# CHALLENGES AND THE FUTURE OF THE IMPLEMENTATION OF BULK WATER PIPELINE CONDITION ASSESSMENT

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## ABSTRACT

The condition assessment of bulk water pipelines is a challenging process as the condition of the main will vary significantly along its length. Furthermore, due to the stochastic nature of corrosion (the undesirable degradation of a material reacting with its environment), the extent of corrosion or degradation experienced can vary significantly over very short distances. This means it is particularly challenging to economically determine the condition of a bulk water pipeline with a high degree of statistical certainty and it typically necessitates the use of a representative sampling approach. A phased approach to identify the locations for representative sampling is recommended in order to facilitate informed decision making throughout the project.

Four phases are typically included in condition assessment projects. These phases include: a desktop study and preliminary investigations, field investigations, detailed pipe integrity assessments and condition assessment post processing. Each of the phases provides direction to the next phase in terms of the selection of appropriate condition assessment tools and techniques from the various options available. There is no single tool or technique that will provide all the condition assessment information required and additionally these tools and techniques may have limitations on operating pressures, access requirements and reach lengths. A number of different tools and techniques are usually required and the selection thereof can only be made once sufficient information on the pipeline is available (sizes, materials, pressures, flows, access points, failure history, etc.). This data may only be available at the completion of the desktop study and preliminary investigations. A project initiation where the desktop study and preliminary investigations can be conducted on a bulk main or water supply system independently of the further phases is recommended in order to correctly define the scope and methodology of the following phases. This approach also improves the budgeting and scheduling accuracy of the remaining phases.

Digital technology has advanced significantly in the past decade, specifically with regard to processing power, battery capacity and storage volumes. These advances are starting to be realised in the advancement of pipeline condition assessment tools. This paper also reviews the development of the available condition assessment tools and methods and their application in the phased approach to bulk water main condition assessments. Additionally the design of bulk water mains with integrated components to allow for the application of future condition assessments is discussed.

## INRODUCTION TO PIPELINE DEGRADATION AND THE REQUIREMENT FOR CONDITION ASSESSMENT

In water supply pipelines the structural integrity of the pipeline is a measure of its ability to carry the in-service (positive and/or negative

