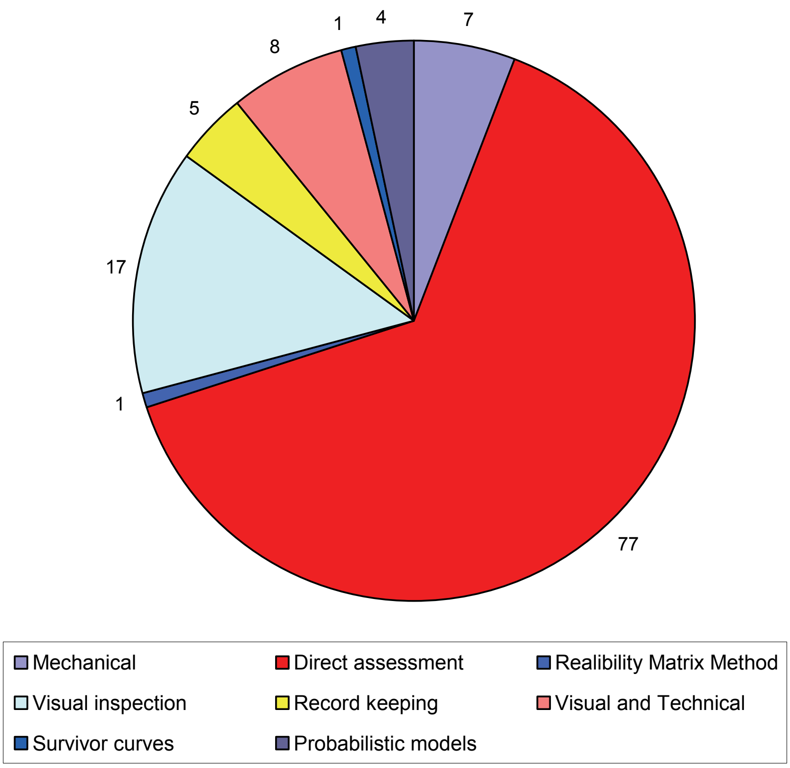


***Fig. 15.*** *Methods Utilised to Measure the Reliability of Infrastructure Assets.*

### 3.2.4.7 Risk Ranking

The sixth question in the survey assesses whether the organisations rank the infrastructure assets they are responsible for by risk, and the results are presented in figure 16. From figure 16 it is evident that in general for each infrastructure asset type approximately majority of the organisations do rank their infrastructure assets by risk. However as with previous questions, it would be interesting to investigate further as to what each of these organisations understands by 'Risk Ranking' and what methodologies they employ to do so.

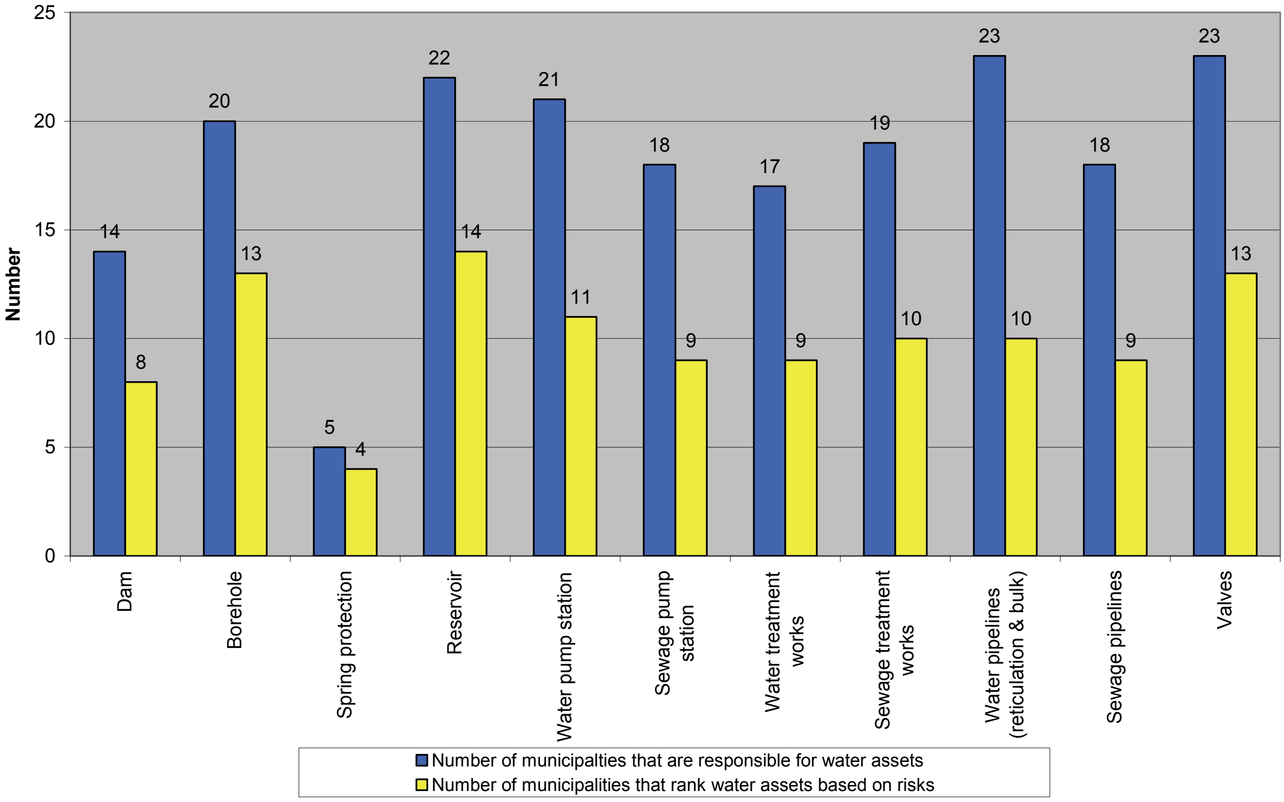


***Fig. 16.*** *Summary of Assets Types Ranked On Risk by Providers.*

### 3.2.4.8 Methods Utilised to Quantify Risks

The seventh question of the survey asks the organisation to identify the methodology and techniques that they utilise to quantify risks. Presented in figure 17 is a summary of all the methods and techniques utilised by service providers to quantify risks. From figure 17 it can be seen that there were eleven different methods listed by the organisations that responded to the questionnaire, of these methods the most common was monetary value (utilised by about 30% of the organisations) followed by ranking on a continuum (utilised by about 22% of the organisations) and qualitative categorisation (utilised by about 17% of the organisations)..

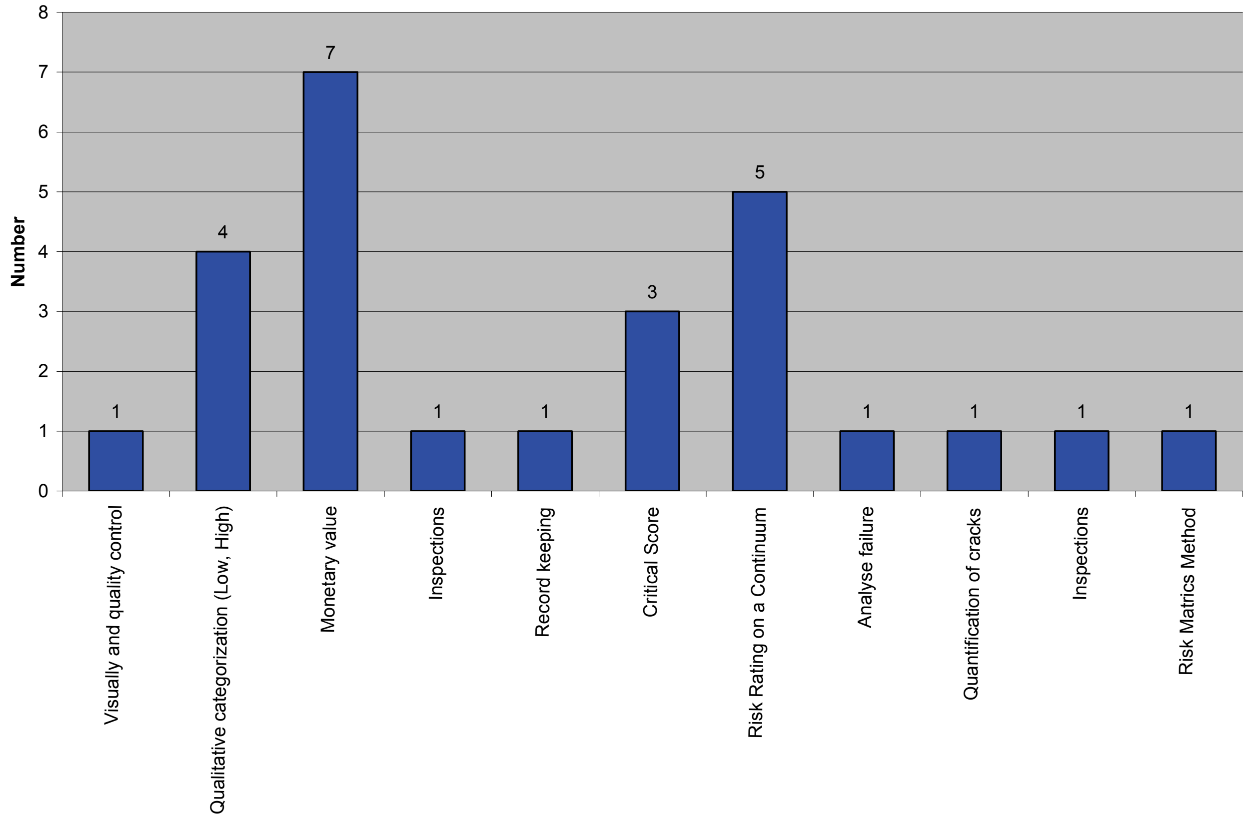


***Fig. 17.*** *Methods Utilised by Organisations to Quantify Risks.*

### 3.2.4.9 Methods Utilised to Mitigate Risks

The eighth question in the survey investigates the method that providers utilise to mitigate the risks associated with their infrastructure assets. Presented in figure 18 are the results of the response from the organisations that replied to the survey. From figure 18 it is apparent that the method most utilised to mitigate risk is "Risk Reduction and Mitigation" (about 39%), followed by "Risk Avoidance" (about 30%) and "Risk Acceptance" (about 22%). The other four methodologies given were only used by the organisations that offered these methods.

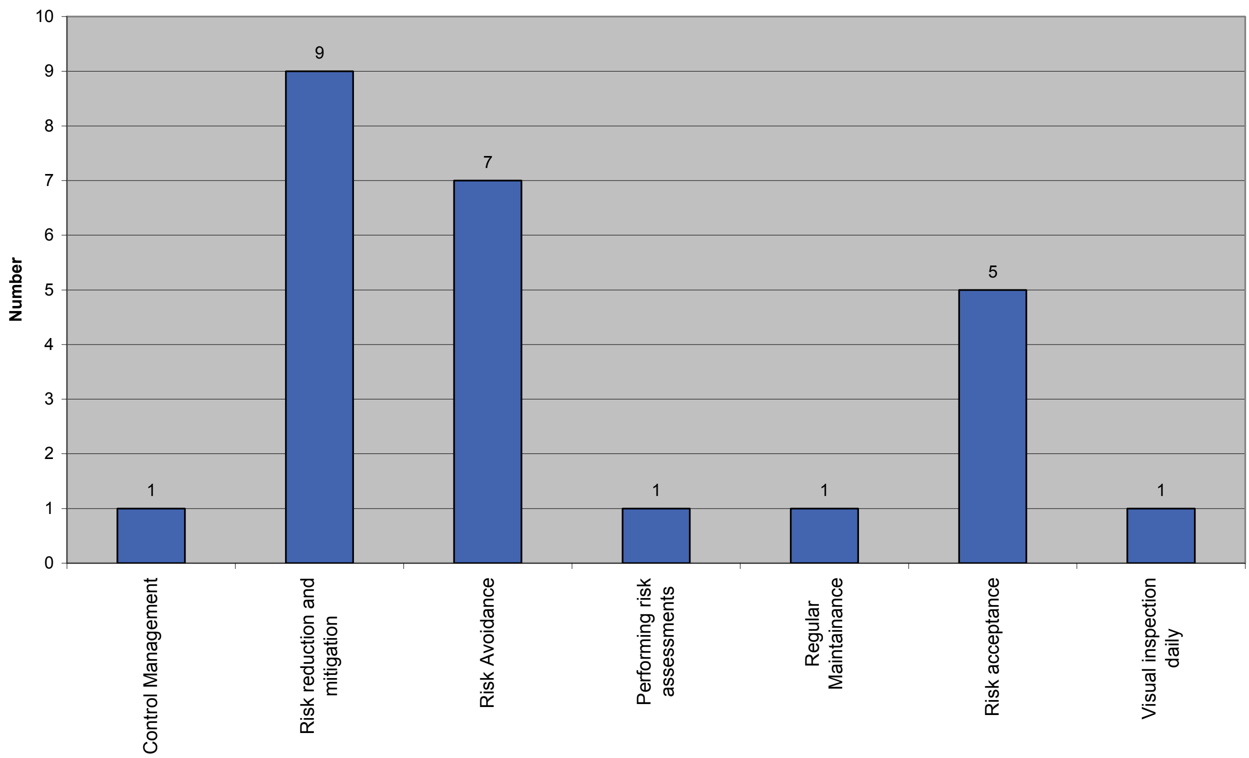


***Fig. 18.*** *Methods Used To Mitigate The Risks In Water Assets.*

#### 3.2.4.10 Risk Register

The ninth question aimed to establish which organisations maintained a risk register for their water infrastructure assets. Presented in figure 19 are the results, and it is evident that the majority of organisations that responded (73%) do not maintain a risk register for their assets.

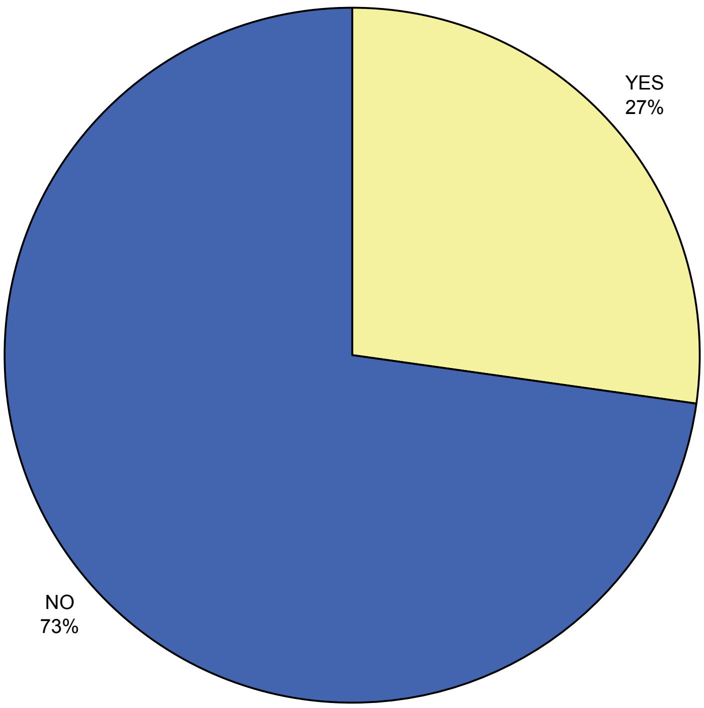


***Fig. 19.*** *Percentage of Organisations That Maintain a Risk Register For Water Assets.*

#### 3.2.4.11 Top Three Activities

The last question in the survey asked the organisations to provide comment on three topics, namely: a) what the organisation believes it top three activities in asset management should be, b) what three constraints are preventing the organisation from carrying out these activities in asset management, and c) any other comments the organisation would like to make on its asset management practices.

Presented in figure 20 are the results obtained for the first part of the question. From figure 20 it can be seen that 'Asset Replacement' and 'Having an Asset Register' were the joint the most common (both 16%) activities stated by the organisations as activities they should be carrying out, followed by 'Risk assessments of assets', 'Condition assessments' and having a 'Maintenance Management Plan' all of which were deemed to be equally important with 12%.

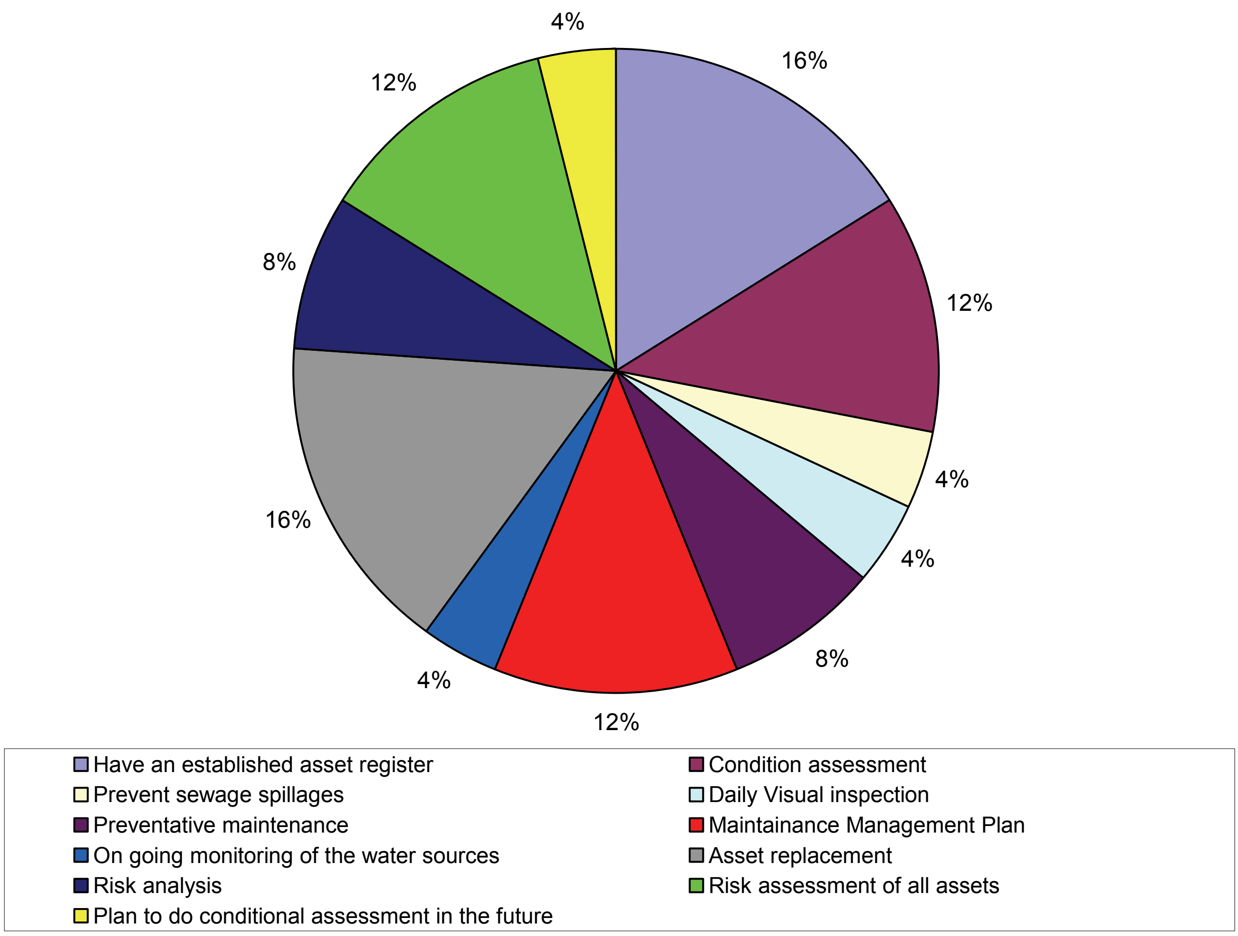


*Fig. 20. Perceived Top Three Asset Management Activities by Organisations.*

It should be noted that the all response obtained for the second part of the question in the survey were grouped into categories representing the overall issue highlighted by the response (full details of the responses provided for the second part of this question can be found in Appendix D Table D8). For example replies from the respondents to the second part of this question of; financial constraints, finance, funds for risk assessment, funding, budget, budget constraints, and insufficient funding were all descriptions of essentially the same constraint, that being financial and thus these responses were grouped together as Financial Issues. The results are presented in figure 21, and from figure 21 it is apparent that the most common constraint identified by organisations was 'Personnel Issues' (44%), followed by 'Financial Issues' (33%) and the "General Equipment Issues' (17%).

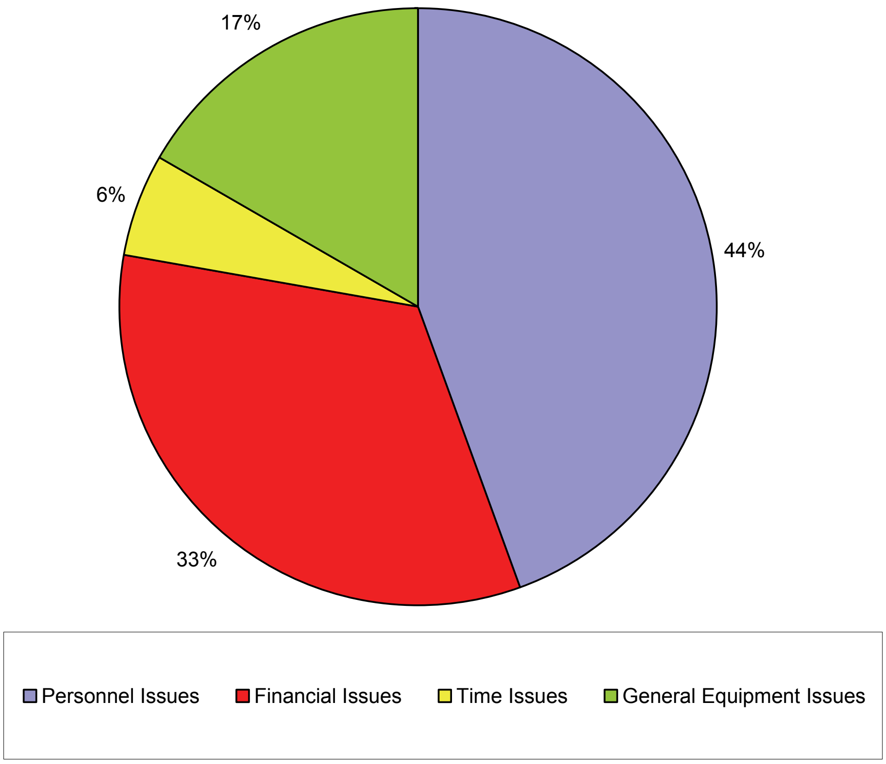


***Fig. 21.*** *Perceived Current Constraints by Organisations.*

As with the second part of the tenth question in the survey, the results from the third part of question were also grouped into categories representing the overall issue being raised (full details of the responses provided for the third part of this question can be found in Appendix D Table D8). These results are presented in figure 22. From figure 22 it is evident that the most common comment identified by the respondents was the need for 'Installation of new systems' (45%) followed by the need for having an 'Asset management policy' (22%) in place.