**FIGURE 1** Factors impacting a pipeline's service life

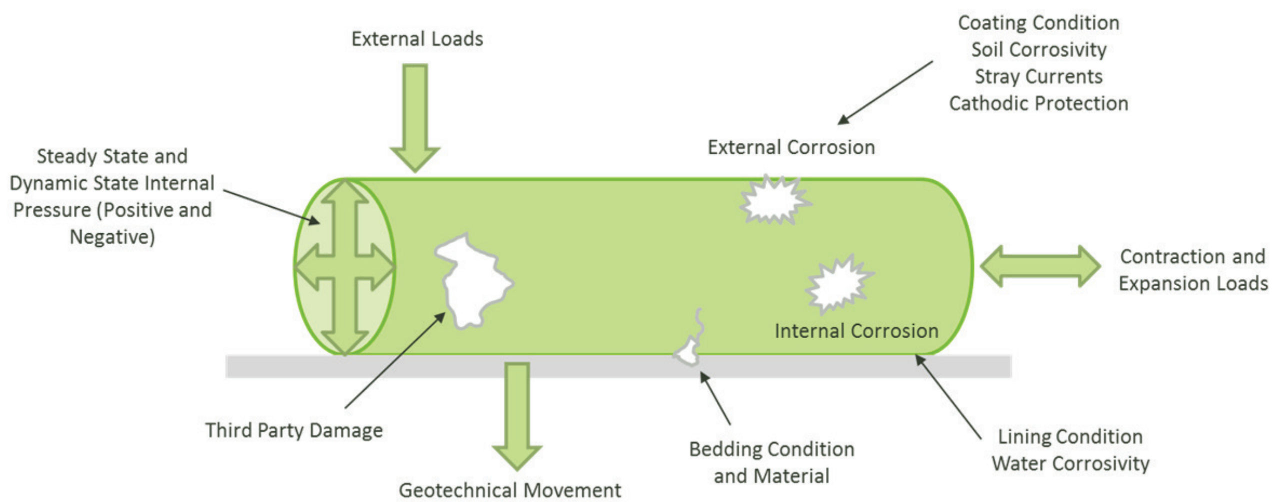
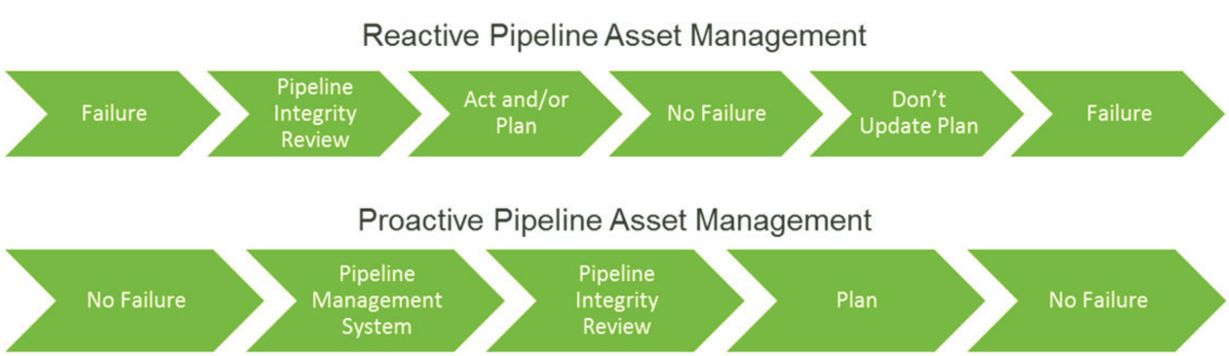



**FIGURE 2** Reactive and Proactive Pipeline Asset Management Principles (adapted from Hopkins, 2003)



pressures) load and external loads consisting of soil, traffic and overburden loads. These loads are carried by the pipe's wall, the thickness and integrity of which are subjected to a number of degradation mechanisms which harmfully impact on the pipeline's structural integrity. In the condition assessment of a bulk water supply, the in-service loads, external loads and the structural integrity of the pipe wall must all be assessed to determine the condition of the bulk main.

Corrosion, the undesirable degradation of a material reacting with its environment, is stochastic in nature, and may vary significantly over the length of a pipeline, the length of which may be measured in tens of kilometres. The degradation of the pipeline may therefore vary significantly over very short distances and may act on both the internal pipe wall surface and the external pipe wall surface with completely different corrosion mechanisms, thereby making it particularly difficult to assess the extent thereof. Additionally the stresses imposed on the pipeline, both in-service and external loads, vary over pipeline length as a result in differences in elevation, pipeline steady state and dynamic state hydraulics, varying construction methods and materials, changes in temperature, ground movement, groundwater and third party damage (Livingston et al, 2010). These various factors that impact the service life of the pipe are summarised in Figure 1.

Stephenson et al. (2001) defines the asset management of water services in South Africa as the process of managing the creation, acquisition, maintenance, operation, rehabilitation, extension and disposal of the assets of an organisation in order to provide an acceptable level of service in a sustainable and long-term cost-effective manner. This process can only take place if there is adequate and accurate data on which to base the asset management decision. The condition assessment of a pipeline provides this data during the maintenance, operation, rehabilitation and extension phases of an asset's service life. A pipeline condition assessment however only represents the condition of the pipeline at an instant in time and, as time passes, the condition of the asset may change. Periodic condition assessment surveys are therefore required to effectively implement the asset management of these items and should form part of the pipeline's asset management plan.

Closely related to the asset management of water services in South Africa is the integrity assessment, where high risk (i.e. large social and/or economic impact) infrastructure is assessed for structural integrity before the asset or services fail and result in service delivery failure and outages. The condition assessments performed as part of the asset management processes can be assessed together with impact of asset failure to provide an integrity assessment. The combination of water services (pipeline) asset management and integrity assessments result in the proactive management of the asset. The principles of proactive water services asset management is provided in Figure 2.

A number of tools and technologies are available to conduct pipeline condition assessments and are employed either directly or indirectly to the pipeline. These tools and techniques and their technological development are discussed in this paper. Additionally a proposed structure, in the arrangement of a phased approach for the delivery of bulk water pipeline condition assessments and then designing to accommodate condition assessments, is presented in this paper.

## PIPELINE INSPECTION TOOLS AND TECHNOLOGIES

### Technology development

Technology has developed significantly over the past few decades and is still developing at a rapid rate, with new technologies and innovations constantly being developed. But what about the pipeline industry? According to Hopkins (2003) the pipeline industry has not seen many significant changes in the way we design, construct and operate pipelines since the 1950's, where the only significant changes include a number of higher quality materials and the birth of the "intelligent pig". The "intelligent pig" (and other pipeline condition assessment tools) is indeed a significant development and has been realised due to some of the digital advance made since Hopkin's article in 2003.

In 1965 Gordon Moore made a predication that the number of transistors per square inch on integrated circuits (directly related to overall computer processing power) would double every two years. This prediction is referred to as Moore's Law and has set the pace where computing has dramatically increased in power and decreased in relative cost at an exponential rate (Intel, 2016). These advancements allow for intelligent condition assessments to process more data at a lower relative cost, thereby providing a more accurate representation of pipe wall integrity. Additionally, the cost of computer memory has significantly decreased over the past few decades with cost of memory decreasing from approximately $200, 000.00 per gigabyte in the early 1980's to $0.07 per gigabyte in 2010 (Komorowski, 2016). The development of Li-ion batteries when compared to older Lead-Acid, Nickel-Cadmium and other batteries has significantly improved battery performance, including power density and energy density at a lower cost. This development, together with the decreased cost of computer memory allows for inspection tools to be implemented over longer lengths and more challenging conditions. The resolution and quality of digital imaging has also significantly improved, where the increased imaging quality on smartphones is a prime example we can relate to. These developments and their impact on pipeline inspection tools are summarised in Figure 3.

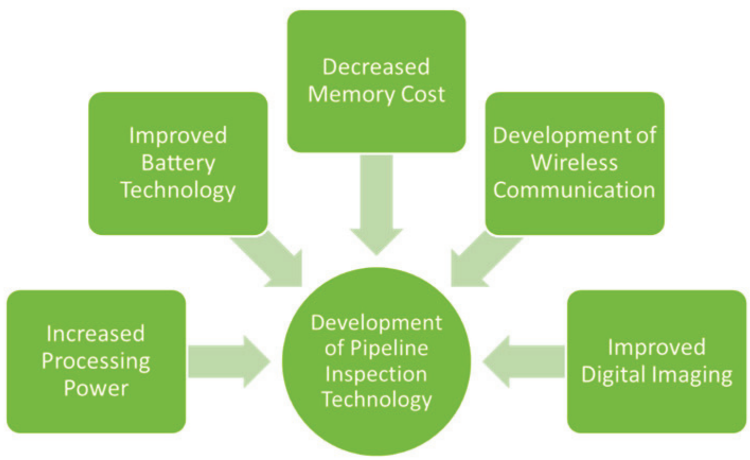



**FIGURE 3** Development of pipeline inspection technology

A number of these developments and improvements were recently realised on a pipeline condition assessment project that presented some difficult inspection requirements. The DN 700 steel pipeline that was inspected is approximately 40 km long and one of the inspection techniques included in the assessment was a drained internal CCTV inspection of the pipeline. This specific pipeline has limited access points to the pipeline, some of them in excess of 5 km apart. A first order CCTV inspection was conducted with traditional inspection equipment. This equipment is limited to inspection lengths of 300 m and could therefore only provide a small representative sample of the pipeline's internal condition. Based on this inspection (and other assessment methodologies) it was recommended to refurbish the pipeline's lining. However to mitigate increased costs for unknown pipeline conditions during this lining