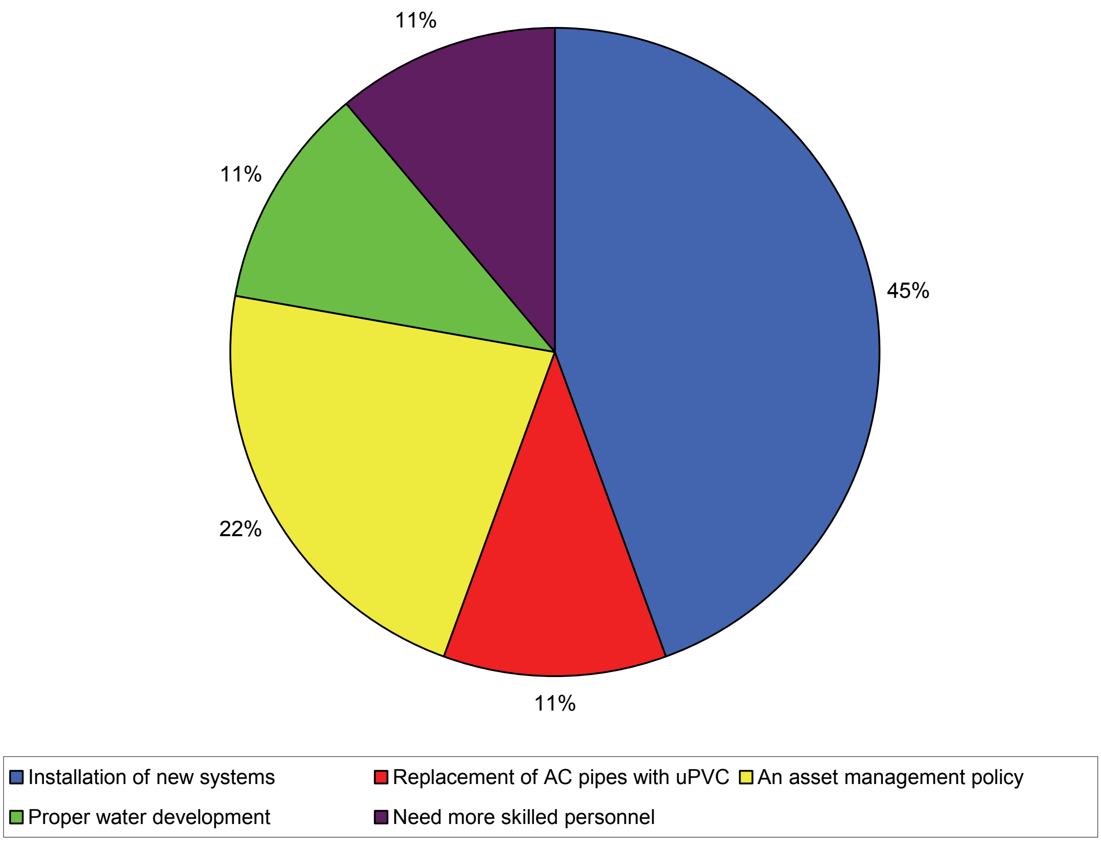


***Fig. 22.*** *Other Comments by Organisations on Asset Management Activities.*

### 3.2.5 Survey Concluding Remarks

Overall 23 out of a possible 150 water service providers responded to the questionnaire. Presented in Table 17 are the number of households and population figures obtained from the 2001 Census. From Table 17 it can be seen that collectively the organisations that responded supply water to 16% of South African households.

**Table 17. Population and Household Numbers Severed by Water Service Providers Surveyed.**

| Organisation | Population | % of South Africa | Households | % of South Africa |
|---|---|---|---|---|
| Camdeboo LM | 44372 | 0.1% | 10318 | 0.1% |
| Makana LM | 75303 | 0.2% | 18011 | 0.2% |
| Baviaans LM | 15335 | 0.0% | 3880 | 0.0% |
| Amatole DM | 961956 | 2.1% | 225724 | 2.0% |
| Matzikama LM | 50207 | 0.1% | 14094 | 0.1% |
| Swartland LM | 72114 | 0.2% | 17402 | 0.2% |
| Stellenbosch LM | 117704 | 0.3% | 28746 | 0.3% |
| Breede River / Winelands LM | 81270 | 0.2% | 20925 | 0.2% |
| Bitou LM | 14594 | 0.0% | 3527 | 0.0% |
| Laingsburg LM | 6680 | 0.0% | 1922 | 0.0% |
| Kgalagadi DM | 36881 | 0.1% | 9384 | 0.1% |
| Masilonyana LM | 98263 | 0.2% | 25839 | 0.2% |
| Nala LM | 32454 | 0.1% | 8847 | 0.1% |
| Setsoto LM | 53712 | 0.1% | 12429 | 0.1% |
| Moqhaka LM | 645440 | 1.4% | 185022 | 1.7% |
| Ugu DM | 704036 | 1.6% | 150611 | 1.3% |
| Uthukela Water | 656988 | 1.5% | 134853 | 1.2% |
| Westonaria LM | 109326 | 0.2% | 29979 | 0.3% |
| Vhembe DM | 1199895 | 2.7% | 264870 | 2.4% |
| Polokwane LM | 508259 | 1.1% | 124974 | 1.1% |
| Lephalale LM | 96106 | 0.2% | 23402 | 0.2% |
| Exxaro Grootegeluk Mine | - | n/a | - | n/a |
| City of Tshwane Metro | 1526936 | 3.4% | 447587 | 4.0% |
| **Total** | 7107831 | 15.9% | 1762346 | 15.7% |

Unfortunately many of questions in the questionnaire were of a qualitative nature and due to the poor response from providers the sample size was too low to allow a statistical meaningful analysis to be carried out. The survey results however can provide an insight into, but cannot be used as conclusive evidence from which to draw quantitative conclusions. Even though the overall response to the survey was low, the organisations that were surveyed provided some interesting and valuable data as the majority of the organisations were responsible for the assets types being investigated in the survey. Several of the organizations provided incomplete questionnaires or responded verbally to some of the questions, but these inputs did not form part of the data analysis.

It was found that the most common method used by the organisations to determine the condition of their assets was visual inspections. However visual inspections can encompass a rather broad definition of activities from cursory inspections to highly detailed examinations and without guidelines or standards it is difficult to judge the value of the visual inspections being carried out. It should be noted that some of the organisations indicated that they were utilising more advanced condition assessment techniques (e.g. Bitou LM utilising Motor Current Analysis for pump stations, and Exxaro Grootegeluk Mine utilising PIG's for determining the condition of pipelines). When addressing the frequency of the condition assessments that are carried out, most of the organisations indicated that they tend to assess their assets at least once a year. For some of the infrastructure assets carrying out an assessment of its condition once a year is acceptable (e.g. pipelines) but for other infrastructure assets a frequency of carrying out condition assessments once a year is perhaps not sufficient when the consequence associated with that asset experiencing a failure are taken into consideration (e.g. Dams and reservoirs).

The survey found that when it comes to measuring the reliability of infrastructure assets that only half of the organisations surveyed actually measure the reliability of their assets and the most common method employed to measure the reliability of their assets was 'direct measurement'. Similarly with visual inspections, it is difficult to fully comprehend what the responding organisations understand and what methodologies they utilise when carrying out 'direct measurement' for reliability.

The result of the survey show that only about half of the organisations rank their assets based on risk and the most common methodology utilised to quantify risks was monetary value followed by ranking on a continuum and qualitative categorisation. The most common risk mitigation methodologies employed by the water service providers are 'Risk Reduction and Mitigation', followed by 'Risk Avoidance' and 'Risk Acceptance'. However, only 27% of organisations surveyed maintained a risk register for their water infrastructure assets.

The survey found that when it came to what activities the organisations thought they should be carrying out as part of their asset management; replacing assets and maintaining an asset register were the two most common answers followed by carrying out risk assessments of their assets, condition assessments of their assets and having a maintenance management plan in place. It is interesting to note that some of these activities (e.g. asset registers) should already be taking place as they are legislative requirements.

The survey found that when it came to identifying the constraints faced by the service providers, the most common constraints identified by organisations were Personnel Issues followed by Financial Issues and General Equipment Issues. It is interesting to note that all the constraints identified are management issues. The comments provided by the organisations on asset management in general showed that there appears to be a need for installing new systems (suggesting that the old infrastructure is thought to be reaching the end of it useful life) followed by the need for having an asset management policy (which suggest that the current policy is not effect or is not being implemented). Overall the comments provided suggest that there seems to be a shortage of skilled people in the positions required to carry out these asset management functions and that majority of the respondents want some form of asset management implemented (as the constraints highlighted by the respondents were indicative of an ineffective or inefficient management function, i.e. not enough, money, people/skills and time).

## 3.3 Discussion on South African Asset Management Practices

The survey results and discussions with water service providers, technology vendors, and sector experts revealed that a wide variety of technologies are available and are used in South Africa (see Tables 1 to 11 for the availability and usage of technologies in South Africa). However, the extent of usage appears to be very low across all the water service providers in the country. Most technologies are only used by a few large utilities and the metros. In most cases, the technologies are used for failure evaluations rather than preventative testing.

Condition assessment is currently not being widely practiced as a structured activity across the country. Most condition assessment is in the form of ad hoc visual maintenance inspections or initial high level screening visual inspections for the compilation of asset registers. From the results of the survey, there does not appear to be much consistency in the visual inspection method. There are no standardised guidelines on water infrastructure condition assessment that cover detailed descriptions for different asset types and that use available condition assessment technologies. Most existing guidelines are based on a simple 5-point scale that is sufficient for high level screening assessments only. Condition assessment technology is currently not catered for.

Predictive modelling of risk, condition and reliability for water assets is currently not widely practiced in South Africa. The survey results show low use of reliability analysis methods, with reliability predominantly being directly assessed. No standardised methods or guidelines have been adopted and no implemented examples have yet emerged that can be shared with other water service providers. The only known case to the researchers is the City of Tshwane who is developing an integrated maintenance framework based on the predictive modelling of risk across various infrastructure types. In this case, the City of Tshwane is predicting the probability of failure of assets into the future based on the condition and age of the asset in its present state. The probability is multiplied with a financial consequence to produce a predictive risk model for each asset. The risk exposure of the asset is used as a means to prioritising the rehabilitation and replacement of assets and quantifying future financial liabilities.

From the results of the survey, there appears to be a widespread awareness of the need to determine asset risks as a management practice, but there is much inconsistency in the quantification and the management of the risks.

A local supporting body of knowledge has started to grow as a guide to local practitioners. The Department of Local Government and Housing in the Western Cape produced standardised guidelines for the implementation of asset management techniques including condition assessment and asset risk determination in 2006 on behalf of the local municipalities in the Western Cape[27]. IMESA contributed to the preparation of the 2006 version of the International Infrastructure Management Manual, which included a country specific section on South Africa. The manual includes guidelines on condition assessment, prediction of asset performance and asset risk determination. IMESA has promoted the manual widely in South Africa including heightened exposure of asset management and the manual at its annual conferences. The Department of Provincial and Local Government issued guidelines for infrastructure asset management in 2007[24]. These guidelines also contain methods that can be used for condition assessment and asset risk determination.

Although there is currently a low level of adoption of strategic asset management practices in South Africa, there have been some very positive movements in the last couple of years. The legislative drive for municipalities (Municipal Finance Management Act) to prepare asset registers for financial compliance has stimulated the preparation of asset registers nationwide. Unfortunately, many municipalities have prepared the registers only with the intention of financial compliance and have missed the opportunity to align the financial registers with technical registers that can be used to assist with asset management planning. Some municipalities have aligned the registers and have implemented condition assessment and asset risk determination methods. It is known to the researchers that at least fifteen of the local municipalities in the Western Cape and several others across the country have prepared asset registers that include visual condition assessment and asset risk determination using the criticality rating method.

Most asset data that is being collected across the country is primary data that describes the location, size, nature, and value of the asset. Data useful for prediction of asset performance is not yet being widely collected. Few water service providers have computerised maintenance management systems that are operating effectively to collect secondary and tertiary asset data that can improve the confidence in condition assessments, prediction of asset performance and asset risk determination. Some water service providers have recently looked at the implementation of such systems to improve maintenance management. An example is Buffalo City, who is using their maintenance management system to program preventative maintenance and to log failures for maintenance reliability analysis. This application has however not yet been extended to incorporate a system wide basis for condition assessment, prediction of asset performance and asset risk determination. The City of Cape Town and Lepelle Northern Water Board are both working towards implementing a strategy that aligns the financial asset registers, the technical asset data and the maintenance management system within the SAP environment. The intention is to incorporate the condition assessment, prediction of asset performance and asset risk determination data requirements within the SAP environment to be able to prepare asset management plans, perform maintenance analysis, and financial analysis in an aligned manner.

A few municipalities across the country have also started preparing asset management plans that incorporate condition analysis and asset risk determination. As the base data in the form of asset registers becomes more available, it is expected that the analysis of the data will increase in complexity and the preparation of more asset management plans will follow.

The future of condition assessment, prediction of asset performance and asset risk determination has great growth potential in South Africa. The need for these practices is supported by the statements in the survey of the respondent's top three asset management activities. Inventory data is increasing in abundance with the legislative drive for all assets to be represented in the balance sheets of public authorities. This is leading to an increase in asset inventories and primary asset knowledge (i.e. what is owned, where it is located, and what it is worth). The level of data sophistication has the potential to increase at an accelerated rate. With asset inventories in place, which are very costly, the barriers to collecting more sophisticated data and conducting more sophisticated analysis are lowered. Service delivery failures are also focusing public attention on reliability, replacement planning, and maintenance, which will further drive the increase in data sophistication.

An increase in the sophistication of data is expected to lead to an increase in the demand for condition assessment technology. Project level decisions on infrastructure replacement programs will require the greater certainty that condition assessment technologies provide. There is also expected to be an increase in the demand for prediction of asset performance and asset risk determination techniques to inform infrastructure replacement programs. Should the demand for technology increase and the usage become more widespread in the country, technology availability is expected to increase and the cost of using the technology is expected to reduce which will be of benefit to the country.

This potential growth in the demand for these technologies and analysis methods will depend on the extent to which the demand is recognised in the country. There is a great need to provide an environment in which the technical discipline can be practiced. It will take responsive officials to identify the need for such analysis, money in the coffers of water service providers to implement such methods, and technical expertise to interpret and act on the results of such analysis. There are several constraints related to the business elements (finance, personnel, management, etc.) of water service providers that have a major impact on the implementation of asset management. Several of these issues were highlighted in the results of the survey such as personnel, financial and time issues. Inadequate human resource capacity is a well documented major constraint in South Africa. Without aligned goals and sufficient capacity from the level of elected officials through management and technical staff, infrastructure asset management practices cannot be implemented. These institutional issues are not unique to South Africa, but are at present very acute and represent a major challenge to the broadening of infrastructure asset management practices in the country. If the infrastructure management needs are not met, ultimately the communities they serve will suffer from reduced service levels.

## 3.4 Comparison with International Trends

International trends regarding technologies for condition and risk assessments and for predicting performance of engineered or built environment assets, depend very much on viewpoint. For example:

(i) Technology developers, researchers and vendors – generally have a bias towards technology push, and may overstate both applicability and benefits;

(ii) Asset developers – are generally constrained by the measures of project success and hence may only adopt established technologies;

(iii) Asset operators – typically subjected to private sector profit motives or public sector service delivery requirements may be constrained in both finance/funding and skills to implement new technology;

(iv) Regulatory agencies – are generally concerned with technologies that make it possible to demonstrate compliance.

The various viewpoints are exacerbated by the fact that there are a number of definitions for asset management[28]. With increasing self-diagnostics capabilities driven by advances in sensors, micro-electromechanical devices, computing and information systems and automation technologies, there is a growing recognition of the need for new skills in sophisticated data collection and to apply well-established physical and mathematical principles for condition assessment, prediction of asset performance and asset risk determination of engineered assets.

Whereas vendors of technologies associated with condition monitoring purport wide adoption, however, judging by the emerging ISO standards[29], it begs to question to what extent the skills and capabilities of asset operators match the claims, and hence the application of condition assessment technologies on water infrastructure assets. References (30), (31) and (33) are examples of asset management by water services authorities elsewhere, with emphasis on planning and portfolio risk analysis. The general trend is more or less the recognition of the need to record asset metadata, then "... to provide conditions tracking and risk assessment tools for evaluating the probability and mitigating the consequences of failure…" of water infrastructure assets to enable more accurate capital budgeting. It is envisaged that the emergence of radio-frequency identification (RFID) will facilitate the process of capturing, storing, retrieving and communication of asset metadata.

Griggs[32] summarises

> "*...that utilities can utilize available information much better than they do. However, they are impeded by lack of a standard procedure for recording data on leaks, breaks, and condition indicators. Ideally, the large amount of information involved would be consolidated into a composite condition index, but this is not feasible. Advanced applications are required for the future. These might include real-time assessment, smart pigs to collect data, small chip sets, and automated pipe data registration. Research needs are indicated in nondestructive testing, leak detection and loss measurement, causes for pipe, joint, lining, and coating deterioration, and in situ methods to test condition. While condition assessment is a promising concept, it is not applied consistently…*".

There may be a number of case studies by private water utilities which are not reported in public domain literature, however, the indication is that there are no formal standards for many of the condition assessment methods utilised, even though de-facto specifications tend to be supported by industry regulators. In the United Kingdom for example the Dempsey and Manook Pit Depth method[11] has been accepted by the water utilities as the industry standard for determining the condition of cast iron distribution mains. Due to the demand for technology to provide more detailed assessments of water infrastructure condition, there is a wider market of vendors offering a range of competing technologies and tools, which has lead to an increase in the range of, and gradual reduction in the costs of technologies available to utilities.

It is obvious that more sophisticated data (e.g. spatial and three-dimensional data) can be obtained for various asset types through the use of available technologies. The increasing adoption and use of computerised information systems for the management of the maintenance function provides impetus for other secondary and tertiary data that provides transactional information for deducing asset performance, albeit, mostly in fiduciary terms. Not all utilities and local authorities use such computerised systems, but there appears to be a more widespread adoption and a greater number of these systems to choose from. In some countries, the collection and management of asset metadata has become compulsory. Asset management planning in Australia and New Zealand, Canada, some parts of USA, and the United Kingdom appear to be at least 10 years ahead of South Africa. Several of these countries already started implementing infrastructure replacement programs many years ago, especially following changes in the ownership structures of utilities spurred on by the emergence of public-private partnerships.

However it should be mentioned that the eThekwini Metropolitan Municipality is currently busy implementing an R850million pipe replacement programme which is a major project within the local government sector. Analysis methods, data standards, and business processes are in a more infancy stage in South Africa, but learning is accelerating.

Modelling methods emphasise the prediction of asset performance are based more on probabilistic, rather than deterministic failure models. For some of the methods, the range of variables sometimes makes it difficult to define a consistent deterministic model with transferable parameters for water assets. The collection of data on the variables that impact on hidden assets, such as pipes, can be expensively impractical, and also costly to develop mechanistic-empirical models. As a result, curve fitting techniques on empirical data account for much of the variance in the data thus reducing the level of certainty in the predictive models. A higher level of certainty arises in models utilising the correlation between known hazard rates, failure modes and failure frequencies or intervals, conforming, for example, to well known statistical distribution such as the Weibull function. There is a reasonable volume of current research characterising reliability using Weibull and other probability density functions.

Risk identification, analysis, mitigation and management are gaining increased emphasis in asset management. Asset risk is gaining significance, e.g. if a pipe that runs under a road fails there could be collateral or cross-utility damage that may impact road users. This kind of situation lends itself to portfolio risk analysis and requires extensive multi-dimensional data. Multi-criteria prioritisation and optimised decision making may be conducted on the basis of such data. Using established probability density functions, there seems to be more consistency in the quantification of the conditional probability of failure than in the quantification in the consequence of failure.

One of the key differences between South Africa and other developed countries is the difference in data availability and detail. The more sophisticated the prediction of asset performance and risk analysis, the more data is required. This indicates an expected tendency of increased sophistication of data as asset management becomes more widely practiced locally. Presented in figure 23 is the progression of data sophistication and the key data management needs associated with that progression.

| **Data level** | **Data type** | **Key Data Management Needs** |
|---|---|---|
| Primary data | Inventory | □ Classification guidelines<br>□ Basic attributes guidelines<br>□ Data storage software |
| Secondary data | Basic condition attributes | □ Assessment guidelines<br>□ Reporting guidelines |
| Tertiary data | Performance data/modelling | □ Advanced condition technology<br>□ Maintenance management software<br>□ Business processes<br>□ Predictive modelling methods<br>□ Optimised decision making methods<br>□ Benchmarking |

Where most Water Service Providers are now

Movement in the future

***Fig. 23.*** *Progression of Data Sophistication.*

From figure 23 it can be seen that several key data management needs have been identified that will need to be addressed to accommodate the increased level of sophistication in data. These data management needs represent some key gaps that can be filled. There is a strong argument for developing guidelines and standardised analysis and reporting in South Africa. Increased consistency will allow benchmarking, minimise cost, and increase adoption under high technical resource constraints. Failure to standardise will lead to vendor driven adoption of technologies and standards, which may result in a high variance in methods adopted across the country.