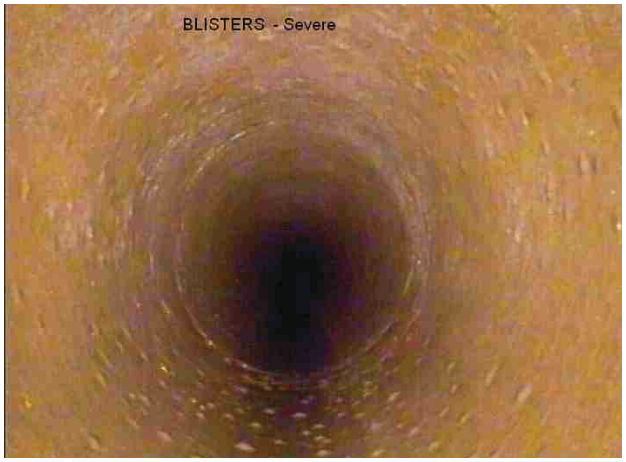



**FIGURE 4** Traditional CCTV inspections image quality

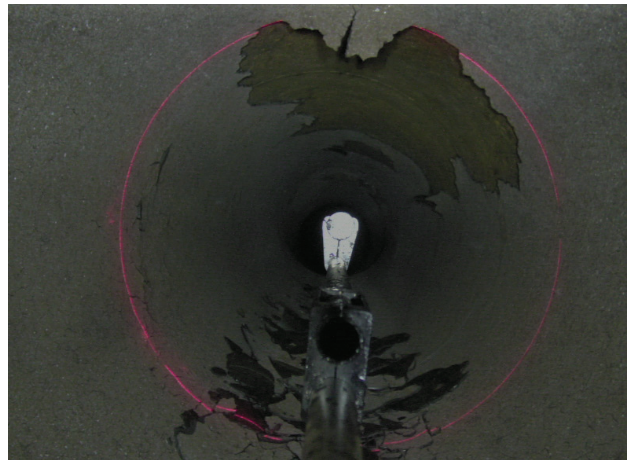


**FIGURE 5** Newer CCTV technology inspection image quality

refurbishment it was decided to increase the representative sample of pipeline that was inspected utilising newer CCTV equipment (that is currently not readily available in South Africa).

This newer drained CCTV technology that was employed can inspect pipeline lengths of up to 2 000 m and is operated by a tethered fibre optic cable (other options are available that are operated by a Wi-Fi signal). Together with increased inspection lengths the quality of CCTV images has significantly improved when compared to the older technology and is demonstrated in the figures below, where two drained CCTV inspection outputs for the same pipeline are provided, one for the newer technology and one for the traditional/older technology. The improvement in inspection quality is attributed to the improvements in processing power, battery performance, cost of on board memory and development and improvement of wireless networks.

## Pipeline inspection tools and techniques

There are numerous pipeline inspection tools and techniques available, but there is no single tool that can be employed to provide all the data one may require. A number of the tools and techniques have developed from the oil and gas industry, whilst others have been developed specifically for the water industry.

The United States Environmental Protection Agency (EPA) (2012) conducted research to identify and characterise the state of technology for the structural condition assessment of drinking water transmission and distribution systems. EPA (2012) researched the available and typically employed non-destructive inspection tools and techniques (commonly referred to as Non-Destructive Testing [NDT] or Non-Destructive Examination [NDE]). These tools and techniques are summarised as follows:

- Pitting Depth Measurement;
- Visual Inspection (man entry inspection, CCTV inspection, video endoscope, 3D optical scanning and laser profiling);
- Electromagnetic Inspection (magnetic flux leakage, remote field eddy current, broadband EM, pulsed eddy current, ground penetrating radar and ultra-wideband pulsed radar);
- Acoustic Inspection (sonar profile, impact echo, acoustic emission, leak detection);
- Ultrasonic Testing (guided wave, continuous measure, discrete measure, phased array, combination UT and seismic pulse echo);
- Pipeline Current Mapping;
- Radiographic Testing;
- Thermographic Testing;
- Assessment from Soil Properties (linear polarization of soil, soil properties, soil corrosivity, soil resistivity, pipe-to-soil potential survey); and
- Emerging sensor technologies and sensor networks including intelligent pigs and robotic survey systems.

The National Association of Corrosion Engineering (NACE), which is primarily concerned with the oil and gas industry, has provided standard techniques for assessing the condition of pipelines including:

- Pipeline External Corrosion Direct Assessment Methodology (ANSI/NACE SP0502-2008); and
- Internal Corrosion Direct Assessment Methodology for Liquid Petroleum Pipelines (NACE SP0208-2008).
- The internal corrosion mechanisms for liquid petroleum pipelines are significantly different compared to the internal corrosion mechanisms of water pipelines, but the inspection principles provided in the guideline may be applied to water pipelines.

The NACE assessment methodologies (external and internal) include the application of the following inspection tools and techniques:

- Close Interval Potential Survey;
- Current Voltage Gradient Surveys (ACVG and DCVG);
- Pearson Surveys;
- Electromagnetic Surveys;
- AC Current Attenuation Surveys;
- Visual Inspections at Excavations (coating condition and adhesion assessment, corrosion product analysis and identification and mapping of corrosion defects using pitting depth measurement, ultrasonic or laser mapping);
- Soil and Water Corrosivity/Resistivity Testing;
- In-line Inspection Tools (i.e. intelligent pigging); and
- Internal Corrosion Coupon Monitoring.

The NACE assessment methodologies are presented as a four step process, where the first and critical step is referred to as the Pre-Assessment. This step is regarded as critical, as it assesses the feasibility of the pipeline condition assessment methodologies and identifies the inspection tools and techniques to be employed. The combination of the NACE methodologies and the tools and techniques provided by EPA provide a holistic approach to water pipeline condition assessments. The importance of selecting the correct pipeline inspection tools and techniques is discussed below.

## Pipeline inspection tools limitations

Bulk water pipeline installations and systems vary significantly. Pipe materials, hydraulic pressures, flow rates, external loading, soil conditions, water conditions, depth of cover, installation practices, pipeline access and operational control differ from one pipeline to another. These differences significantly affect the application or suitability of various pipeline inspection tools. Pipe materials. Ferrous pipe materials (steel, ductile iron, etc.) can be assessed by a wider variety of tools in comparison to polymer pipes (PVC, HDPE, etc.) and concrete pipes (pre-stressed concrete pipe, asbestos/fibre cement, etc.) to a lesser extent.

These tools and techniques include, but are not limited to: ultrasonic testing, pipeline current mapping, radiographic testing, pipe-to-soil potential surveys, voltage gradient surveys, person surveys, AC current attenuation surveys and in-line inspection techniques. Not all ferrous pipes can however be tested with these inspection techniques due to the following reasons:

- Presence of pipeline coatings and linings;
- Pipeline ovality;
- Debris within the pipeline; and
- Locations to connect test equipment (e.g. cathodic protection test posts) or to conduct tests (e.g. exposed sections of pipes for ultrasonic testing).

Hydraulic pressures and flow rates. Online or live inspection equipment may be limited to certain hydraulic pressures and flow rates. Specific areas of concern are pipelines with higher pressures, in excess of 2.5 MPa and pumping mains where the flow rates cannot be reduced or controlled. Additionally bulk water mains can rarely be shut down for extended periods of time, thereby eliminating the possibility to utilise equipment that require drained conditions.