The study shows that many of the available condition assessment technologies are being used in South Africa, but they are being used in isolated cases, mainly by the metropolitan municipalities and water boards, and mainly for project level assessments. The main difference in the adoption of condition assessment technology is that there is a wider usage of technology in several other countries for research and commercial purposes. This increased usage also results in more established and standardised methods of collection and reporting. In South Africa, the need for condition assessment and performance monitoring needs to be promoted widely to stimulate the demand for different technologies. Assistance then needs to be provided to ensure standardised collection, analysis and reporting. Minimum data requirements for different condition technologies will assist practitioners greatly to avoid confusion and to prevent vendor driven results.

Prediction of asset performance in South Africa is very much in its infancy. Many of the methods developed in other countries are either consultant software driven or organisation specific. These models are not readily transferable and will require local adaptation to suit local needs and data constraints. The cost of developing predictive performance models is high and acts as a barrier to entry for many local organisations. There is therefore a need to promote further research into this area to assist with the development of generic models that can make prediction of asset performance more attainable for water service providers in South Africa.

South African water service providers are also starting to engage in asset risk determination as a basis of prioritisation. As is the case with prediction of asset performance, asset risk determination is more widely used abroad. There are, however, numerous methods used by different organisations. The greatest need in South Africa is to develop a common understanding and approach to risk management to lower the barriers to entry for water service providers. Research into the development of a generic asset risk determination framework that considers the low availability of data will be of value to local water service providers.

# 4. Conclusions and Recommendations

This study has provided a comprehensive literature review of the tools and techniques available for the condition assessment of water infrastructure assets. The review has also provided domestic and international case studies where these tools and techniques have been utilised. Tables 1 to 11 presented in section 2.2.2 provide a useful reference tool to identify the techniques available to determine the condition of infrastructure assets in the water industry, including the availability of these techniques in South Africa.

A review of the asset management practices within the water industry in South Africa has been conducted primarily through a questionnaire. The results show that current practices in South Africa for condition assessments rely heavily on ad-hoc visual inspections, for which there are no standardised guidelines for water infrastructure assets and these visual inspections are normally conducted at a high level. The prediction of asset performance is not widely practiced and data for reliability and maintenance analysis is not collected widely. Similarly to condition assessments there are no standard methods or guidelines developed for asset performance. There is a widespread awareness of asset risk, but there is not much consistency in the approach to risk quantification and management. The IIMM and DPLG guidelines for criticality scoring for asset risk determination do provide local guidance, but are not yet widely adopted.

A comparison of water infrastructure asset management practices between the more developed countries and South Africa indicates that a substantial difference lies in the availability of asset data and the use of the data in planning major infrastructure replacement programs. Most South African water service providers are in the process of collecting primary asset data driven by legislation and are only starting to plan infrastructure replacement programs. Developed countries have a greater volume of secondary and tertiary data collected primarily by computerised information systems on which to conduct more sophisticated performance, reliability and risk analysis. Much more extensive infrastructure replacement programs have been implemented in some developed countries, which have increased the level of detail in condition assessment and data analysis.

The analysis showed that South Africa has several key data management needs that will need to be addressed to accommodate the increased level of sophistication in data. A need has been identified for developing guidelines and standards for analysis and reporting which will lead to increased consistency allowing benchmarking and cost minimisation. Failure to standardise will lead to vendor driven adoption of technologies and standards, which may result in a high variance in methods adopted across the country.

This review of current asset management practices indicates a low level of adoption of asset management in the country at this stage. The survey also indicates that institutional capacity is a major constraint to the effective implementation of infrastructure asset management. Implementation of a new discipline requires the learning of new skills and an increase in effort. This 'spare capacity' does not appear to be readily available in the country with organisations lacking skills and sufficient staff numbers. Unless the institutional capacity is created by increasing skill levels and numbers of technical staff, there is little chance that a new technical discipline will be adopted and widely implemented. The need for asset management is great within local government, but the ability to implement is currently a concern.

It is important that the recommendations made to the Water Research Commission should first be aligned with the policies and strategy of the Department of Water Affairs if feasible, before being implemented. The following recommendations are made to the Water Research Commission:

There is a current need to support and guide the data progression from basic data through to the higher levels of data sophistication. Many organizations are grappling with basic inventories, which set the basis for further data improvement. With the current pressure to produce infrastructure asset registers, it is recommended that a standard classification of assets that aligns with the accounting classification be developed. Guidance on the basic attributes that should be collected for the different asset types should also be provided. Awareness needs to be raised of data management needs and issues through websites and conferences and guidelines and best practice manuals should be developed to support key data management needs.

It is recommended that minimum standards are set for condition assessments and reporting for the different condition assessment technologies. These standards need to be developed in order to reduce vendor influence on the collection of data and ensure that condition data is widely comparable.

There is a critical need for the development of standard condition indices that provide a standard point of reference across different water service providers. Common condition indices should be developed on a consultative basis in much the same way as the roads sector developed its condition indices, which have been successfully used for many years. Research and development will be required with wide stakeholder participation.

Further research into the prediction of asset performance is required to assist with the development of generic models that can make prediction of asset performance more attainable for water service providers in South Africa. Models that have been used successfully abroad should be adapted to the local physical environment and be tailored to function with the low availability of data in South Africa.

The development of a common approach to asset risk determination is necessary in order to produce comparable data in much the same way as a common condition index. It is recommended that a risk framework that covers the needs of small municipalities to large water service providers be developed based on asset risk determination methods used abroad.

Increased participation in benchmarking is required to raise awareness of the performance parameters related to condition and risk and to provide a common basis of comparison between water service providers. It is recommended that more condition and risk based parameters be included within existing benchmarking programs.

The creation of a receptive environment for the implementation of asset management practices, particularly within the local government sphere, is a necessity. It is recommended that the development of technical audits as a means to stimulate technical management actions, in the same manner as financial and accounting audits, be promoted as a means of improving the technical management of infrastructure assets. The underlying value of infrastructure assets is substantial in infrastructure rich organizations such as municipalities. Indifferent technical management practices that lead to the accelerated deterioration and erosion of the value of the assets should be as great a concern as the indifferent management and control of financial assets.

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# APPENDIX A – DETAILS OF PROVIDERS OF TOOLS AND TECHNIQUES

| **Technology type** | **Application** | **Vendors** |
|---|---|---|
| Closed-circuit television inspection (CCTV). | Pipe interior inspection | • EGS (Asia) Ltd of Hong Kong.<br>• SIGHT LINES Pipe Survey Services, South Africa<br>www.sightlines.co.za |
| Karo-System | Pipe interior inspection<br>Microwave sensor for the inspection of the soil surrounding pipe wall. | • German Federal Ministry of Education, Science, Research & Technology in partnership with Industry and other Research Institutions.<br>• Kuntze, H.B. Fraunhofer Institute for Information & Data Processing (IITB), Fraunhoferstrasse 1, D-76131 Karlsruhe, Germany. Phone: 49(0)721/6091-0 |
| Pipe scanner and evaluation technique (PSET) | Pipe interior inspection | |
| Laser Based Scanning Systems (LBSS) – laser based profiler can be coupled to a CCTV camera to increase the accuracy of the inspection. | Pipe interior inspection | Envirosight LLC, Video Pipeline Inspection<br>111 Canfield Ave., Bldg. A, Unit 14<br>Randolph<br>NJ<br>USA<br>Phone: 866-936-8476<br><br>http://www.envirosight.com |
| Ultrasonic testing (UT) | Pipe interior inspection. Most suitable for metallic pipes and tuberculation on the pipe wall.<br><br>Most suitable for metallic pipes and not AC as the acoustic waves are likely to attenuate significantly in deteriorated pipe. | **Olympus NDT**<br>48 Woerd Ave<br>Waltham, MA 02453<br>**USA**<br>Phone: +1 781 419 3900<br>http://www.olympusndt.com<br><br>Olson Engineering, Inc 5191 Ward Road, Suit 1, Wheat Ridge, CO 80033<br>303 423 1212<br>http://olsonengineering.com |
| Guided Waves (GW) | Metallic pipe inspection. | Guided Ultrasonic Ltd<br>www.guided-ultrasonics.com/<br><br>SGS SA<br>1 place des Alpes<br>P.O. Box 2152<br>1211 Geneva 1<br>Switzerland<br>www.sgs.com |
| Remote field eddy current (RFEC) | Pipe interior inspection | • Earth Tech Engineering – Pipeline Condition assessment (ETE-PCA) from Australia<br>• Rock Solid Pty of Australia |
| Linear polarization technique | Metallic pipes only. | |

| Technology type | Application | Vendors |
|---|---|---|
| (LPT) | Used to determine the external corrosion of a metallic pipe | |
| Acoustic emissions (AE) monitoring | Pre-stressed concrete pipe | Echologics Engineering Inc.<br>Tel: +1 (416) 249-6124<br>www.echologics.com |
| Impact echo (IE) | Pipe wall thickness integrity – location and extent of flaws such as cracks, delaminations, voids, honeycombing, and debonding in plain, reinforced and post-tensioned concrete structures. | • Olson Engineering, Inc 5191 Ward Road, Suit 1, Wheat Ridge, CO 80033 303 423 1212 http://olsonengineering.com<br><br>• Geo-Vision, Geophysical Services, a division of Blackhawk Geo-services. 1151 Pomona Road, Unit P, Corona, California, 92882. Phone: 909-549-1234 www.geovision.com<br><br>• Pure Technologies<br>www.puretechnologiesltd.com |
| Surface Wave –Time Dormain Reflectometry (SW-TDR) | Condition of coating at prescribed locations for the submerged sections.<br>Information on wall thickness<br>Mainly metal pipes. | |
| PIRAT System | Pipe condition assessment method | • CSIRO (Australia Research Agency) Rogers, K. – CSIRO Division of Manufacturing Technology, Australia<br>Gilbert, J. – CSIRO Division of Building Construction & Engineering, Australia.<br>Campbell, G. – Melbourne Water, Australia |
| Tri-Scan | Pipe condition assessment method | |
| Sewer Scanner and Evaluation Technology (SSET) | • Pipe condition assessment method | • Toa Grout, Core Corp. (Japan) & the Tokyo Metropolitan Government's Sewer Services (TGS) – 1994.<br>Iseley Enterprises, Inc. , 220 Briar Creek Road, Greer, SC, 29650-3002, Phone: (864) 322-2614 |

| **Technology type** | **Application** | **Vendors** |
| --- | --- | --- |
| Smart Pigs<br>• CalScan<br>• MagneScanHR<br>• UltraScan<br>• Geopig | Pipe condition assessment method | • Pipetronix Inc. 2207 Oil Center Court. Houston, Texas 77073-3334 Phone: (800) 324-7633<br>• Stefan Papenfuss, Tuboscope Pipeline Services, P.O Box 808, 2835 Holmes Road, Houston, TX 77001, USA http://www.varco.com<br>• List of manufacturers & distributors http://www.piggingassnppsa.com/Consultancy-Services.htm |
| Half-Cell Potential measurement | Concrete structures, e.g. dams | |
| Polarization resistance measurement | Concrete structures, e.g. dams | CC Technologies Canada Ltd<br>Bay 123, 2340 Pegasus Way NE<br>Calgary, AB Canada T2E 8M5<br>Phone: (430) 250 9041<br>E-mail: info@cctechnologies.ca |
| Transponders and data-loggers | Mostly used in open channel systems. | Blue Tower Communications<br>UK Office<br>Suite 1<br>Basepoint Business Centre<br>Aviation Park West<br>Christchurch<br>BH23 6NX<br>Phone: +44 845 2300 156<br>Fax: +44 845 2300 157<br><br>mailto:infoWeb@BlueTowerComms.com |
| SCADA and Telemetry | SCADA can be extended to satellite telemetry, radio telemetry, cell phone telemetry | **Bentek Systems**<br>SCADA & Telemetry Solutions<br>504 - 42nd Ave.S.E.<br>Calgary, Alberta, Canada T2G 1Y6<br>(403) 243-5135 Fax: (403) 243-5165<br>www.scadalink.com<br>**Data flow Systems**<br>webmaster@dataflowsys.com<br>Adroit Technologies, South Africa<br>www.adroit.co.za<br>Wonderware Southern Africa<br>www.futuristix.co.za |
| Vibration analysis | In machinery, particularly rotating machinery. | CERCIA, School of Computer Science<br>The University of Birmingham, UK<br>http://www.cercia.ac.uk<br><br>**Plant Asset Management Services**<br>http://www.vibrationmonitoring.co.uk<br><br>SA Instrumentation & Control<br>Phone: +27 (0) 82 445 9991, 086 111 4217,<br>http://randci.co.za |

| Technology type | Application | Vendors |
|---|---|---|
| Current sensor (Motor Current Analysis) | Systems that operate by motor, transformer, generator | CERCIA, School of Computer Science<br>The University of Birmingham, UK<br>http://www.cercia.ac.uk<br><br>Plant Asset Management Services<br>http://www.vibrationmonitoring.co.ukSA Instrumentation and Contro http://randci.co.za<br><br>Perspective CMMS<br>http://www.pemms.co.uk<br><br>PredictNDT Pty Ltd<br>http://www.predictndt.com<br><br>Gilchrist Technology Inc<br>http://www.gilchristtechnology.com |
| Infrared Thermography (Thermal imaging) | Particularly rotating machinery.<br>Electrical inspections | |
| Laser Shaft Alignment | Shafts of rotating equipment (high speed rotating) | |
| Oil analysis | Oil in electrical transformers. Detects contaminants in oil. | |
| Automated Mapping Facilities Management GIS (AM/FM/GIS) | Network assets, e.g. pipelines | Sentinel USA<br>http://www.sentinelusa.com/<br><br>FedSoft, India<br>http://www.fedsoft.net/automatedmapping.htm<br><br>Coler & Colantonio, Inc.'s<br>http://www.col-col.com/ |
| Sonar | Pipelines | AMTEC Surveying Limited of Chesterfield, England<br>Redzone Robotics, Pittsburgh, Pennsylvania, USA<br>http://www.redzone.com |

## APPENDIX B – QUESTIONNAIRE

A copy of the final version of the questionnaire has been included in this appendix.

### Review of Technology Used in Strategic Asset Management; Existing and Future Needs

#### INFORMATION FOR PARTICIPANTS

**Our Request for Permission**

Africon, working on behalf of the Water Research Commission courteously invites your organization to participate in a Research Questionnaire for The Review of Technology used in Strategic Asset Management; Existing and future needs.

Africon, in collaboration with Water for Africa and Professor Joe E. Amadi Echendu, is conducting a survey to review technologies applicable to asset management practices in the water industry with particular focus to the South African environment. The study will identify opportunities for technology and asset management practices and adoption. The survey will address four issues namely:

(i) Condition assessment
(ii) Performance/reliability prediction,
(iii) Risk management
(iv) Technologies

**General information about the survey**

(i) The survey comprises 10 questions.
(ii) All data and information collected in this survey will be handled confidentially.

The results of the study will be used to;

(i) Identify where there are opportunities for benchmarking and adoption of new technologies to the water industry as well as where there may be needs that are currently not being met.

If you would like to discuss any aspects of the study, you may contact:

**Dr Chris von Holdt:** chrisvh@africon.co.za
043 721 0900

**Your Consent to Participate**

I ……………………….hereby voluntarily grant my permission for my company/organization to participate in the survey. I understand that the nature of the research does not present foreseeable safety and health implications.

I understand my right to choose whether or not to participate in the survey and that the information furnished will be handled confidentially. I am aware that the results of the investigation may be used for the purposes of publication

Would you like to obtain a confidential copy of the survey report? Yes/No ______

Please complete below then fax to 086 602 1469 or send a scanned copy to MarnaG@africon.co.za

You may wish to retain a copy of this page for your records.

Signature ______________________________ Date ___________________________

Company/Organization ___________________________________________

Name of Respondent ___________________________________________

Designation ___________________________________________

Contact Information (email, telephone physical/postal address)

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

Please indicate the Industry Classification for your Company/Organization.

| | | Please Tick ✓ |
|---|---|---|
| 1 | Local authority (municipality) | |
| 2 | Water services institution (bulk supply) | |
| 3 | Water services institution (other) | |
| 4 | Government department | |
| 5 | Mining & mineral processing | |
| 6 | Manufacturing | |
| 7 | Other | |

If other, state the industry classification for your company or organization.

1 ___________________________________________________________

2 ___________________________________________________________

3 ___________________________________________________________

4 ___________________________________________________________

5 ___________________________________________________________

## Questionnaire

1 What water assets are you responsible for?

| | Please Tick ✓ |
|---|---|
| Dam | |
| Borehole | |
| Spring protection | |
| Reservoir | |
| Water pump station | |
| Sewage pump station | |
| Water treatment works | |
| Sewage treatment works | |
| Water pipelines (reticulation & bulk) | |
| Sewage pipelines | |
| Valves | |

2 How often do you perform condition assessment on water assets?

**Please give indication of annual frequency and work done** (e.g.: 2 / year-visual inspection).

| | Annual Frequency | Action Taken |
|---|---|---|
| Dam | | |
| Borehole | | |
| Spring protection | | |
| Reservoir | | |
| Water pump station | | |
| Sewage pump station | | |
| Water treatment works | | |
| Sewage treatment works | | |
| Water pipelines (reticulation & bulk) | | |
| Sewage pipelines | | |
| Valves | | |

3 What technologies do you use for condition assessment?

| | Technology Used | Other Technology |
|---|---|---|
| Dam | | |
| Borehole | | |
| Spring protection | | |
| Reservoir | | |
| Water pump station | | |
| Sewage pump station | | |
| Water treatment works | | |
| Sewage treatment works | | |
| Water pipelines (reticulation & bulk) | | |
| Sewage pipelines | | |
| Valves | | |

4 Do you measure reliability of water assets?

| | Yes/No |
|---|---|
| Dam | |
| Borehole | |
| Spring protection | |
| Reservoir | |
| Water pump station | |
| Sewage pump station | |
| Water treatment works | |
| Sewage treatment works | |
| Water pipelines (reticulation & bulk) | |
| Sewage pipelines | |
| Valves | |

5 What methods are used to measure reliability of water assets?

| | Reliability Method | Other Method |
|---|---|---|
| Dam | | |
| Borehole | | |
| Spring protection | | |
| Reservoir | | |
| Water pump station | | |
| Sewage pump station | | |
| Water treatment works | | |
| Sewage treatment works | | |
| Water pipelines (reticulation & bulk) | | |
| Sewage pipelines | | |
| Valves | | |

6 Do you rank water assets based on risk?

| | Yes/No |
|---|---|
| Dam | |
| Borehole | |
| Spring protection | |
| Reservoir | |
| Water pump station | |
| Sewage pump station | |
| Water treatment works | |
| Sewage treatment works | |
| Water pipelines (reticulation & bulk) | |
| Sewage pipelines | |
| Valves | |

7 What methods are used to quantify the risks?

| | Risk Quantification Method | Other Method |
|---|---|---|
| i) | | |
| ii) | | |
| iii) | | |
| iv) | | |
| v) | | |

8 How do you mitigate the risks in water assets?

| | Risk Mitigation |
|---|---|
| i) | |
| ii) | |
| iii) | |
| iv) | |
| v) | |

9 Does your organization maintain a risk register for water assets?

**Yes/No**

10 Briefly provide a general comment on:

a) What you believe the top three asset management activities you should be doing?

b) What are the three current constraints that prevent you from doing this?

c) Any other comments you'd like to make on you current asset management practices.