Installation practices. Pipeline jointing systems (i.e. flanged, welded or spigot and socket) significantly alter the electrical continuity of a pipeline and the possibility to propagate longitudinal ultrasonic sound waves in the pipeline. These limitations may eliminate the suitability of a number of the above electro-potential measurement techniques, such as close interval potential surveys and voltage gradient surveys, and the application of guided wave ultrasonic testing.

Pipeline access. Various tools have specific pipeline access requirements and associated reach lengths. Traditional drained CCTV inspection equipment typically has inspection reach lengths of 300 m and require adequately sized pipeline access points to insert the equipment into the pipeline. Many of the older pipelines have limited access points of the required size (if any), thereby significantly reducing the inspection sample.

Therefore not all inspection tools and techniques are applicable to every pipeline condition assessment and the selection thereof is critical to the success of a pipeline condition assessment project. A phased approach to pipeline condition assessments where the completion of each phase provides direction for the selection of the next phase's tools and techniques is recommended and is discussed in the paragraph below.

## PHASED PIPELINE CONDITION ASSESSMENT APPROACH

The phased approach consists of four distinct phases which are illustrated in Figure 6 below. Each phase is defined in such a way in order to provide direction to the next phase in terms of the selection of appropriate condition assessment tools and techniques from the various options available.

This approach also allows for informed decision making at the end of each phase that allows for the next phase's cost to be accurately calculated and its feasibility of the next phase assessed. All four phases are required to provide an accurate pipeline integrity assessment.

### Desktop study and preliminary investigations

The available pipeline records (including design drawings), reports from previous assessments, and operational data are sourced and studied during this phase. If this information is not available, preliminary field investigations will be performed to develop a pipeline record, typically in the format of an asset database. These field investigations will consist of georeferencing all of the pipelines accessories (valves, chambers, meters, reservoirs, pump stations, etc.). Visual inspections and condition ratings are normally assigned to this infrastructure during this inspection. If no operational data is available, flows and pressures may be logged over a period of time to provide the required pipeline hydraulic data.

Once the available pipeline records and drawings have been obtained or developed and studied, a hydraulic model and geo-refined CAD or GIS models will be developed. From these models the following pertinent information is obtained:

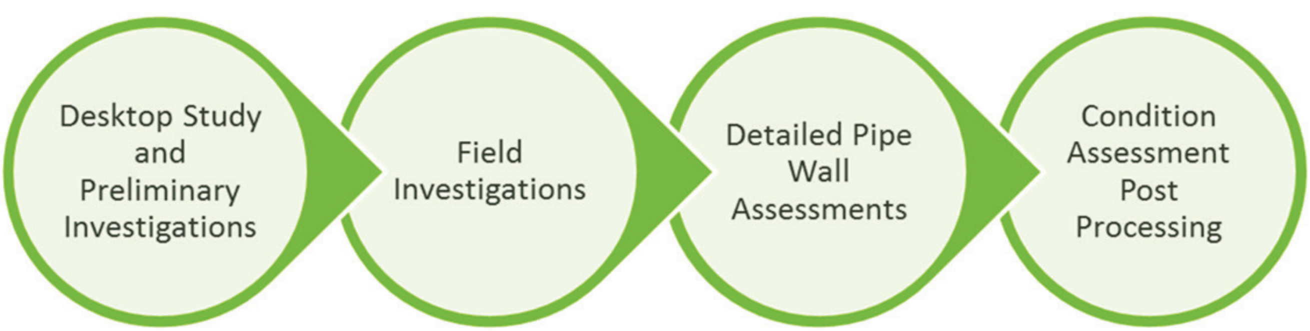
- Pipeline pressures;
- Pipeline flow rates;
- Pipeline access points size and spacing;
- Pipeline material, pressure rating, diameter, jointing method and length;
- Pipeline route detail including pipeline access, general soil conditions, presence of stream or river crossings and general topography;
- Locations and details of cathodic protection ground beds and test posts (if present);
- Presence of high voltage overhead powerlines, railway lines and other sources of stray currents; and
- Pipeline operational constraints in terms of available downtime.