# APPENDIX C – TRACKING THE QUESTIONNAIRE

Table C1 – Record of Questionnaire Tracking with Organisations

| Organisation | Type | Africon Contact Person | Questionnaire Sent | Questionnaire Received | Organisation Person | Week: 1/12/2008-8/12/2008 | Week: 08/12/2008-15/12/2008 | Week: 15/12/2008-19/12/2008 | Week: 05/01/2009-12/01/2009 | Week: 12/01/2009-19/01/1009 | Week: 19/01/2009-26/01/2009 | Week: 26/01/2009-02/02/2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Eastern Cape** | | | | | | | | | | | | |
| Cacadu DM | DM/WSA | Nivelene Naidoo | Yes | | Mr V Lwana | Mr Snyman - psnyman@cacadu.co.za | No answer | | No answer | | No answer | |
| Camdeboo LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Clr K Hossman | Nokwanda xamesi - Nokwanda.Xamesi@lgnet.org.za- Manager Technical Services - 0837983625 | | DONE | DONE | DONE | DONE | DONE |
| Blue Crane | LM / WSA | Nivelene Naidoo | Yes | | Clr S Froehlich | Simpiewo Majali - simpiewo.majali@lgnet.org.za- Manager Technical Services - | | | | | | No reply |
| Route LM | LM / WSA | Nivelene Naidoo | Yes | | Clr N Vanda | Thandekile.Mnyimba@lgnet.org.za/Benitto.Herandien@lgnet.org.za - Advised Tech Mng. Resigned. Send to Mun. Mng. | | | | | | |
| Ikwezi LM | LM / WSA | Nivelene Naidoo | Yes | | Cr Z Peter | No answer | Mr Njila - Technical Director -6063 - dabula@makana.gov.za - 076 6124131 | | | Marsha advised she'll follow up with Infras. dept | No reply | No reply |
| Makana LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Clr Z A Lose | No has been changed | Tel: (042) 230 0310/ - srv@telkomsa.net | | | Martha will fill it in – she'll send it asap | DONE | DONE |
| Sunday's River Valley LM | LM / WSA | Nivelene Naidoo | Yes | | Clr P Daniels | | | | | Wrong contact details | Wrong contact details | Wrong contact details |
| | DM / WSA | Nivelene Naidoo | Yes | | Cr K Felix | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Baviaans LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Nico Jonker | Bennie Arends - benniea@lgnet.org.za/PA.: Porcha.Draai@lgnet.org.za - Director: Technical Services | PA Portia advised received and will inform Bennie to submit by 19/12/08 | PA Portia advised received and will inform Bennie to submit by 19/12/08 | PA Portia advised received and will inform Bennie to submit by 19/12/08 | No reply, phone just rings | No reply | DONE |
| Kouga LM | DM / WSA | Chris von Holdt | Yes | | Graham Cowley | | | | | | | pa-Letti says she will give him the questionaire |
| Amatole DM | DM / WSA | Chris von Holdt | Yes | **Yes** | Ms Mvana | DONE | DONE | DONE | DONE | DONE | DONE | DONE |
| Buffalo City LM | DM / WSA | Nivelene Naidoo | Yes | | Cr A C Mpela | | | | | | | |
| Chris Hani DM | DM / WSA | Nivelene Naidoo | Yes | | Cr S Nduku | | | | | | No reply | Sent reminder |
| O.R Tambo DM | DM / WSA | Nivelene Naidoo | Yes | | Mr S K Mnukwa | | | | | | No reply, phone just rings | No reply, phone just rings |
| Alfred Nzo DM | DM / WSA | Nivelene Naidoo | Yes | | Cr M Tokota | | | | | | | |
| Nelson Mandela Metro | DM / WSA | Nivelene Naidoo | Yes | | Mr V Lwana | | | | | | | |
| City of Cape Town Metro | DM / WSA | Nivelene Naidoo | Yes | | Mr. Clive Justus | Sifiso advised he sent it through guys. with different Ques. To fill in- will be ready by Friday | | | | Sifiso advised no time, over committed | Sifiso advised no time | over committed |
| West Coast DM | DM / WSA | Nivelene Naidoo | Yes | | Mr WD Loff | | | | iabvanderwesthuizen@wcdm.co.za-sent reminders | Mr v/d Westhuizen advised no time, should be ready by the 28th | over committed | over committed |
| Matzikama LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Mr Gert van Wyk | | JC Stevens advised he will fax it by Friday | | DONE | DONE | DONE | DONE |
| Cederburg LM | LM / WSA | Nivelene Naidoo | Yes | | Mr. G. F.Matthyse | | Hanalie advised he is busy but will inform him of the due date | | | Advised he is not in the office as yet, she will get Roland to send it through | | Roland not in-advised to send to Ben Skippers: Man Water & Sani. 0828877284 |
| Saldanha Bay LM | LM / WSA | Nivelene Naidoo | Yes | | MrDave Daniels | | | Advised Franscois is on Leave til 12/01/09 | | Advises Mr van Wyk is out of office- will pass the massage | No reply | 0227017180-Kate/Joy for questionaire |
| Swartland LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Mr Simon Biko | | | | | DONE | DONE | DONE |
| Cape Winelands DM | LM / WSA | Nivelene Naidoo | Yes | | Mr.T. van Essen | | | | | | | |
| Witzenberg LM | DM / WSA | Nivelene Naidoo | Yes | | Ms Spasie Kika | Technical Director - Hendrik Krohn - hendrik@witzenberg.gov.za - 023-3168540 | | Left message TCB | | Still busy with questionnaire. TCB tomorrow | Left message. TCB | Mr Hersurd in a meeting |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drakenstein LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Ronald Visagie | | Advised she forwarded it to andreK@drakenstein.gov.za-Water department | | | No reply. Cell 0824979246- left message | | |
| Stellenbosch LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Ms. Sharon Davids | | | | | DONE | DONE | DONE |
| Breede Valley LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Kobus Fourie | No answer | | No answer | | DONE | DONE | DONE |
| Breede River / Winelands LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Ceraj Ismail | Advised Jako is on Leave until Jan 09 - Advised PA Wyona -TCB | | Informed that they are having problems with answering- advised they will mail ques. They are having problems with. | | | | |
| Overberg DM | LM / WSA | Nivelene Naidoo | Yes | | Mr Soyisile Mokweni | | lucia@odm.org.za Lucia -(Rec)advised no answer/ not sure if he received Ques. - advised to send it again. | | | | | |
| Overstrand LM | DM / WSA | Nivelene Naidoo | Yes | | Mr. Sakkie Franken | | | | | Engaged | Engaged | Engaged |
| Cape Aghulhas LM | LM / WSA | Nivelene Naidoo | Yes | | Cllr M Walters | | | | | | | |
| Swellendam LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Dirk Jantjes | | | | | Mr Wentzel, HOD Engineering – ewentzel@swellenmun.co.za | | |
| Eden DM | LM / WSA | Nivelene Naidoo | Yes | | Mr Peet Kees | | | | | | | |
| Kannaland LM | DM / WSA | Nivelene Naidoo | Yes | | Cllr S C P Biljohn | | | | | Advised to send it by end of Biz today | No reply. | Just rings |
| Hessequa LM | LM / WSA | Nivelene Naidoo | Yes | | Mr.Kenny De Lange | | | | | | | |
| Mosselbay LM | LM / WSA | Nivelene Naidoo | Yes | | Ettienne Steyn | | | | | Sent reminder | | |
| George LM | LM / WSA | Nivelene Naidoo | Yes | | E Scheepers | | | | | | | |
| Oudtshoorn LM | LM / WSA | Nivelene Naidoo | Yes | | Vincent Gouws | | | | | | | |
| Bitou LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Mrs Nondumiso Gunguluza | | | | | Advised Frikkie Lombard will follow up with Pam Diko 044 501 3261 | No reply. | Just rings |
| Knysna LM | LM / WSA | Nivelene Naidoo | Yes | | Mr.T.Ngoqo | | | | | | | |
| Centrel Karoo DM | LM / WSA | Nivelene Naidoo | Yes | | N Perring | | | | | | | |
| Laingsburg LM | DM / WSA | Nivelene Naidoo | Yes | **Yes** | Mr. Freddie Maxhegwana | | | | | DONE | DONE | DONE |
| Prince Albert LM | LM / WSA | Nivelene Naidoo | Yes | | Theron Wilhem | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beaufort West LM | LM / WSA | Nivelene Naidoo | Yes | | Dawid Rossouw | | | | | | | |
| Kgalagadi DM | DM / WSA | Nivelene Naidoo | Yes | **Yes** | Mr M Mmoiemang | | | | | DONE | DONE | DONE |
| Moshaweng LM | LM / WSA | Jochie Prinsloo | Yes | | P Sampson | | | | | Engaged | No reply. | |
| Ga-Segonyana LM | LM / WSA | Nivelene Naidoo | Yes | | K Olipeng | | | | | | | |
| Gamagara LM | LM / WSA | Nivelene Naidoo | Yes | | Ms L Bosman | | | | | Engaged/ just ringing | No reply. | |
| Namakwa DM | DM / WSA | Jochie Prinsloo | Yes | | M.R.Claase | | | | | | | |
| Richterveld LM | LM / WSA | Nivelene Naidoo | Yes | | J. Cloete | | | | | | | |
| Nama Khoi LM | LM / WSA | Nivelene Naidoo | Yes | | Mr NA Baartman | | | | | Engaged/ just ringing | Engaged/ just ringing | Engaged/ just ringing |
| Kamiesberg LM | LM / WSA | Nivelene Naidoo | Yes | | M Claase | | | | | No one accepts responsibility for water services | No one accepts responsibility for water services | No one accepts responsibility for water services |
| Hantam LM | LM / WSA | Nivelene Naidoo | Yes | | Me J Gouws | | | | | | | |
| Karoo Hoogland LM | LM / WSA | Jochie Prinsloo | Yes | | Mr G van Schalkwyk | | | | | | | |
| Khai-Ma LM | LM / WSA | Nivelene Naidoo | Yes | | Mr W Visagie | | | | | Tech Mang. Will be avail from next week | overcommitted | Not yet completed |
| Ubuntu LM | LM / WSA | Nivelene Naidoo | Yes | | Mr M Fillis | | | | | He'll look into it asap | Not yet completed | Not yet completed |
| Umsobomvu LM | LM / WSA | Nivelene Naidoo | Yes | | NB Mdala | | the email was send, Themba promises to review it and will respond asap | | | Problem receiving questionnaire, resent again | | Not yet completed |
| Kareeberg LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Z Dingile | | Mr Frans Groenevalt, email: frans.groenevalt@lgnet.org.za | | | not yet completed, will forward it to all relavant dept. | | Not yet completed |
| Renosterberg LM | LM / WSA | Nivelene Naidoo | Yes | | Mr MJ Mtubu | | | | | He is swamped in work, hell look into it | | not yet complete |
| Thembelihle LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Z Monokale | | | | | Engaged | Engaged | |
| Mier LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Mapanka | | | | | not avail in office, he works full time on-site | not avail in office, he works full time on site | not avail in office, he works full time on-site |
| Khai Garib LM | LM / WSA | Nivelene Naidoo | Yes | | Mr B Brand | | | | | No response | | No response |
| Frances Baard DM | DM / WSA | Jochie Prinsloo | Yes | | Mr PJ van der Walt | | | | | Not yet completed | | No response |
| Sol Plaatjie LM | LM / WSA | Nivelene Naidoo | Yes | | Mr T F Mashilo | | | | | Email not delivered, resent it again | | No email or fax copy of questionnaire received |
| Dikgatlong LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Eilerd | | | | | not yet completed | | not yet completed |
| Magareng LM | LM / WSA | Nivelene Naidoo | Yes | | Mr A Moremi | | | | | | | |
| Phokwane LM | LM / WSA | Nivelene Naidoo | Yes | | Mr MP Dichaba | | | | | No response, goes automatically to voicemail | No response | No response |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Xhariep DM | DM / WSA | Nivelene Naidoo | Yes | | Mr Mofokeng | Advised no w ater or technical director or manager - consultant from Dwaf- will be back 5 Jan 09 | | Advised no technical manager and advised district municipaliy does not deal with wate | | No Tech Mang, the DM does not deal with water issues or assets | No Tech Mang the DM does not deal with water issues or assets | |
| Letsemeng LM | LM / WSA | Nivelene Naidoo | Yes | | Me ML Wolf | No answer | No answer | No answer | No answer | No answer | No answer | |
| Kopanong LM | LM / WSA | Nivelene Naidoo | Yes | | Mr. T.S. Mantshiyane | | | | | Peter advised too busy, will see into it next week | Peter is working on it | Peter is working on it |
| naledi LM | LM / WSA | Nivelene Naidoo | Yes | | Mr T Motshoikha | Ringing | | Advised to speak to the area manager Joe Ngamane - 082 5742 146- V/mail | Questionnaire forwarded to AD Likale Tech Manager | No response, voicemail | | Just rings |
| Mangaung LM | LM / WSA | Nivelene Naidoo | Yes | | Mr G Fritz | Wrong contact details | Unable to goggle contact number | | | Sent Reminder | Sent Reminder | Sent Reminder |
| Mantsopa LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Anton Greeff | | Water Director: Thandi Chabalala - moeketsit@mantsopa.co.za | Thandi called back - advised she will complete over the holidays - back 7 Jan09. | | Not yet completed, it's partly completed | Will follow up and respond | Not available |
| Masilonyana LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Mrs M Maboye-Mapike | Mr Lakes Chakane - 057 - 7331887 -Director Water - ext. 2244 - Call later for mail address | No Reply | No Reply | No Reply | Switchboard advises cannot take message | Lakes advised to check on it | e-mail system down since last week, TCB |
| Tokologo LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Seakge | Technical Manager - kelesitsemogoasi@ymail.co.za-PA - S Matibane - 053 - 5410014 / 0739583997 | | S Matibane - Acting Technical - 0739583997- advised to send it through to kelesitsemogoasi@ymail.co.za | | e-mail system down, will respond asap-Mr Matibane | Sent message, no answer | e-mail server still down..TCB |
| Tswelopele LM | LM / WSA | Nivelene Naidoo | Yes | | Mr M.P. Mokgoro | Vernon Blair - blairv@dwaf.gov.za - 051 - 405 9000 -Director: Water use | Not in office | Advised Mr Blair is in Pretoria - Left mess. With Mr Buffel - Will let him know of due date | | No answer | Left message with s/board. Mr Buffel does not return calls | Not in, left a message with Nolene |
| Matjhabeng LM | LM / WSA | Nivelene Naidoo | Yes | | Mr R Spies | No Reply | Ringing | Sent through e-mail again | | Just rings | Just rings | Just rings |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nala LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Mr Mabaso | Sydwell Nxumalo - Technical Director infrastructure - snxumalo@nala.org.za - 056 514 9206 | Advised on leave till 5 Jan 09 | Advised on leave till 5 Jan 09 | Advised by Janet he is in a meeting - advised they will maill it back by end of business today | DONE | DONE | DONE |
| Thabo Mofutsanyane DM | DM / WSA | Nivelene Naidoo | Yes | | Mr I Kegakilwe | Mr Bernard Mphahlele - bernard.tm@lg.fs.gov.za- Technical Manager | Advised they are not responsible for water assets advised to call local Mun. -Sydney 0823706968 or Hope - 0832894487 | Hope advised he will send it through by 13h00 tomorrow | Hope informed his PA to mail the completed Questionaire through - Advised he will follow up with her | Called IT van Zyl, advised that its not his problem Hope only gave him the Questionnaire recently | Called IT van Zyl, advised that its not his problem Hope only gave him the Questionnaire recently | Called IT van Zyl, advised that its not his problem Hope only gave him the Questionnaire recently |
| Setsoto LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Mr M. Lithebe | advised he will be back on the 29th - on leave | advised he will be back on the 29th - on leave | | Advised to resend and TCB Tomorrow - to call on cell - 0828363196 | DONE | DONE | DONE |
| Dihlabeng LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Job. Tshabalala | | publicworks@dihlabeng.co.za - dalian Nel - PA advised to send to her so that she can remind him of the due date. | nel.daleen@gmail.com - PA advised he will be back on 12/01/09 - on leave - advised she will follow-up | Advised sysem crashed but gave document to andrea | Advised Adrea that he will look into it | No answer in his office | No answer |
| Phumelela LM | LM / WSA | Nivelene Naidoo | Yes | | Mrs M. Joyce Mthembu | Hope Nthembu - lhnthembu@yahoo.com - 058 9138317 | No answer | Hope advised he is busy with it | Advised by Hope will send it through by 09:30 | Called IT van Zyl, advised that its not his problem Hope only gave him the Questionnaire recently | Called IT van Zyl, advised that its not his problem Hope only gave him the Questionnaire recently | Called IT van Zyl, advised that its not his problem Hope only gave him the Questionnaire recently |
| Moqhaka LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | Mr Patric Thipane | George Makaukau / Hennie Routenbach - hennie@moqhaka.gov.za/george@moqhaka.gov.za - Technical Director and Water Manager - EXT 9911 | | Hennie advised mail was down - asked to resend - follow up tomorrow | Tried calling George - spoke to PA - Pinky - resend - eddie@moqhaka.gov.za -056 2169135- to send through tomorrow | George has been out of office, he'll look into it | | |
| Mafube LM | LM / WSA | Nivelene Naidoo | Yes | | Mr PI Radebe | | | | | | | |
| **Kwazulu-Natal** | | | | | | | | | | | | |
| Ugu DM | DM / WSA | Nivelene Naidoo | Yes | **Yes** | Cllr NA Mhlongo | | | | | | | |
| Umgungundlovu DM | DM / WSA | Dave Coetzee | Yes | | Mr A. M. Lukhele | | | | | No response | No answer | No response |
| Msunduzi LM | LM / WSA | Nivelene Naidoo | Yes | | Mr L Voighs | | | | | | | |
| Uthukela DM | DM / WSA | Nivelene Naidoo | Yes | **Yes** | Mr Siya Nkehli | | | | | No answer | No answer | No answer |
| Umzinyathi DM | DM / WSA | Nivelene Naidoo | Yes | | M.S Yengwa | | | | | No answer | No answer | No answer |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amajuba DM | DM / WSA | Nivelene Naidoo | Yes | | Dr V J Mthembu | | | | | | | |
| Newcastle LM | LM / WSA | Nivelene Naidoo | Yes | | G Mncube | | | | | | | |
| Zululand DM | DM / WSA | Manuel Hlongwane | Yes | | J Jordaan | | | | | | | |
| Uthungulu DM | DM / WSA | Nivelene Naidoo | Yes | | Mr BB Biyela | | | | | Not in office, he is not available for response | | |
| Umhlathuze LM | LM / WSA | Nivelene Naidoo | Yes | | Cllr J Harvey | | | | | Spoke to a receptionist, will forward my message to relevant person | | The responsible person will only be back in 3 weeks time |
| iLembe DM | DM / WSA | Nivelene Naidoo | Yes | | Cllr S.W Mdabe | | | | | No answer, ever since | No answer, ever since | No answer, ever since |
| Sisonke DM | DM / WSA | Nivelene Naidoo | Yes | | Cllr w m msiya | | | | | engaged | engaged | engaged |
| eThekwini Metro | DM / WSA | Dave Coetzee | Yes | | Dr Micheal Sutcliffe | | | | | No answer, left a voicemail | No answer | They are busy, will try and make time and get back to me |
| Bojanala DM | DM / WSA | Nivelene Naidoo | Yes | | Cllr T Morokhu | | | | | The responsible person is not available | Still not completed | No answer |
| Moretele LM | LM / WSA | Nivelene Naidoo | Yes | | Mr. MF Lelaka | | | | | No answer | No answer | No answer |
| Madibeng LM | LM / WSA | Nivelene Naidoo | Yes | | Clr. Mary Tlhopane | | | | | | | |
| Rustenburg LM | LM / WSA | Nivelene Naidoo | Yes | | Mr KP Khunou | | | | | | | |
| Moses Kotane LM | LM / WSA | Nivelene Naidoo | Yes | | Cllr V Kheswa | The number does not exist | Wrong contact details | Wrong contact details | Wrong contact details | Wrong contact details | Finally got a number | No answer |
| Central DM | DM / WSA | Nivelene Naidoo | Yes | | Clr L Magagane | No response | | No response | No response | No response | No response | |
| Bophirima DM | DM / WSA | Nivelene Naidoo | Yes | | Nill Schalk | | | No response | No response | No response | No response | No response |
| Ventersdorp LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Tom Nkomo | | | | | | | |
| Potchefstroom LM | LM / WSA | Nivelene Naidoo | Yes | | Cllr Sammy Thekiso | | | | | | | |
| Merafong City LM | LM / WSA | Nivelene Naidoo | Yes | | Clr MF Gqokonqana | they wont be able to respond because no one is responsible for Water & Sanitation | | | | | | |
| **Gauteng** | | | | | | | | | | | | |
| Emfuleni LM | LM / WSA | Elmarie Knoetze | Yes | | Mr Hennie Duvenhage | | | | Left a message for the Technical Manager | | | |
| Midvaal LM | LM / WSA | Elmarie Knoetze | Yes | | Mr Waldo Schirge | | | | Not available | | | |
| Lesedi LM | LM / WSA | Elmarie Knoetze | Yes | | Mrs N Tlolane | | | | | | | |
| Nokeng tsa Taemane LM | LM / WSA | Elmarie Knoetze | Yes | | Mr L van Staden | | | | | | | |
| Kungwini LM | LM / WSA | Elmarie Knoetze | Yes | | Mr Thobela | | | | | | | |
| West Rand DM | DM / WSA | Elmarie Knoetze | Yes | | Mr F Dudumastte | | | | | | | |
| Mogale City LM | LM / WSA | Elmarie Knoetze | Yes | | George Viljoen | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Randfontein LM | LM / WSA | Elmarie Knoetze | Yes | | Mark Riddels | | | | | | | |
| Westonaria LM | LM / WSA | Elmarie Knoetze | Yes | **Yes** | Mr S Mbanjwa | DONE | DONE | DONE | DONE | DONE | DONE | DONE |
| Ekurhuleni Metro | DM / WSA | Elmarie Knoetze | Yes | | Mr D van der Merwe | | | | | | | |
| City of Jhb Metro | DM / WSA | Elmarie Knoetze | Yes | | Mr Slindokuhle Hadebe | | | | | | | |
| City of Tshwane Metro | DM / WSA | Elmarie Knoetze | Yes | **Yes** | Piet Cronje | DONE | DONE | DONE | DONE | DONE | DONE | DONE |
| Albert Luthuli LM | LM / WSA | Nivelene Naidoo | Yes | | Mr HE Netshishivwe | Engaged | Engaged | No response | | No one available in the office | No one available in the office | Not avaible |
| Msukaligwa LM | LM / WSA | Nivelene Naidoo | Yes | | Mr ZS Zwane | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent |
| Mkhondo LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Bheki Mtshali | | | | | | | |
| Pixley Ka Seme LM | LM / WSA | Nivelene Naidoo | Yes | | Mr Z. H Luhlanga | Ringing but no one picks up | Just ringing | Just ringing | Just ringing | Just ringing | Just ringing | |
| Lekwa LM | LM / WSA | Nivelene Naidoo | Yes | | Mr H. van der Merwe | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent |
| Dipaleseng LM | LM / WSA | Nivelene Naidoo | Yes | | Mr V.E. Makhubu | Engaged, if it does ring, no one answers | | Engaged, if it does ring, no one answers | | Engaged, if it does ring, no one answers | | |
| Govan Mbeki LM | LM / WSA | Nivelene Naidoo | Yes | | Mr D. Mahlangu | Not available till the 19th | Not available till the 19th | Not available till the 19th | Not available till the 19th | she is overcommitted, will look into it asap | Not yet completed | Not yet completed |
| Nkangala DM | DM / WSA | Nivelene Naidoo | Yes | | Mr P. Mnisi | | Engaged | | Engaged | Engaged | Engaged | Engaged |
| Delmas LM | LM / WSA | Nivelene Naidoo | Yes | | Mr J. Ngoma | Nico Prinsloo, email: nico@delmas.co.za | | Nico not available | | Not yet completed | Not yet completed | Not yet completed |
| Emalahleni LM | LM / WSA | Nivelene Naidoo | Yes | | Mr D.Maseko | | No response, just ringing | No response | | No response | No response | No response |
| Steve Tshwete LM | LM / WSA | Ettienne Janse van Rensburg | Yes | | Mr R. Bouwer | the contact numbers are non-existent | | the contact numbers are non-existent | | the contact numbers are non-existent | the contact numbers are non-existent | the contact numbers are non-existent |
| Highlands Local LM | LM / WSA | Nivelene Naidoo | Yes | | Mrs H. Motau | Willem Benade, email: mhlongon@emakhazenilm.co.za | | Just ringing but no response | | Just ringing but no response | | |
| Dr JS Moroka LM | LM / WSA | Steve Tigele | Yes | | Mr B.S. Magdele | | | | | | | |
| Thaba Chweu LM | LM / WSA | Nivelene Naidoo | Yes | | Mr D.J. Dippenaar | engaged | | engaged | | engaged | engaged | engaged |
| Mbombela LM | LM / WSA | Nivelene Naidoo | Yes | | Mr B. Mazibuko | Just ringing, no response | | Just ringing, no response | | Just ringing, no response | Just ringing, no response | Just ringing, no response |
| Nkomazi LM | LM / WSA | Nivelene Naidoo | Yes | | Mrs F. Ngomane | Mr MI Nkosi, email: secretary.technical@nkomazi.org.za | | | | He is busy, TCB | not yet completed | No response |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Limpopo** | | | | | | | | | | | | |
| Mopani DM | DM / WSA | Nivelene Naidoo | Yes | | M H Mokgobi | Ngoa Ramathoka, email: ramathokanl@mopani.gov.za, ext: 1010 | On leave till the 9th | Called Ludwick on his cell, 0832567560, left a voice message | | S/board advised both Ludwick and PA not available | not yet completed | He will send it through, completed but problems with mail server |
| Vhembe DM | DM / WSA | Nivelene Naidoo | Yes | **Yes** | M.T Makumule | Mr Masakoana, email: masakoanat@vhembe.gov.za | Mr Masakoana not in the office, advises to send document to his PA | He advises he has misplaced the Questionnaire, requests to be resend | No answer | Mr Masakoane says its done, but problem with mail server, will get someone to mail it | Sent to Marna, DONE | Sent to Marna, DONE |
| Capricorn DM | DM / WSA | Nivelene Naidoo | Yes | | Clr. J. Matsaung | Kennedy Chihota, Acting Mang. Infras. Services | Tiny the PA advised that he's busy, will remind him | | No answer | No answer | No answer | No answer |
| Polokwane LM | LM / WSA | Nivelene Naidoo | Yes | **Yes** | T Muller | Just ringing | Just ringing | Just ringing | | DONE | DONE | DONE |
| Thabazimbi LM | LM / WSA | Johan van den Berg | Yes | | Cornelius Booysen | | | | | | | |
| Lephalale LM | LM / WSA | Johan van den Berg | Yes | **Yes** | April Shiko | DONE | DONE | DONE | DONE | DONE | DONE | DONE |
| Modimolle LM | LM / WSA | Johan van den Berg | Yes | | Mahubila Radingwana | | | | | | | |
| Bela-Bela LM | LM / WSA | Nivelene Naidoo | Yes | | H. Ledwaba | Sent e-mail | No response | | No response | | | |
| Mogolakwena LM | LM / WSA | Nivelene Naidoo | Yes | | Mr D.H.Makobe | Thabo Mogashoa, email: mogashoat@mogalakwena.gov.za Water Director | | No response | | David Malape- Head Water & Sanitation- sent questionnaire | David advised he is too busy. TCB | David's phone just rings but no response |
| Greater Sekhukhune DM | DM / WSA | Nivelene Naidoo | Yes | | Mr N.D Masemola | | No answer | | No answer | | | |
| **Waterboard Mines** | | | | | | | | | | | | |
| Amatola Water | | Chris von Holdt | Yes | | | | | | | | | |
| BiWater | | | Yes | | | | | | | | | |
| Utukela Water | | Chris Schmidt | Yes | | Ronald Gillmer | Ronald advised that he will not be able to fill it in This year - advised TCB in Jan. | | Ronald advised that he will not be able to fill it in This year - advised TCB in Jan. | | | | |
| Randwater | | Johan van den Berg | Yes | | E Varkevisser: | | | | | | | |
| Exxaro Grootegeluk Coal | | Johan van den Berg | Yes | **Yes** | Wolfie Jahn | DONE | DONE | DONE | DONE | DONE | DONE | DONE |

# Appendix D – Results From Questionnaires

Table D1 - Question 1

| Organisation Name | Question 1 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dam | Borehole | Spring Protection | Reservoir | Water Pump Station | Sewage Pump Station | Water Treatment Works | Sewage Treatment Works | Water Pipelines (Reticulation & Bulk) | Sewage Pipelines | Valves |
| Camdeboo LM | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Makana LM | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Baviaans LM | | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Amatole DM | Yes | Yes | Yes | Yes | Yes | | Yes | | Yes | | Yes |
| Matzikama LM | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Swartland LM | Yes | Yes | | Yes | Yes | Yes | | Yes | Yes | Yes | Yes |
| Stellenbosch LM | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Breede River / Winelands LM | Yes | | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Bitou LM | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Laingsburg LM | | Yes | Yes | Yes | Yes | | | | Yes | | Yes |
| Kgalagadi DM | | Yes | | Yes | | | | Yes | Yes | | Yes |
| Masilonyana LM | | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Nala LM | | | | | | Yes | | Yes | Yes | Yes | Yes |
| Setsoto LM | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Moqhaka LM | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Ugu DM | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Uthukela Water | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Westonaria LM | | | | Yes | Yes | Yes | | Yes | Yes | Yes | Yes |
| Vhembe DM | | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Polokwane LM | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Lephalale LM | | Yes | | Yes | Yes | | | | Yes | | Yes |
| Exxaro Grootegeluk Mine | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| City of Tshwane Metro | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Table D2 Part 1 – Question 2

| Organisation | Question 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dam | | Borehole | | Spring Protection | | Reservoir | | Water Pump Station | |
| | Frequency | Action | Frequency | Action | Frequency | Action | Frequency | Action | Frequency | Action |
| Camdeboo LM | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection |
| Makana LM | 2/Year | Visual Inspection | 2/Year | Visual Inspection | 2/Year | Visual Inspection | 2/Year | Visual Inspection | 2/Year | Visual Inspection |
| Baviaans LM | | | Monthly | Visual Inspection | | | 1/Year | Visual Inspection | 1/Year | Visual Inspection |
| Amatole DM | Seldom | | None | | None | | Seldom | | Seldom | |
| Matzikama LM | Daily | Visual Inspection | Daily | Visual Inspection | | | Daily | Visual Inspection | Daily | Visual Inspection |
| Swartland LM | 10 Years | Dam Safety Inspection | 1 Year | | | | | | 1 Year | |
| Stellenbosch LM | | | | | | | | | | |
| Breede River / Winelands LM | Annually | Visual Inspection | | | | | Daily | Visual Inspection | Daily | Visual Inspection |
| Bitou LM | 5 Years | | 5 Years | | | | Yearly | Yearly | Yearly | |
| Laingsburg LM | | | Annually | | Annually | | Daily | Visual Inspection | Monthly | Visual Inspection |
| Kgalagadi DM | | | 1/In 3 Years | | | | 1/3 Years | | | |
| Masilonyana LM | Monthly Inspection | Routine Inspection Of The Conditions | Monthly Inspection | Routine Inspection Of The Conditions | Monthly Inspection | Routine Inspection Of The Conditions | Monthly Inspection | Routine Inspection Of The Conditions | Monthly Inspection | Routine Inspection Of The Conditions |
| Nala LM | | | | | | | | | | |
| Setsoto LM | 12/Year | Monthly Visual Inspections | 52/Year | Weekly Inspections | | | 24/Year | Constant Telemetric/Visual | 365/Year | Daily Inspections |
| Moqhaka LM | Yearly | Visual Inspection | Yearly | Visual Inspection | | | Yearly | Visual Inspection | Monthly | Visual Inspection |
| Ugu DM | Yes | Annual | Yes | Ad-Hoc | Yes | Ad-Hoc | Yes | Monthly | Yes | Weekly |
| Uthukela Water | 5 Year Inspection | Dam Safety | 3/Year | Visual Inspection | | | 6/Year | Visual Inspection | 6/Year | Visual Inspection |
| Westonaria LM | | | | | | | Daily | Visual Inspection | Daily | Visual Inspection |
| Vhembe DM | | | Daily | Visual Inspection | | | Weekly | Visual Inspection | Daily | Visual Inspection |
| Polokwane LM | 5 Years | Dam Safety Inspection | As Needed | | As Needed | | As Needed | | As Needed | |
| Lephalale LM | | | Yes | Regularly | | | Yes | Seldom | Yes | Regularly |
| Exxaro Grootegeluk Mine | 1x Month | DWAF does the Assessment | 1x Month | Level & Water Quality | | | 1x Month | Visual Inspection | 1x Month | On-Line Vibration & Temperature |
| City of Tshwane Metro | | | | | | | | | | |

Table D2 Part 2 – Question 2

| Organisation | Question 2 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sewage Pump Station | | Water Treatment Works | | Sewage Treatment Works | | Water Pipelines (Reticulation & Bulk) | | Sewage Pipelines | | Valves | |
| | **Frequency** | **Action** | **Frequency** | **Action** | **Frequency** | **Action** | **Frequency** | **Action** | **Frequency** | **Action** | **Frequency** | **Action** |
| Camdeboo LM | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Fortnightly | Visual Inspection | Fortnightly | Visual Inspection | Daily | Visual Inspection |
| Makana LM | 2/Year | Visual Inspection | 2/Year | To Be Upgraded | 2/Year | To Be Upgraded | 2/Year | To Be Constructed | 2/Year | To Be Constructed | 2/Year | |
| Baviaans LM | 1/Year | Visual Inspection | 4/Year | Visual Inspection | | Visual Inspection | 1/Year | Visual Inspection | | | | |
| Amatole DM | | | Seldom | | | | None | | | | None | |
| Matzikama LM | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Maintenance |
| Swartland LM | 1 Year | | | | 1 Year | | | | | | | |
| Stellenbosch LM | 1 Year | | | | 2 Year | | Seldom | | CCTV 5 Yearly | | | |
| Breede River / Winelands LM | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Weekly | Visual Inspection | Annually | Visual Inspection | Annually | Visual Inspection |
| Bitou LM | Yearly | | Yearly | | Yearly | | Yearly | | Yearly | | Yearly | |
| Laingsburg LM | | | | | | | Every Month | Visual Inspection | | | Every Month | Visual Inspection |
| Kgalagadi DM | Monthly | | | | Weekly | Visual Inspection | | | Weekly | Visual Inspection | Every 3 Months | |
| Masilonyana LM | Monthly Inspection | Routine Inspection Of The Conditions | Monthly Inspection | Routine Inspection Of The Conditions | Monthly Inspection | Routine Inspection Of The Conditions | Monthly Inspection | Routine Inspection Of The Conditions | Monthly Inspection | Routine Inspection Of The Conditions | Monthly Inspection | Routine Inspection Of The Conditions |
| Nala LM | Daily | | | | Daily | Purify Sewage Water | Monthly | Look For Leakages | | | | |
| Setsoto LM | 104/Year | Bi-Weekly Visual Inspection | 365/Year | Daily Inspections | 365/Year | Daily Inspections | Ongoing | Check For Leakages | Ongoing | Check For Sewer Spillages | Ongoing | Open/Close When Required |
| Moqhaka LM | Monthly | Visual Inspection | Monthly | | Monthly | Visual Inspection | As Needed | Excavate When Needed | As Needed | Excavate When Needed | As Needed | Excavate When Needed |
| Ugu DM | Yes | Weekly | Yes | Daily | Yes | Daily | Yes | Ad-Hoc | Yes | Ad-Hoc | Yes | Ad-Hoc |
| Uthukela Water | 6/Year | Visual Inspection | 6/Year | Visual Inspection | 6/Year | Visual Inspection | 6/Year | Visual Inspection | 6/Year | Visual Inspection | 6/Year | Visual Inspection |
| Westonaria LM | Daily | Visual Inspection | | | Daily | Visual Inspection | Weekly | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection |
| Vhembe DM | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection | Daily | Visual Inspection |
| Polokwane LM | As Needed | | As Needed | | As Needed | | As Needed | | As Needed | | As Needed | |
| Lephalale LM | | | | | | | Yes | Seldom | | | Yes | Seldom |
| Exxaro Grootegeluk Mine | 1x Month | Visual Inspection | 1x Month | Visual Inspection | 1x Month | Visual Inspection | 1x Month | Video Cameras, Corrosion Plates | 1x Month | Visual Inspection | 1x Month | Visual Inspection |
| City of Tshwane Metro | | | | | | | Daily | | | | | |

Table D3 – Question 3

| Organisation | Question 3 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dam | Borehole | Spring Protection | Reservoir | Water Pump Station | Sewage Pump Station | Water Treatment Works | Sewage Treatment Works | Water Pipelines (Reticulation & Bulk) | Sewage Pipelines | Valves |
| Camdeboo LM | Outsourced to consultants | Outsourced to consultants | | Visual inspection & Consultants | Visual inspection & Consultants | Visual inspection & Consultants | Visual inspection & Consultants | Visual inspection & Consultants | | | |
| Makana LM | | | | | SCADA | | SCADA | | | | |
| Baviaans LM | | Visual Inspection | | | | | | | | | |
| Amatole DM | Visual inspection | | | Visual inspection | Visual inspection | | Visual inspection | | | | |
| Matzikama LM | None | None | None | None | None | None | None | None | None | None | None |
| Swartland LM | | | | | | | | | | | |
| Stellenbosch LM | | | | | | SCADA | | Acoustic emissions | | CCTV | |
| Breede River / Winelands LM | Laser alignments | | | Impact echo test | Pipe inspection real-time inspection technique (PITAT) | Pipe inspection real-time inspection technique (PITAT) | Pipe inspection real-time inspection technique (PITAT) | Pipe inspection real-time inspection technique | Pipe inspection real-time inspection technique (PITAT) | Pipe inspection real-time inspection technique | Pipe inspection real-time inspection technique |
| Bitou LM | Visual inspection | CCTV | Visual inspection | Motor current analysis | Motor current analysis | Motor current analysis | Motor current analysis | Motor current analysis | Pipeline inspection gauges | Sewer scanning & evaluation | Visual inspection |
| Laingsburg LM | | ` | Visual | Visual | Visual | Visual | Visual | Visual | Visual | Visual | Visual |
| Kgalagadi DM | | Water meters | | water meters | | | | | Pressure control | | manual |
| Masilonyana LM | R1 | | | Visual assessment | Visual assessment | Visual assessment | Visual assessment | Visual assessment | Visual assessment | Visual assessment | Visual assessment |
| Nala LM | | | | | | Inspections | | | | | |
| Setsoto LM | Visual inspections only | Visual inspections only | | Visual inspections only | Visual inspections only | Visual inspections only | Visual inspections only | Visual inspections only | Visual inspections only | Visual inspections only | Visual inspections only |
| Moqhaka LM | Flow in manholes of toe drains and visuals | Check condition of pipes, penels and pumps | | Visual inspection of structures | Visual Inspection of panels, motors and pumps | Visual Inspection of panels, motors and pumps | Visual Inspection of all equipment | Visual Inspection of all equipment | Visual Inspections for leaks/reported leaks | Visual upon reporting of blockages | Visual upon reporting of blockages |
| Ugu DM | Use Consultants | Visual only | Visual only | Visual only | Visual only | Visual only | Visual only | Visual only | Visual only | Visual only | Visual only |
| Uthukela Water | Visual Inspection | Visual Inspection | | Visual Inspection | Visual Inspection | Visual Inspection | Visual Inspection | Visual Inspection | Visual Inspection | Visual Inspection | Visual Inspection |
| Westonaria LM | | | | Visual inspection | Visual inspection | Visual inspection | | Visual Inspection | Visual inspection | Visual inspections | Visual inspection |
| Vhembe DM | | Motor current analysis | | Vibration Analysis | Pipeline inspection gauge | Vibration analysis | Vibration analysis | Vibration analysis | Vibration analysis | Vibration analysis | Vibration analysis |
| Polokwane LM | Appoint a Dam Safety Inspector | | Physical Inspection | Physical Inspection | Physical Inspection | Physical Inspection | Physical Inspection | Physical Inspection | | | |
| Lephalale LM | | Motor current analysis – visual inspections | | Visual Inspections | Visual Inspections | | | | Visual Inspections | | Visual Inspections |
| Exxaro Grootegeluk Mine | | | | | Vibration analysis | | | | Pipeline inspection gauges | | |
| City of Tshwane Metro | | | | | | | | | | CCTV | |

Table D4 – Question 4

| Organisation | Question 4 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dam | Borehole | Spring Protection | Reservoir | Water Pump Station | Sewage Pump Station | Water Treatment Works | Sewage Treatment Works | Water Pipelines (Reticulation & Bulk) | Sewage Pipelines | Valves |
| Camdeboo LM | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Makana LM | Yes | | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Baviaans LM | | | | | | | | | | | |
| Amatole DM | | | | | | | | | | | |
| Matzikama LM | Yes | | | | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Swartland LM | Yes | | | | | | | | | | |
| Stellenbosch LM | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Breede River / Winelands LM | YES | | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Bitou LM | Yes | | | | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Laingsburg LM | | | | Yes | | | | | Yes | | Yes |
| Kgalagadi DM | | Yes | | Yes | | | | | Yes | | Yes |
| Masilonyana LM | | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Nala LM | | | | | | | | Yes | | | |
| Setsoto LM | | | | | | | | | | | |
| Moqhaka LM | | | | | | | | | | | |
| Ugu DM | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Uthukela Water | | | | | | | | | | | |
| Westonaria LM | | | | Yes | Yes | Yes | | Yes | Yes | Yes | Yes |
| Vhembe DM | | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Polokwane LM | | | | | Yes | Yes | Yes | Yes | | | |
| Lephalale LM | | Yes | | | | | | | | | |
| Exxaro Grootegeluk Mine | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| City of Tshwane Metro | | | | | | | | | | Yes | |

Table D5 – Question 5

| Organisation | Question 5 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Dam** | **Borehole** | **Spring Protection** | **Reservoir** | **Water Pump Station** | **Sewage Pump Station** | **Water Treatment Works** | **Sewage Treatment Works** | **Water Pipelines (Reticulation & Bulk)** | **Sewage Pipelines** | **Valves** |
| Camdeboo LM | Mechanical | Mechanical | Mechanical | Visual | Visual & Mechanical | Visual & Mechanical | Visual & Mechanical | Visual & Mechanical | Visual & Technical | Visual and Technical | Visual and Technical |
| Makana LM | | | | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Survivor curves | Direct Assessment | Direct Assessment |
| Baviaans LM | | | | | | | | | | | |
| Amatole DM | | | | | | | | | | | |
| Matzikama LM | Inspection | Inspection | | Inspection | Inspection | Inspection | Inspection | Inspection | Inspection | Inspection | Inspection |
| Swartland LM | | | | | | | | | | | |
| Stellenbosch LM | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment |
| Breede River / Winelands LM | Direct assessment | | | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment |
| Bitou LM | Direct assessment | Direct assessment | | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment |
| Laingsburg LM | | | | Direct assessment | | | | | | | Direct assessment |
| Kgalagadi DM | | Direct assessment | | Direct assessment | | | | Direct assessment | Direct assessment | | Direct assessment |
| Masilonyana LM | Reliability Matrix Method | | | | | | | | | | |
| Nala LM | | | | | | | | Readings, measure inflow vs. outflow | | | |
| Setsoto LM | | | | | | | | | | | |
| Moqhaka LM | Direct Assessment | Direct Assessment | | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment |
| Ugu DM | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment |
| Uthukela Water | Visual inspection | Visual inspection | | Visual inspection | Visual inspection | Visual inspection | Visual inspection | Visual inspection | Visual inspection | Visual inspection | Visual inspection |
| Westonaria LM | | | | Record keeping | Record keeping | | Record keeping | | Record keeping | | Record keeping |
| Vhembe DM | | Direct assessment | | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment | Direct assessment |
| Polokwane LM | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment | Direct Assessment |
| Lephalale LM | | Direct Assessment | | | | | | | | | |
| Exxaro Grootegeluk Mine | Direct assessment | Direct assessment | | Direct assessment | Probabilistic models | Probabilistic models | Probabilistic models | Direct assessment | Probabilistic models | Direct assessment | Probabilistic models |
| City of Tshwane Metro | | | | | | | | | Direct assessment | | |

Table D6 – Question 6

| Organisation | Question 6 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Dam** | **Borehole** | **Spring Protection** | **Reservoir** | **Water Pump Station** | **Sewage Pump Station** | **Water Treatment Works** | **Sewage Treatment Works** | **Water Pipelines (Reticulation & Bulk)** | **Sewage Pipelines** | **Valves** |
| Camdeboo LM | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Makana LM | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Baviaans LM | | No | | No | No | No | No | No | No | No | No |
| Amatole DM | No | No | No | No | No | | No | | No | | No |
| Matzikama LM | No | No | | No | No | No | No | No | No | No | No |
| Swartland LM | No | No | | No | No | No | | No | No | No | No |
| Stellenbosch LM | Yes | Yes | Yes | Yes | Yes | | Yes | | No | Yes | No |
| Breede River / Winelands LM | No | | | No | No | No | No | No | No | No | No |
| Bitou LM | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Laingsburg LM | | Yes | Yes | Yes | Yes | | No | | Yes | | Yes |
| Kgalagadi DM | | Yes | | Yes | | | | Yes | Yes | | Yes |
| Masilonyana LM | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Nala LM | | | | | | No | | No | | No | No |
| Setsoto LM | No | No | | No | No | No | No | No | No | No | No |
| Moqhaka LM | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Ugu DM | No | No | No | No | No | No | No | No | No | No | No |
| Uthukela Water | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Westonaria LM | | | | Yes | Yes | Yes | | Yes | Yes | Yes | Yes |
| Vhembe DM | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Polokwane LM | No | Yes | Yes | Yes | Yes | Yes | No | No | Yes | Yes | Yes |
| Lephalale LM | | Yes | | Yes | Yes | | | | Yes | | Yes |
| Exxaro Grootegeluk Mine | Yes | Yes | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| City of Tshwane Metro | | | | | | | | | | | |