Only then can the suitable pipeline inspection tools be identified for the following phases. For this reason a project initiation where the desktop study and preliminary investigations can be conducted on a bulk main or water supply system independently of the further phases is recommended. This enables the scope and methodology of the remaining phases to be correctly defined based on accurate information. This approach also improves the budgeting and scheduling accuracy for the remaining phases. Once the desktop study and preliminary investigations are completed, the field investigations proceed.

### Field investigations

The difficulty of assessing the condition of bulk water mains was introduced at the beginning of this paper, where the requirement of statistical

**FIGURE 6** Phased Condition Assessment Approach



sampling was discussed. This statistical sampling approach is a risk based model, where the areas of a high failure risk are obtained. Three main components are typically assessed: 1) Areas of high pipe wall stress, 2) Areas of high corrosion risk and 3) Areas of historic failure. The combination of these three areas identifies the representative sample of high failure risk areas that are assessed in greater detail in the next phase of the condition assessment.

Field investigations are required to identify both the areas of high pipe wall stress and the areas of high corrosion risk. Leak detection may be employed to augment the historic failure record. The field investigations also provide valuable information that is utilised in the corrosion rate, end of life and failure probability calculations in Condition Assessment Post Processing phase that are required to develop the pipeline asset management plans. Depending on the specific pipeline, a typical set of field investigations for buried ferrous pipes is discussed below and is summarised in Figure 7. The majority of these investigation tools and techniques have limitations and may not be applicable to all pipelines.

Areas of high pipe wall stress. The internal pipeline wall stresses are calculated utilising the hydraulic model defined during the desktop study. Transient pipeline pressures (surge conditions) may be recorded with pressure transducers that sample at a frequency large enough to record the rapid changes in pipeline pressures (typically ≥100 Hz). These transient pressures can be used to calibrate the hydraulic models to ensure the calculated pipe wall stresses are correct. The stresses on the pipeline caused by external pipeline loadings can be calculated if the locations and details of pipeline road and rail crossings and any other areas of overburden are known. Drone surveys may be employed to identify any areas where infrastructure encroaching on the pipeline may result in undesirable external loads on the pipeline.

Areas of high corrosion risk. Both the external corrosion and internal corrosion risks require assessment. For the external corrosion assessment the soil corrosivity of the pipe route is surveyed (typically with a soil resistivity survey), coating failures are identified using a DCVG or ACVG survey, the integrity of the cathodic protection system is assessed with a Close Interval Potential (CIP) Survey, the presence or extent of stray currents are measured and the overall integrity of the coating is assessed using current attenuation surveys. For the internal corrosion assessment, drained or live CCTV inspections are employed to identify areas where the lining has failed and the pipeline has corroded and where there is third party damage to the pipe. Water quality testing where water corrosivity indices are calculated may be employed and the testing for the presence of bacteria that may cause Micro-biologically Induced Corrosion (MIC) may be conducted. The most accurate method to define corrosion rates (required for condition assessment post processing) is with corrosion coupons that are installed in the corrosive environment and removed after a period to measure the extent of corrosion over that time period.

## Detailed pipe integrity assessments

The detailed pipe integrity assessments are performed at the high failure risk locations. Excavations are normally required for the direct assessments and the pipeline's coating (if applicable) may need to be removed, depending on the coating type and integrity testing techniques followed. The coating must be reinstated prior to backfilling the excavation after the assessments, as this is not only good practice, but the testing is performed in the areas with the highest risk. The purpose of the integrity testing is to identify and measure pipeline anomalies such as pitting corrosion and to assess the extent of general pipeline corrosion. The following tools and techniques are used at this phase of the assessment and may be employed as a combination of tools:

- Pitting Depth Measurement;
- Visual Inspections;
- Electromagnetic Inspection (magnetic flux leakage, remote field eddy current, broadband EM, pulsed eddy current, ground penetrating radar and ultra-wideband pulsed radar);
- Ultrasonic Testing (guided wave, continuous measure, discrete measure, phased array, combination UT and seismic pulse echo); and
- Radiographic Testing.