Table D7 – Question 7 and Question 8

| Organisation | Question 7 | | | | | Question 8 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Method 1 | Method 2 | Method 3 | Method 4 | Other | Method 1 | Method 2 | Method 3 | Method 4 | Other |
| Camdeboo LM | Visually and quality control | Visually and quality control | Visually and quality control | Visually and quality control | | Control Management | Regular Maintenance | | | |
| Makana LM | Qualitative Categorisation | | | | | Risk reduction and mitigation | | | | |
| Baviaans LM | | | | | | | | | | |
| Amatole DM | | | | | | | | | | |
| Matzikama LM | Monetary value | Critical Sole | | | | Risk Reduction | Basic Avoidance | | | |
| Swartland LM | | | | | | | | | | |
| Stellenbosch LM | | | | | | Risk reduction and mitigation | | | | |
| Breede River / Winelands LM | Not applicable | | | | | Risk reduction and mitigation | | | | |
| Bitou LM | Monetary value (R100,000) | | | | | Risk reduction and mitigation | | | | |
| Laingsburg LM | Monetary value (R100 000) | | | | | Risk Avoidance | | | | |
| Kgalagadi DM | Risk rating on continuum | Monetary value (R100,000) | | | | | | | | |
| Masilonyana LM | Quantification of cracks | Risk Matrices Method | | | | Performing risk assessments | | | | |
| Nala LM | Inspections | Cleaning | | | | | | | | |
| Setsoto LM | | | | | | Risk acceptance | | | | |
| Moqhaka LM | Qualitative categorization (low. High) | | | | | Risk Avoidance | | | | |
| Ugu DM | not applicable | | | | | | | | | |
| Uthukela Water | Qualitative categorisation (low, High) | | | | | Risk avoidance | | | | |
| Westonaria LM | Record keeping | Analyse failure | | | | Record Keeping | Daily inspections | | | |
| Vhembe DM | Risk rating on continuum ( low=o, high=100) | Qualitative categorization( Low, High) | Monetary value (R100,00) | Critical score | | Risk reduction and mitigation | | | | |
| Polokwane LM | | | | | | Risk Avoidance | Risk Acceptance | | | |
| Lephalale LM | Qualitative categorization (Low, High) | | | | | Risk reduction and mitigation | Risk Acceptance | Other | | |
| Exxaro Grootegeluk Mine | Qualitative categorisation (low, High) | Monetary value (R100,000) | Critical Score | | Reliability Centred Maintenance | Risk avoidance | Risk reduction and mitigation | | | |
| City of Tshwane Metro | Critical Score | | | | | Risk reduction and mitigation | Risk avoidance | Risk acceptance | | |

Table D8 – Question 9 and Question 10

| Organisation | Question 9 | Question 10 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Answer | Part A Asset Management | | | Part b Constraints | | | Other Comments | |
| | | a | b | c | a | b | c | a | b |
| Camdeboo LM | Yes | Control | Management | Maintenance | Human Resource Shortage | Financial Constraints | | Need more personnel, especially Skilled and Finance Staff | |
| Makana LM | Yes | The accountability of water resources to supply quality water services to the jurisdiction | To ensure ongoing monitoring of the water sources | | Financial constraints | Lack of skills | Under-staffed | To collectively ensure that proper water development | |
| Baviaans LM | No | Have a GAMAP/GRAP complaint asset register in place | | | Capacity | | | | |
| Amatole DM | No | Have an established asset register | Plan to do conditional assessment in the future | | | | | | |
| Matzikama LM | No | Would like you to guide me through the different stages | | | | | | | |
| Swartland LM | No | Condition assessment | Asset replacement | | Funding | | | | |
| Stellenbosch LM | No | Assess the assets - age, condition, serviceability | Record assets in asset register | Budget and manage the risk associated with assets | Budget | Capacity | Unknown Services | To maintain assets which in some instances is not economical and should be replaced | |
| Breede River / Winelands LM | No | Planning Phase - Acquisition Phase and | | operating and maintenance | at this stage we only have an asset control policy and need | | | no | an asset management policy |
| Bitou LM | Yes | Risk asset Management | Asset management | Risk quantification | Knowledge | Time | Understanding | | |
| Laingsburg LM | No | Maintenance | Limitation of Risk | | Shortage of skilled staff | Technology | Finance | Improvement of old systems | Installation of new systems |
| Kgalagadi DM | | | | | | | | | |
| Masilonyana LM | | Register assets | Verification of assets | Risk assessment of all assets | Asset register not appropriate | Lack of personnel | Funds for Risk Assessment | | |
| Nala LM | No | Prevent sewage spillages | purify water and pump it back to the river | Save drinking water | Blocked Sewages | Breakdown of pumps and motors | | | |
| Setsoto LM | No | Condition assessment | Reliability assessment | Ranking of risks | Funding | Lack of Knowledge | Technology | | |
| Moqhaka LM | No | Risk Assessment | Preventative management | Replacement of outdated equipment | Skills shortage amongst staff | Financial Constraints | General Age of equipment | Asset management | Replacement of AC pipes with uPVC |
| Ugu DM | No | | | | | | | | |
| Uthukela Water | Yes | Asset register | Maintenance Management Plan | Risk analysis | Budget | Information | Skills | | |
| Westonaria LM | No | Daily Visual inspection | Good record keeping | Proper maintenance * Skilled personnel | Budget constraints | | | | |
| Vhembe DM | Yes | Continues assessment of assets | | | Budget constrained | Lack of dedicated staff | | Planning & implementation of modern technology of new asset | |
| Polokwane LM | No | | | | Personnel | Funds | Equipment | | |
| Lephalale LM | No | Refer to Attachment | | | | | | | |
| Exxaro Grootegeluk Mine | Yes | Routine Work Management * Shutdown Management * Tactics (RCM principles) | | | Lack of skills | High turnover | System flexibility | To fully implement asset management practices in our highest priority | |
| City of Tshwane Metro | No | Regular analysis of maintenance data: leaks and burst | Regular analysis of water losses in supply zones | In time replacement of suspect or defunct pipelines | Insufficient human resource capacity in some areas | Insufficient funding | | | |

# Appendix E – Detailed Results Charts

## E1 Detail Charts for Technologies Utilised for Condition Assessments

Presented in figure E1a to E1k are the detailed chart results for each infrastructure type of the third question in the questionnaire. From figures E1a to E1k it can be seen that the majority of respondents utilise visual inspection as the most common method for determining the condition of their water and waste water infrastructure assets. It would be interesting to investigate further as to what these organisations mean by visual inspection and what criteria they use for evaluating the condition of their assets during these visual inspections. It is somewhat concerning that visual inspection is relied on to determine the condition of water and waste water pipes especially considering that pipelines in general tend to be buried, which does not facilitate visual inspections. It is curious to note that one of the respondents claimed to use pipeline inspection gauges (PIG's) as the method used to determine the condition of their water pump stations, especially considering that pigging is commonly used to determine the condition of pipelines in the oil and gas industry. However, it was commendable to see that some of the respondents stated that they were utilising pipeline inspection gauges (PIG's) for determine the condition water pipelines.

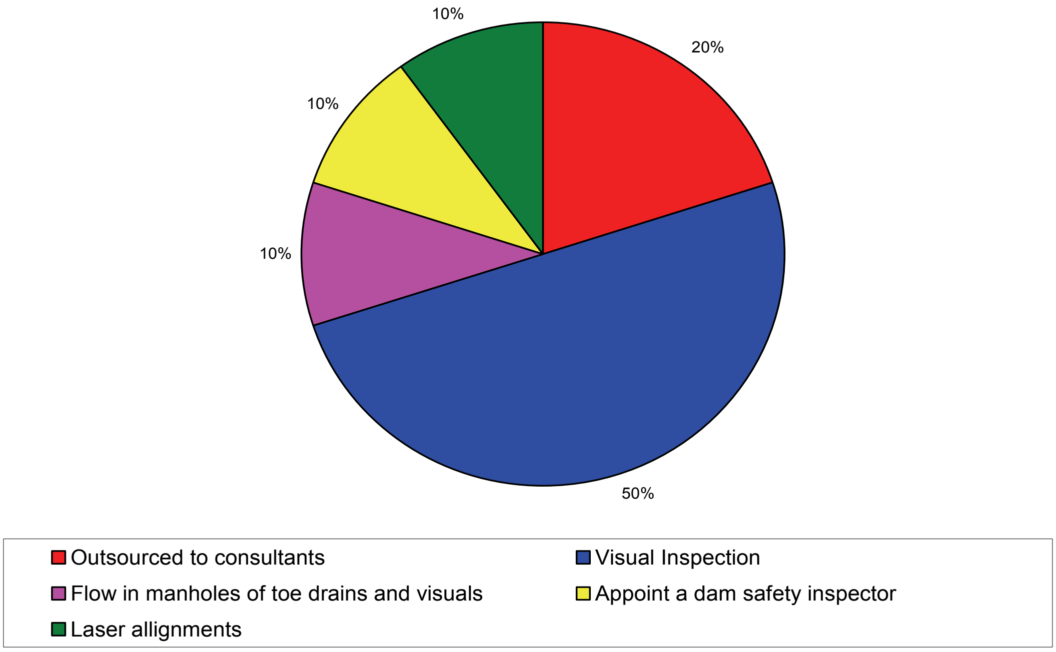


***Fig. E1a.*** *Types of Technologies Utilised for Condition Assessments of Dams.*

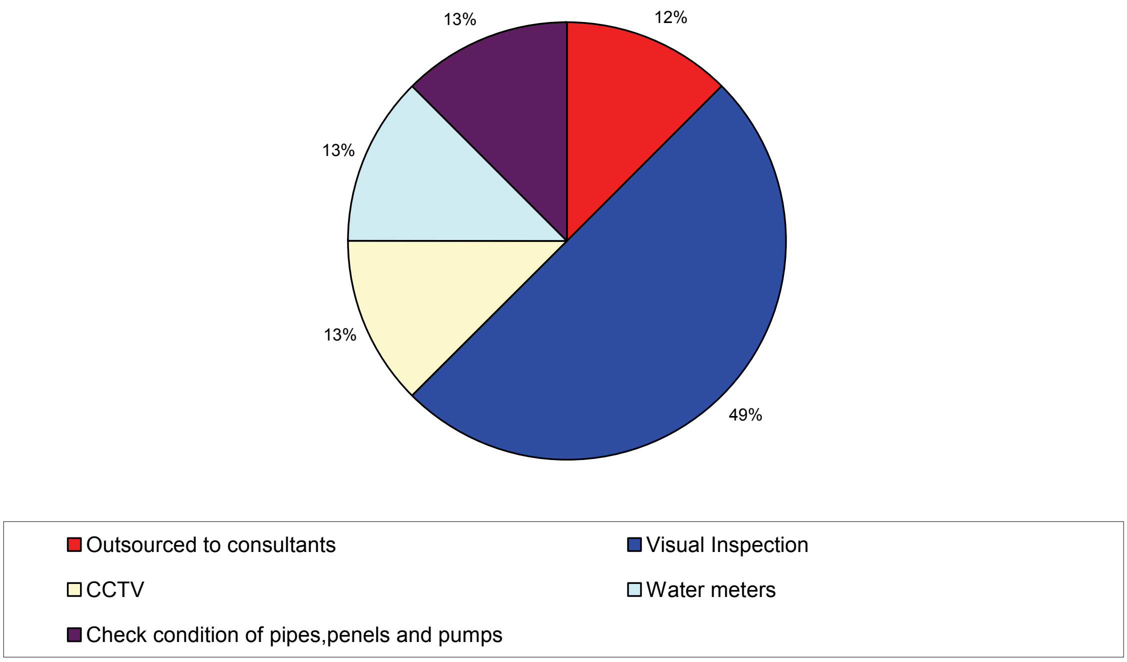


***Fig. E1b.*** *Types of Technologies Utilised for Condition Assessments of Boreholes.*

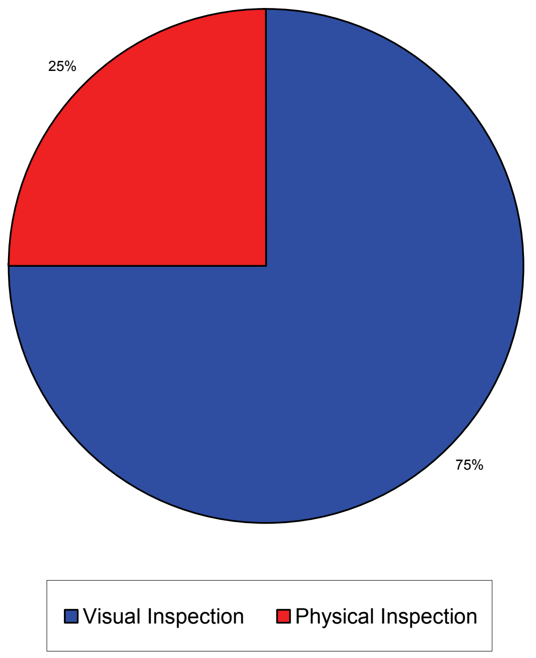


*Fig. E1c. Types of Technologies Utilised for Condition Assessments of Spring Protection.*

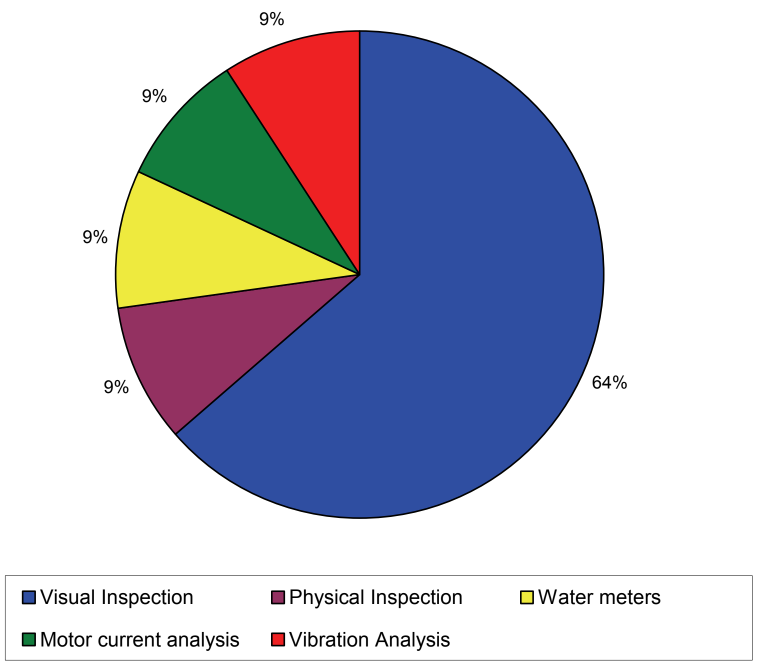


*Fig. E1d. Types of Technologies Utilised for Condition Assessments of Reservoirs.*

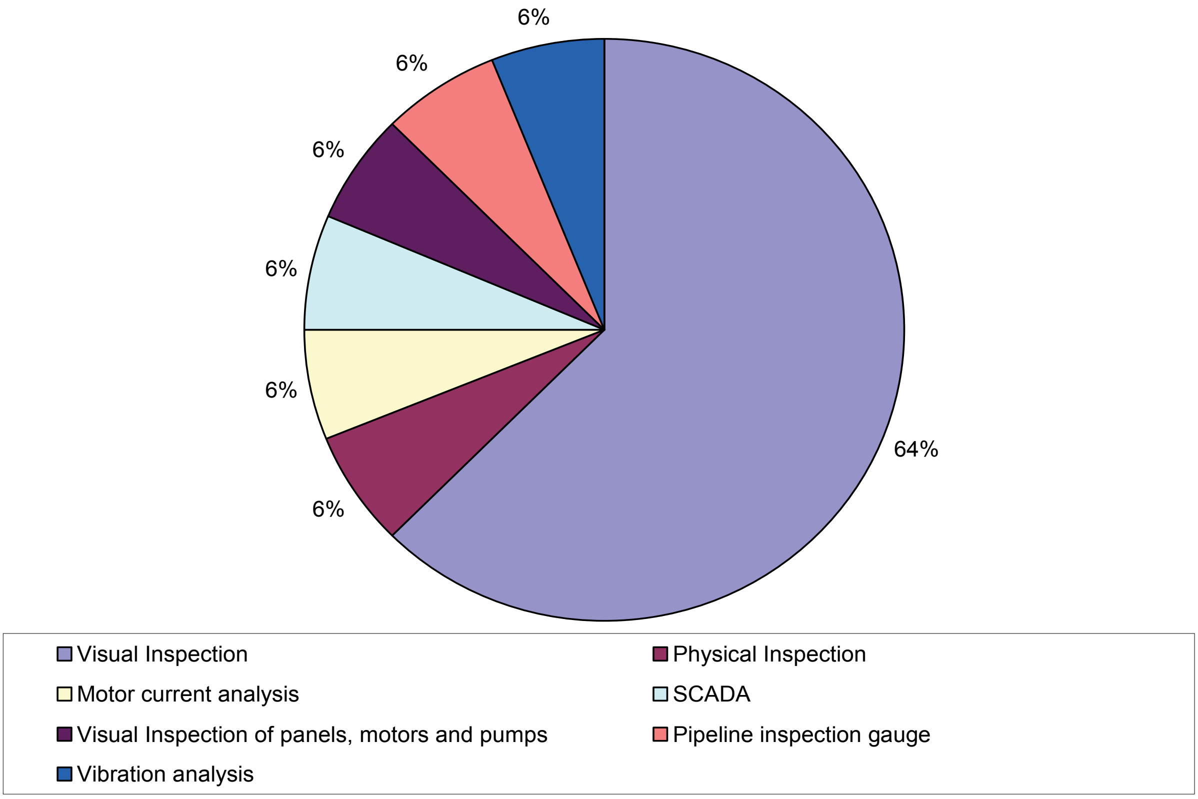


***Fig. E1e.*** *Types of Technologies Utilised for Condition Assessments of Water Pump Stations.*

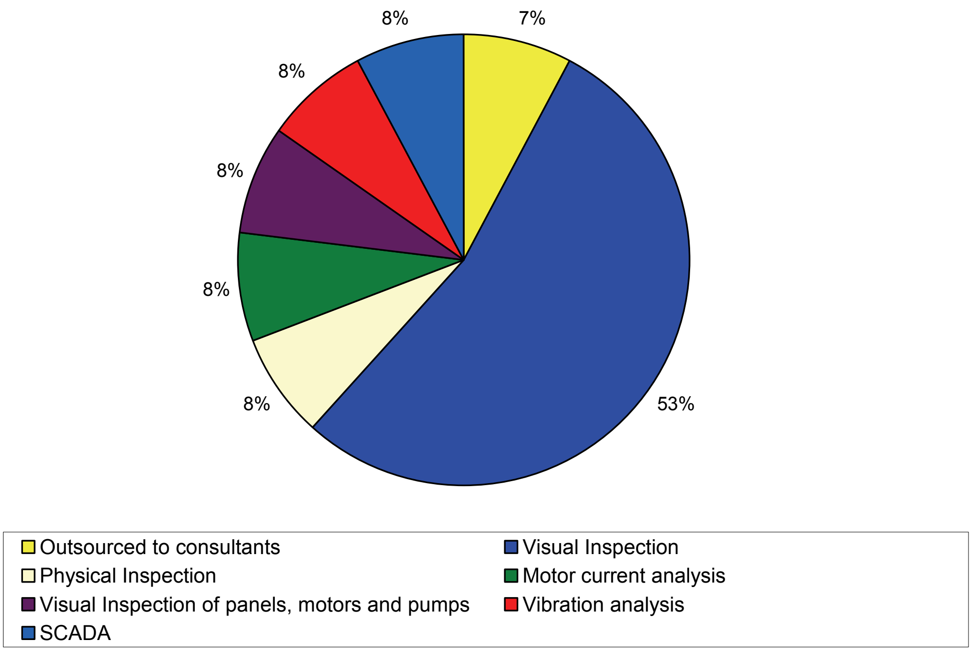


***Fig. E1f.*** *Types of Technologies Utilised for Condition Assessments of Sewage Pump Stations.*

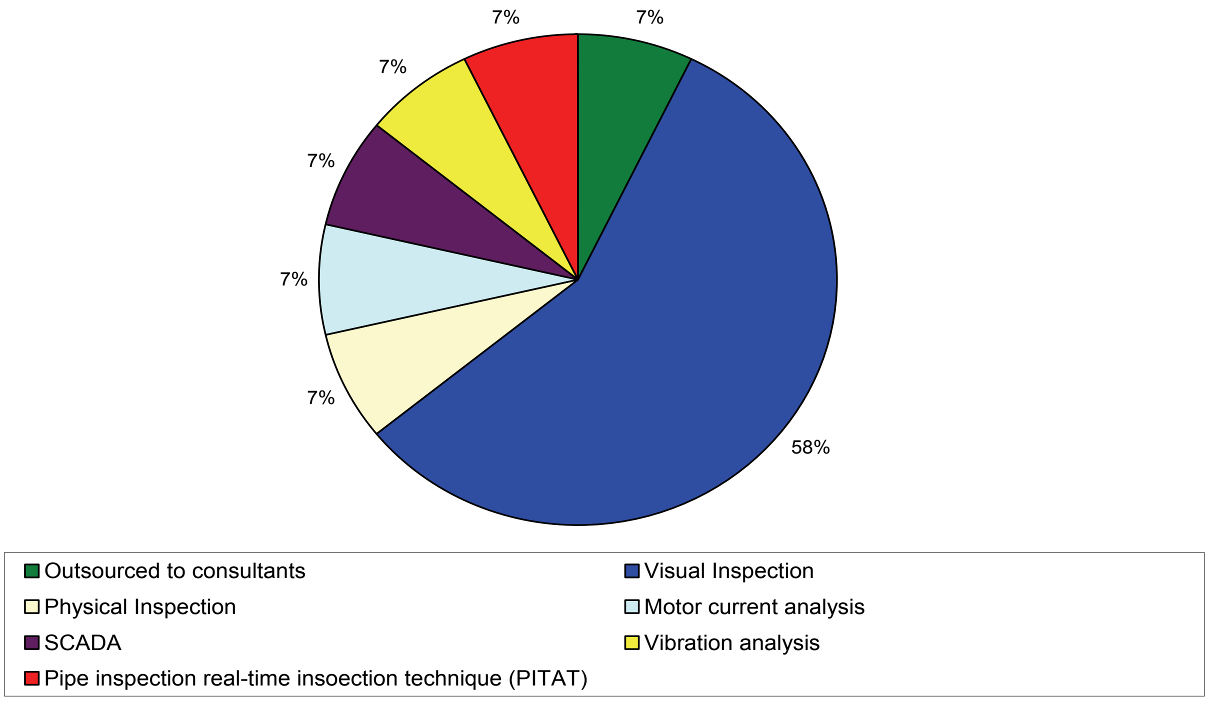


***Fig. E1g.*** *Types of Technologies Utilised for Condition Assessments of Water Treatment Works.*

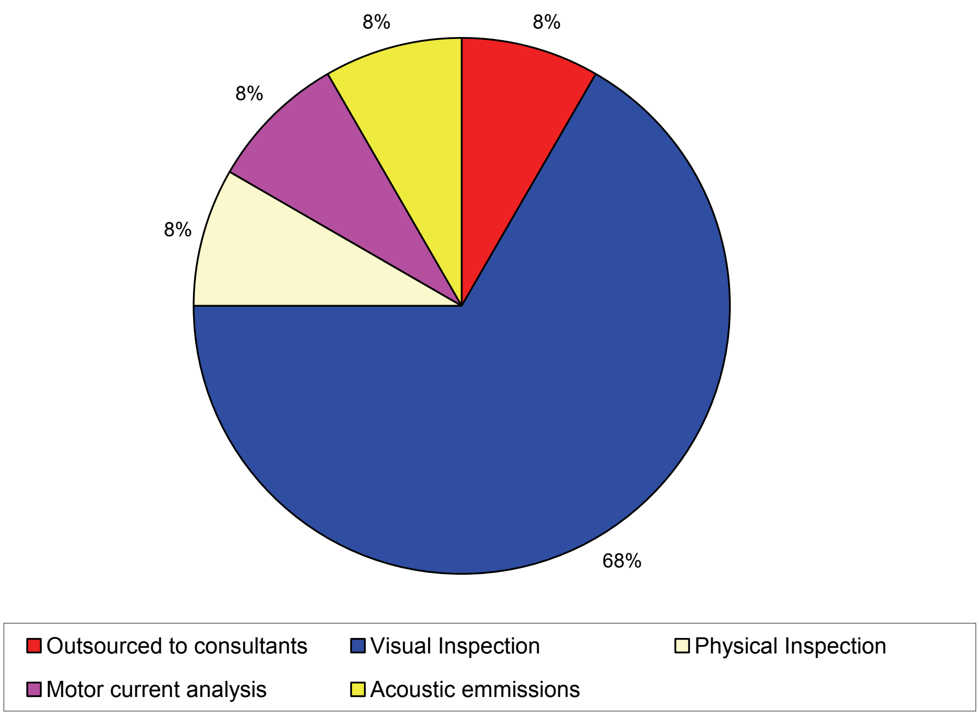


***Fig. E1h.*** *Types of Technologies Utilised for Condition Assessments of Sewage Treatment Works.*

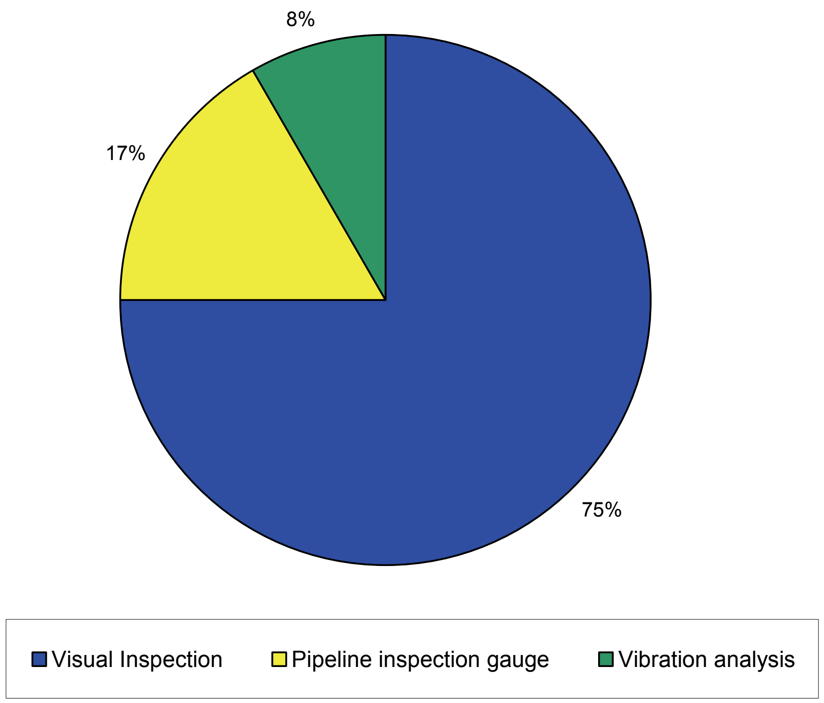


***Fig. E1i.*** *Types of Technologies Utilised for Condition Assessments of Water Pipelines.*

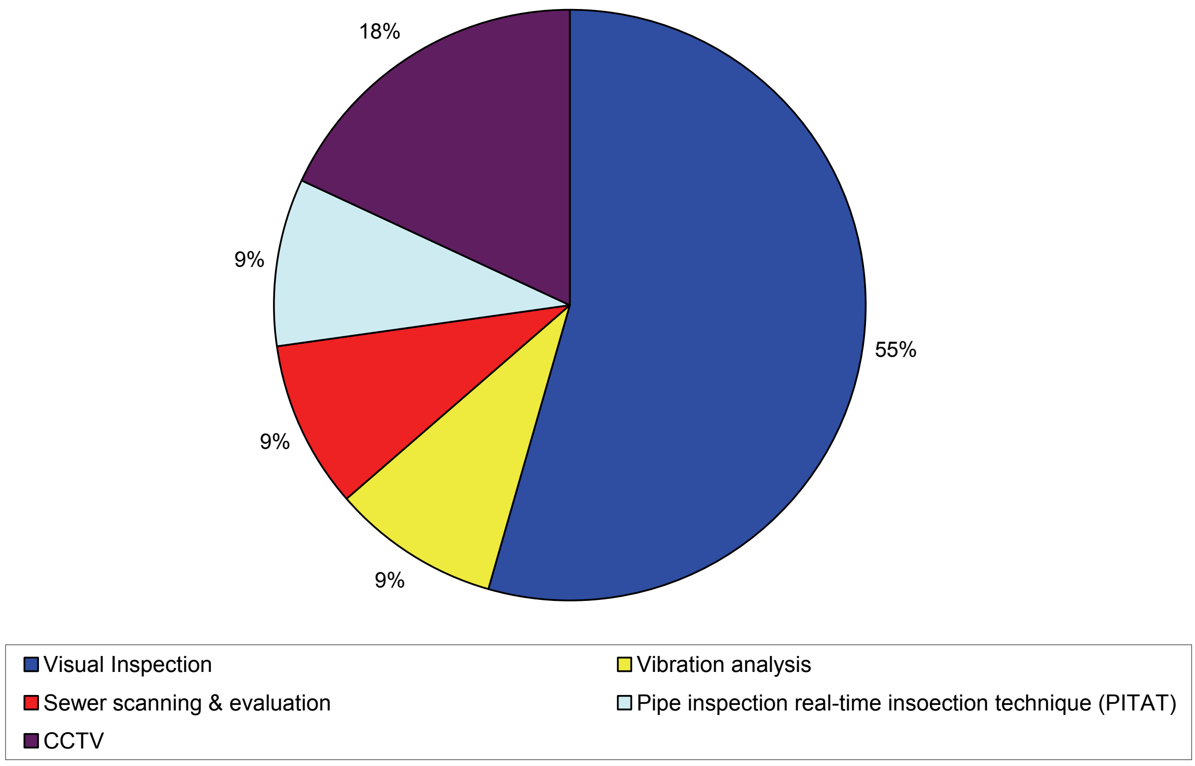


***Fig. E1j.*** *Types of Technologies Utilised for Condition Assessments of Sewage Pipelines.*

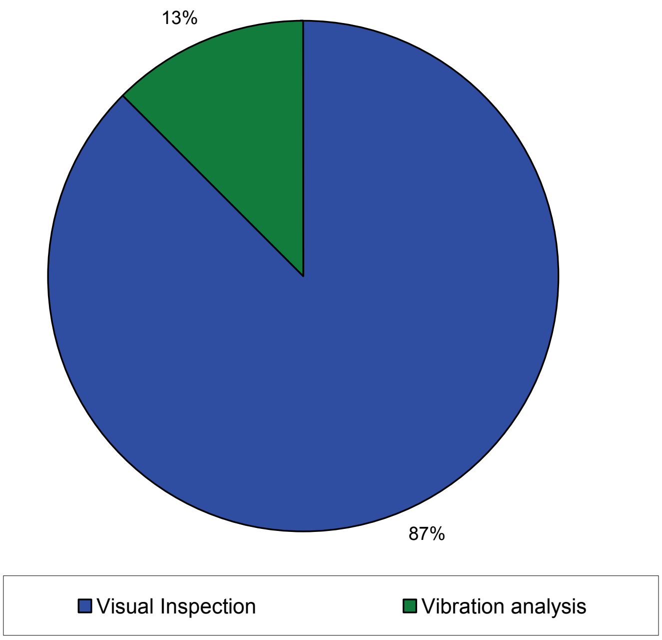


***Fig. E1k.*** *Types of Technologies Utilised for Condition Assessments of Valves.*

## E2 Detail Charts for Methods Utilised for Measuring Reliability of Infrastructure Assets

Presented in figure E2a to E2k are the detailed chart results for each infrastructure type of the fifth question in the questionnaire. From figures E2a to E2k it is evident that the method most relied on to determine reliability of water and waste water infrastructure assets is direct measurement, followed by visual inspection.

It is unfortunate that the scope of the questionnaire could not allow further investigate into what the organisation that responded to the questionnaire understood by "direct measurement" and what activities they undertake when they use "direct measurement" to determine the reliability of their assets.

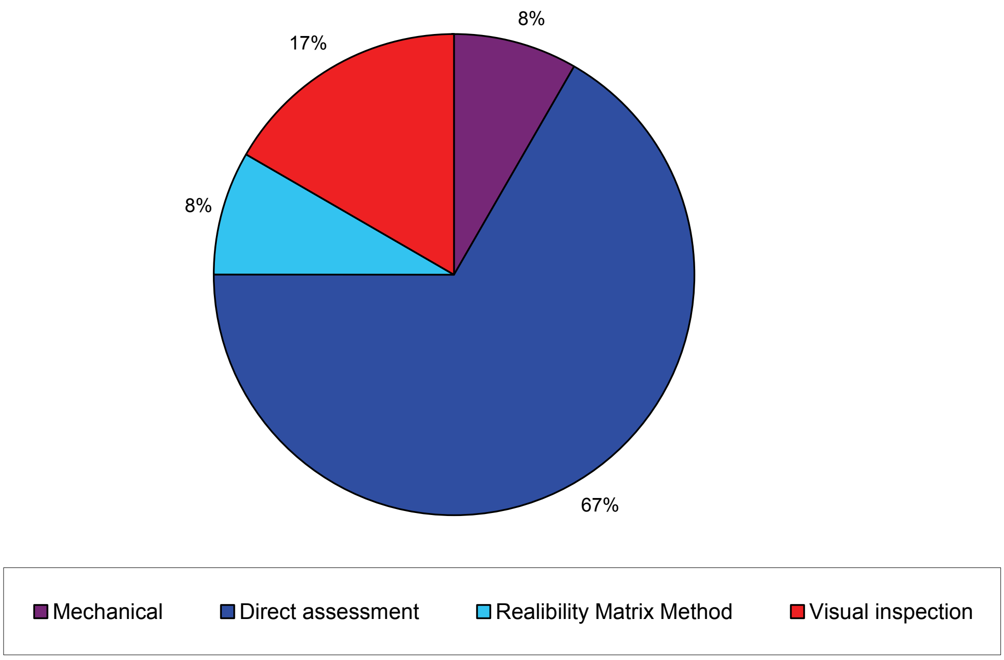


***Fig. E2a.*** *Methods Utilised to Measure the Reliability of Dams.*

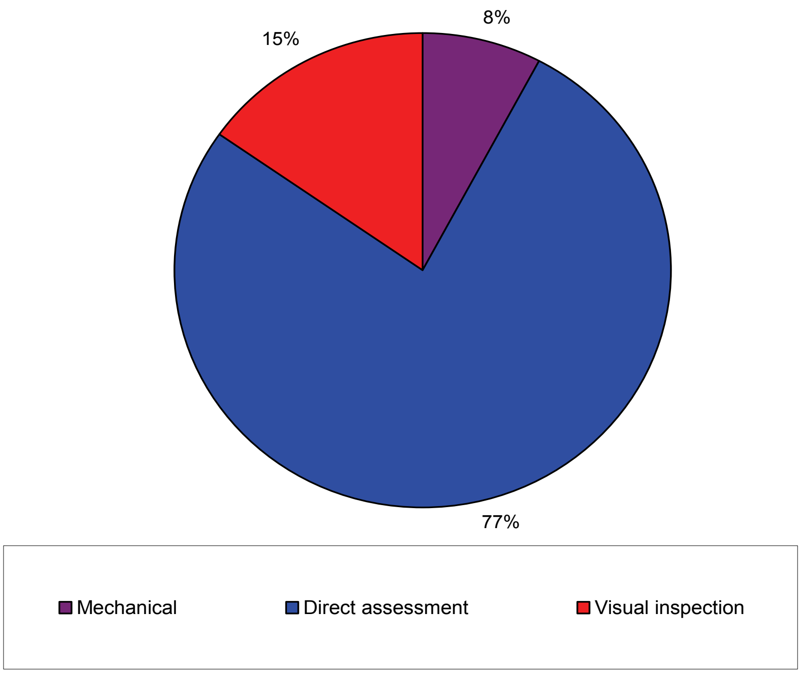


***Fig. E2b.*** *Methods Utilised to Measure the Reliability of Boreholes.*

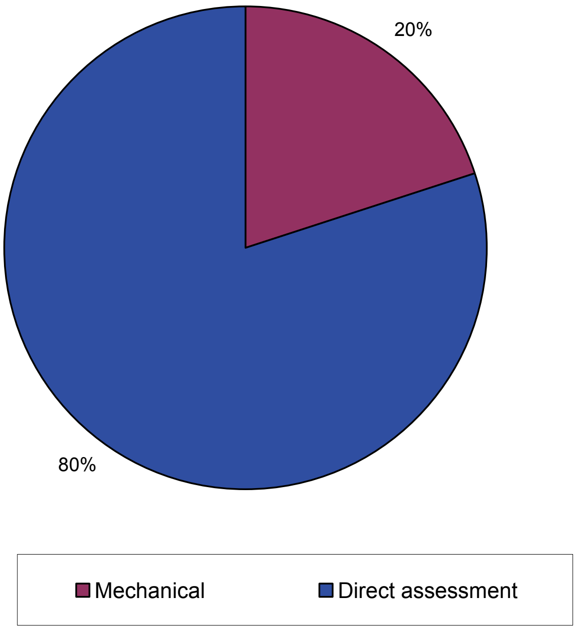


***Fig. E2c.*** *Methods Utilised to Measure the Reliability of Spring Protection.*

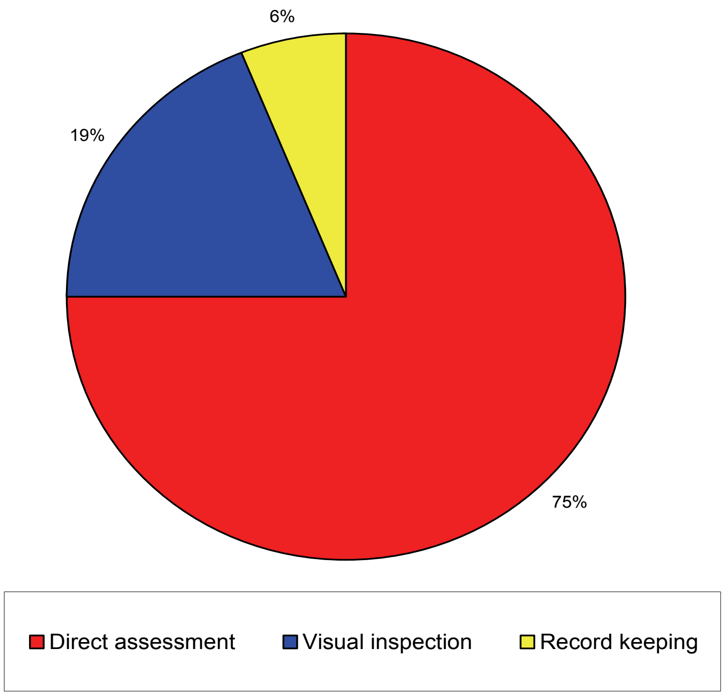


***Fig. E2d.*** *Methods Utilised to Measure the Reliability of Reservoirs.*

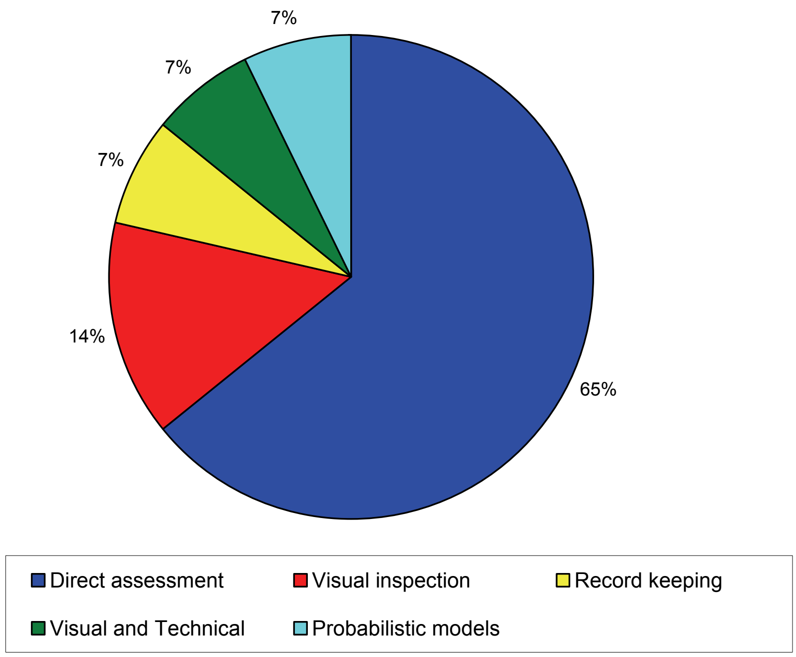


***Fig. E2e.*** *Methods Utilised to Measure the Reliability of Water Pump Stations.*

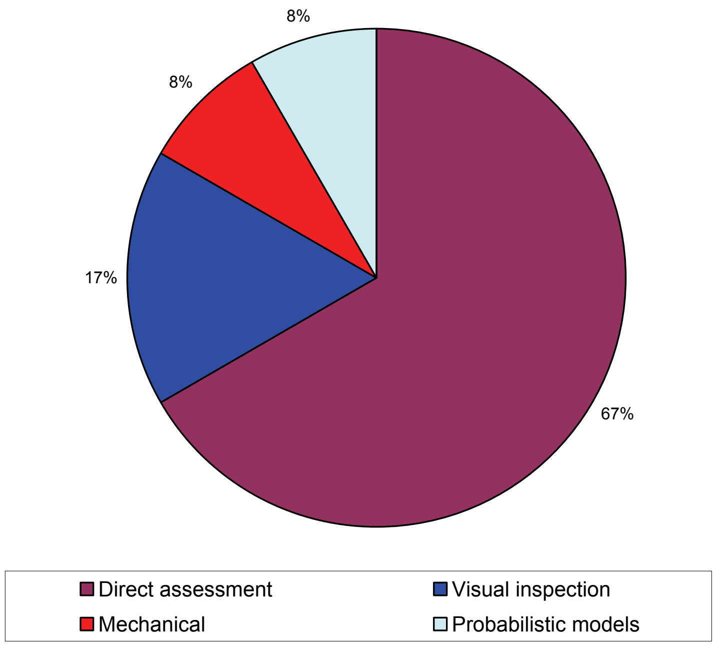


***Fig. E2f.*** *Methods Utilised to Measure the Reliability of Sewage Pump Stations.*

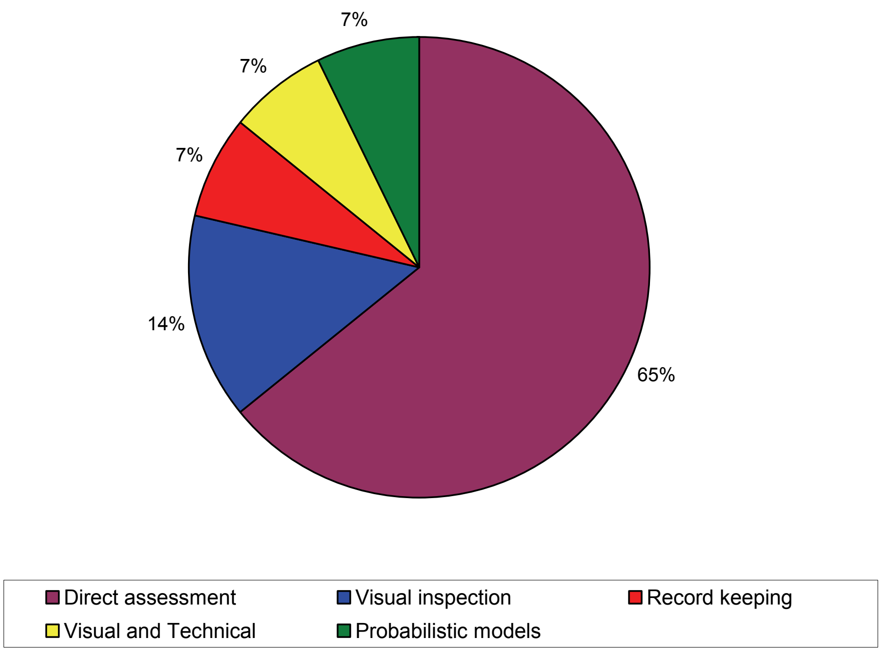


***Fig. E2g.*** *Methods Utilised to Measure the Reliability of Water Treatment Works.*

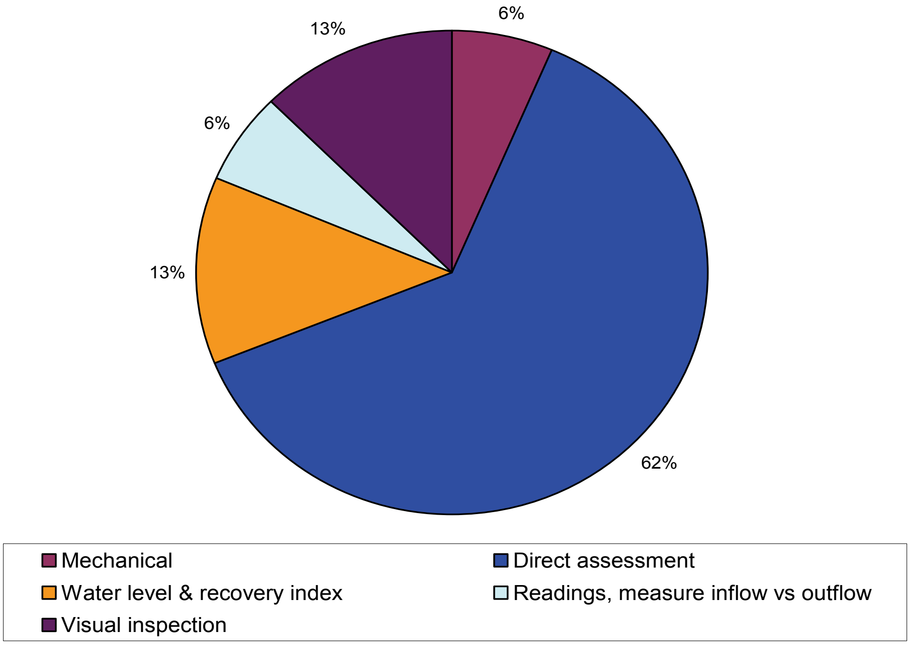


***Fig. E2h.*** *Methods Utilised to Measure the Reliability of Sewage Treatment Works.*

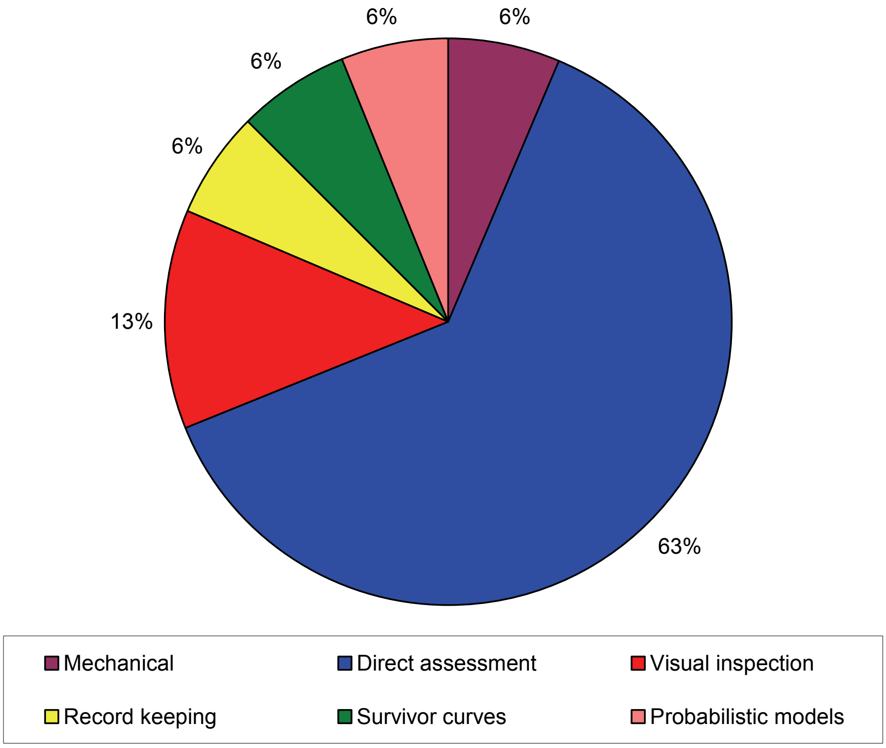


***Fig. E2i.*** *Methods Utilised to Measure the Reliability of Water Pipelines.*

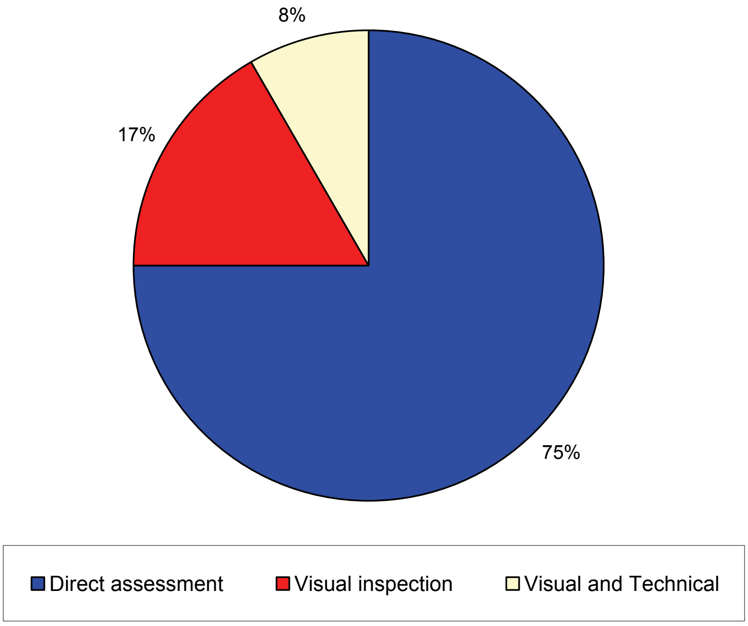


***Fig. E2j.*** *Methods Utilised to Measure the Reliability of Sewage Pipelines.*

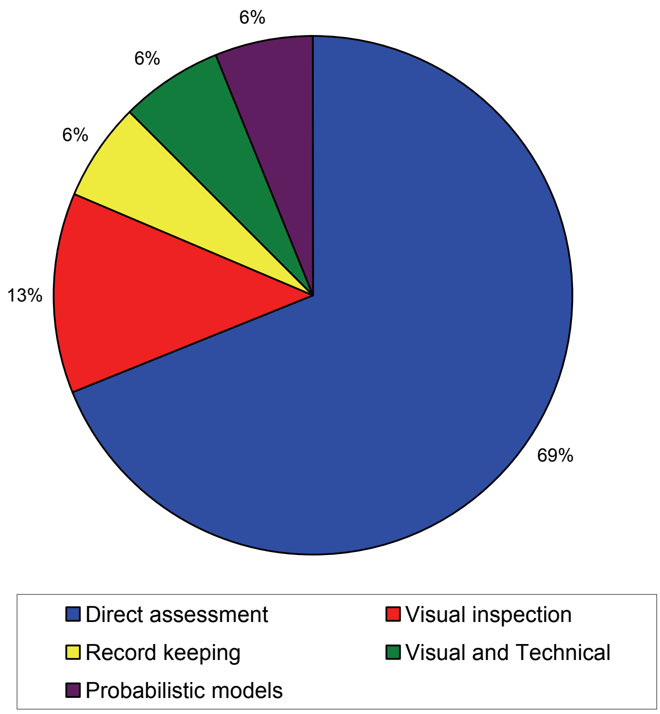


***Fig. E2k.*** *Methods Utilised to Measure the Reliability of Valves.*

# APPENDIX F – WCEAM 2009 CONFERENCE PAPER

## A CASE STUDY ON CONDITION ASSESSMENT OF WATER AND SANITATION INFRASTRUCTURE

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The management of physical assets covers a wide scope and range of processes that include acquisition, control, use, disposal and re-cycling of built environment structures in a manner that satisfies the constraints imposed by business performance, environment, ergonomics, and sustainability requirements. Technologies applicable towards the management of infrastructure assets for water and sanitation services are advancing rapidly apparently influenced by advances in condition monitoring, information and communication technologies. This paper discusses condition and risk assessment of water and sanitation assets. Although inferences are drawn from available public domain literature and non-probabilistic survey of representatives of organisations engaged in water and sanitation services, the findings reiterate that the most rapid trends are in technologies for the collection and transfer of data. We also find that the understanding and practice of asset management in water and sanitation services providers is still in infancy, and thus begs to question some of the purported benefits of technology applications for such organisations.

Key Words: Engineering Asset Management, Water and Sanitation Infrastructure, Technology Trends.

## Introduction

Technologies applicable towards the management of physical assets have advanced rapidly and asset-intensive businesses can take advantage of the technological developments to increase operational efficiency and to provide improved products and services. Noting the considerable impact of water and sanitation on health, economy, environment, and society at large, a core issue for service providers is to determine the condition of extensive infrastructure that includes buried pipes, dams, pumping stations, reservoirs, reticulation, treatment and transport systems.

Technology can, and should be deployed towards monitoring the quality of potable water and effluents to ensure compliance with applicable health regulations. In societies with significant socio-economic disparity, there is the added imperative to establish adequate capacity for water and sanitation services both in terms of new and existing infrastructure. For example, infrastructure planners and operators need to determine the risks and interventions required in the creation, acquisition, maintenance, operation, decommissioning, disposal and/or rehabilitation of water and sanitation assets. Capital investments, operations and maintenance, and rehabilitation of water and sanitation infrastructure have traditionally been in the realm of massive public funding, and this is increasingly placing unbearable fiscal burden on government departments. The combined challenges of social cohesion, technological advancements and economic growth have provided incentives for increased participation by private sector investors and managers in water and sanitation services.
This paper extrapolates from our review of methods, tools and techniques that are available for use in infrastructure condition assessment and risk management. Based on observed cases of water and sanitation providers in South Africa, we then summarise the extent to which

available condition monitoring, information and communication technologies influence asset management activities like condition assessment, risk analysis and predictive modelling.
As illustrated in figure 1, for the water and sanitation sector, technology embedded in physical assets, information systems, and business processes can be exploited towards addressing the wide-ranging socio-economic challenges that include satisfying healthy service delivery requirements, whilst concurrently minimizing environmental footprints in energy consumption, water extraction, and effluent discharge; all of which have to occur within highly constrained capital and operational expenditure programmes. Data, information systems and communication technologies provide the means for linking the infrastructure components to the asset management processes and towards resolving the challenges and achieving the business objectives for the owner/operator of the asset base.

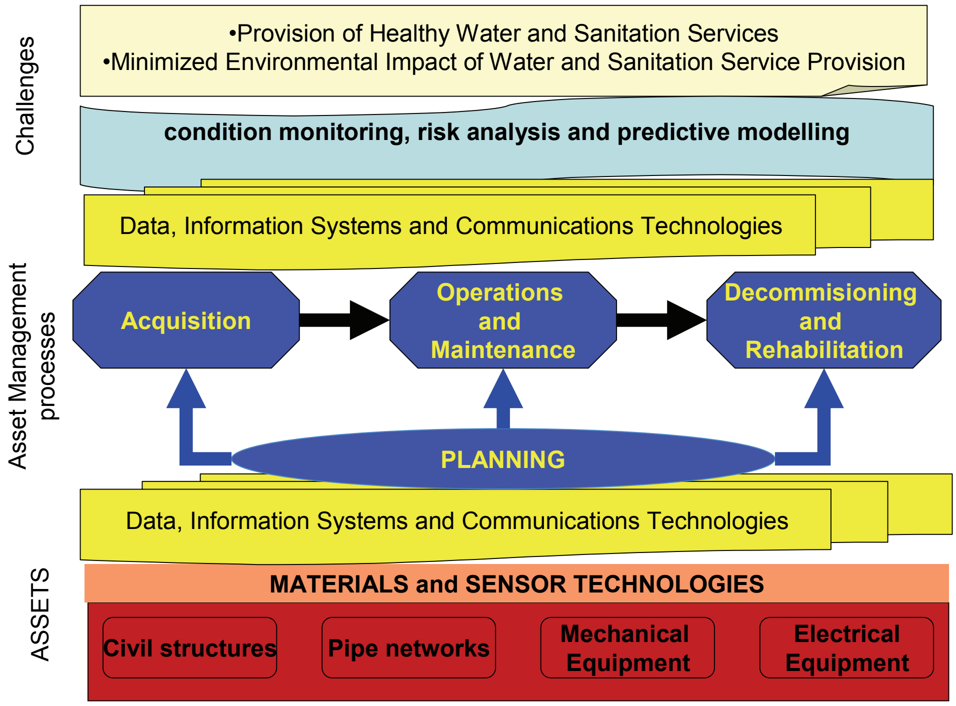


Fig 1. Water and Sanitation Services Asset Management Model highlighting ICT Applications

## Research

Effective decision making regarding long term planning, risk management, maintenance, operations, or other asset management activities, is dependent on the availability of appropriate data and information. Sensors, computerised systems, and communication technologies provide tools for the collection of condition and transactional data against asset records that can be processed into useful categories of information, which, subsequently, inform decision making. Asset management practices entail the use of information to make value-adding decisions regarding asset condition, performance and risk. A systematic, consistent and relevant technical assessment should provide condition information to enable infrastructure planners and operators to determine the risks and interventions required in the management of water and sanitation assets. The collection of pertinent data is a major task [1] and the assessment should at least:

- provide a rating of the asset condition “as found”;
- indicate the risks associated with allowing the asset to remain in the “as found” condition; and
- identify the scope of work that may be necessary to restore to, and/or sustain the asset at desired condition.

Marlow *et al* (2007)[2] provide a comprehensive breakdown of condition monitoring tools and techniques that can be applied to equipment and structures deployed in water and wastewater services. Their study produced a set of inclusive tables that break down the various inspection tools and techniques, environmental surveys and condition monitoring techniques. Our literature review (cf: for example, Andrews (1998)[3], Randall-Smith *et al* (1992)[4], Billington *et al* (1998)[5], Snyder *et al* (2007)[6], Ferguson *et al* (2004)[7], Stone *et al* (2002)[8] and), reveals a myriad of techniques for sensing the desired physical parameters as well as a number of computational models that can be applied towards the prediction of asset condition and risk profile. Whereas Watson *et al*[9], [10] and [11] may be useful references on practice guidelines, however, a key gap observed in our literature review is the apparent lack of specific sets of condition indices for each category of water and sanitation infrastructure assets.

Following our literature review of condition and risk monitoring techniques, we then focused our study on the application of these technologies by owners/operators of water and sanitation infrastructure. We developed a questionnaire to assist us in our study of how these techniques were applied by water and sanitation services providers in South Africa. We targeted a judgemental sample of people that included representatives of service providers, technology vendors and consultants. The service providers included 145 municipal agencies, some of which are responsible for water distribution, bulk transfer and sanitation; plus 5 companies primarily engaged in extraction, treatment and bulk transfer of water. The range of infrastructure owned/operated by the respondents' organisations typically included boreholes, dams, reservoirs, pump stations, treatment plants, and pipeline transfer systems. Despite concerted efforts at persuading respective representatives of the respective organisations in our geographical delineation, only 23 respondents, almost exclusively representing local municipalities, completed our questionnaire. It is worthwhile to note that the responding municipalities serve less than 16% of households in a geographical population comprising more than 45 million people. The study was also conducted within the background of a recent legislation that more or less requires government departments and public agencies to adopt and implement asset management principles and practices.

The bar graphs in figure 2 show the respondent feedback on how often they carried out condition assessments of the infrastructure assets and what technologies were used. The respondents claim that their respective organisations carry out daily, monthly and yearly inspections of their assets but more so on pump stations, pipelines and reservoirs facilities. It was revealing that some organisations seldom carried out condition assessment of their facilities, even if it was only limited to visual inspections, and especially with the wide range of technologies seemingly available. We were also perplexed to observe that some respondents indicated that condition assessments were "outsourced to consultants", thus giving the impression that the particular organisations did not really pay attention to what technologies were applied.

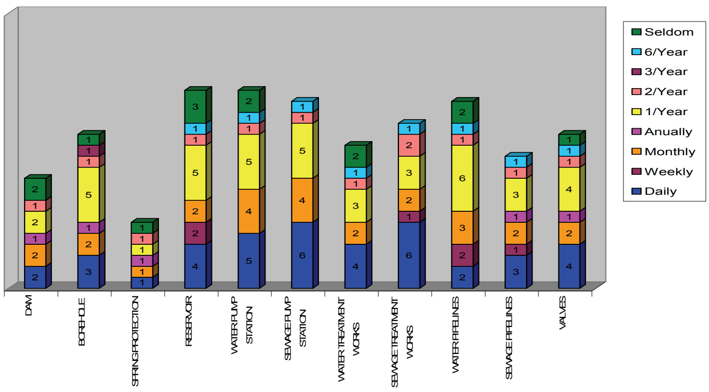

***Fig 2a.*** Frequency of inspections for condition assessment of infrastructure

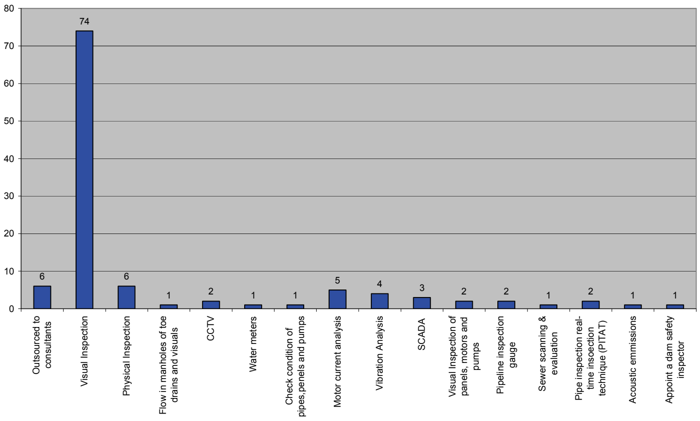


***Fig 2b.*** Inspection technologies for condition assessment of infrastructure

With regard to risk management, we approached the issue by asking the municipal organisations whether or not they measured reliability, based on the assumption that our respondents understood our definition of reliability as "the chance of pre-defined failure occurring under given conditions within a stipulated time period". The bar graph in figure 3 suggests that less than half of the municipal organisations measured the reliability of the respective assets under their care. Of more concern is that majority of respondents indicated 'direct assessment' as a method for measuring reliability and 'monetary value' as the method for risk ranking of assets. Such feedback more or less supported our apriori impression that majority of respondents did not understand how to measure reliability or risk. In fact, less than a third of our respondents indicated that their respective organisations maintained a risk register.

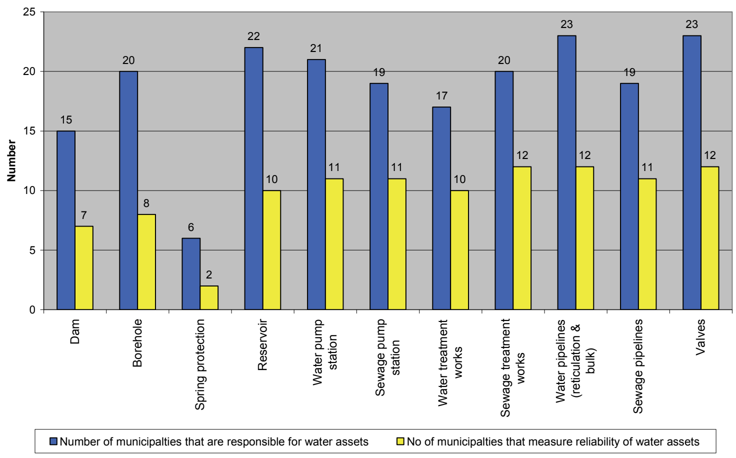


***Fig 3.*** 'Direct assessment' of reliability as a measure of risk

## Discussion

Whereas the respondents' feedback suggest visual inspections as the prevailing common method for condition assessments, however, visual inspections can encompass a rather broad definition of activities ranging from cursory inspections to highly detailed technical examinations utilising sophisticated instrumentation. The same applies for 'direct assessment' as the measure of reliability and the use of 'monetary value' as the basis for risk ranking. All the municipal organisations in the geographical delineation used for our case study are under pressure to prepare asset registers, especially to demonstrate financial compliance with the relevant legislation. The apparent lack of sector asset management guidelines over and above vendor equipment standards may exacerbate how to conduct condition and risk assessments of water and sanitation infrastructure assets, and hence the valuation of such assets. Although

the technology exists and there are examples of the application of some of the methods for condition and risk assessments, however the need for an enabling environment is also exacerbated by the requirement to develop new skills, and this is further compounded by weak organisational commitments to the principles and practice of engineering asset management.
The overall impression from our non-probabilistic survey demonstrates that the understanding of engineering asset management is at an infancy stage for the water and sanitation service providers that participated in the study. With this in mind, we propose the following data progression structure to facilitate the journey in engineering asset management for such organisations.

| **Data level** | **Data type** | **Key Data Management Needs** | |
|---|---|---|---|
| Primary data | Inventory | □ Classification guidelines<br>□ Basic attributes guidelines<br>□ Data storage software | Where most Water Service Providers are now |
| Secondary data | Basic condition attributes | □ Assessment guidelines<br>□ Reporting guidelines | |
| Tertiary data | Performance data/modelling | □ Advanced condition technology<br>□ Maintenance management software<br>□ Business processes<br>□ Predictive modelling methods<br>□ Optimised decision making methods<br>□ Benchmarking | Movement in the future |

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