In high risk pipelines and pipelines where the consequence of failure is high, in-line inspection tools such as intelligent pigs may be employed. The results of such an inspection is not a representative sample, but rather an accurate representation of the entire pipeline. The relative cost of in-line inspections is currently extremely high and these tools are not commonly employed on water pipelines. This technology is however developing and may be more accessible in the near future. Additionally the pipeline may require extensive internal cleaning and retro-fitting to be "piggable" prior to the inspection in addition to the already expensive implementation of in-line inspections.

## Condition assessment post processing

Once all the field investigations and detailed pipe integrity assessments are complete the structural integrity of the pipeline based on the areas of highest failure risk can be assessed. The information obtained in the field investigations is assessed using Physical/Mechanistic Models and/or Statistical/Empirical Models. The following pipe wall assessments based on the actual wall thickness and pits measured during the detailed pipeline integrity assessments are performed:

- Resistance to hoop stress;
- Resistance to buckling;
- Assessment of mechanical damage (dents and gouges);

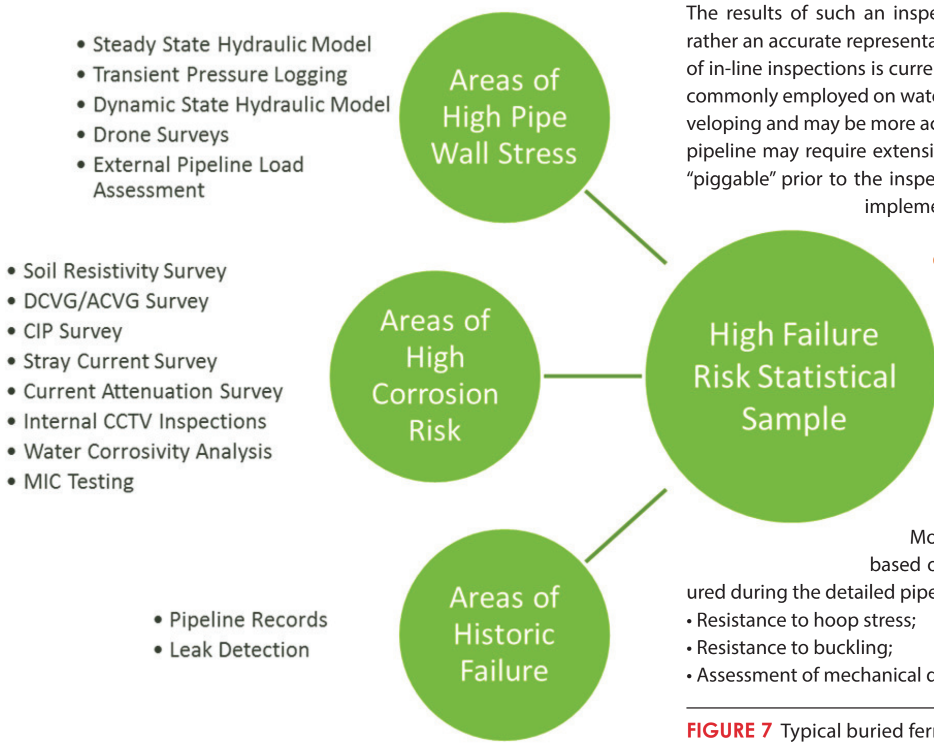



**FIGURE 7** Typical buried ferrous pipeline field investigation approach

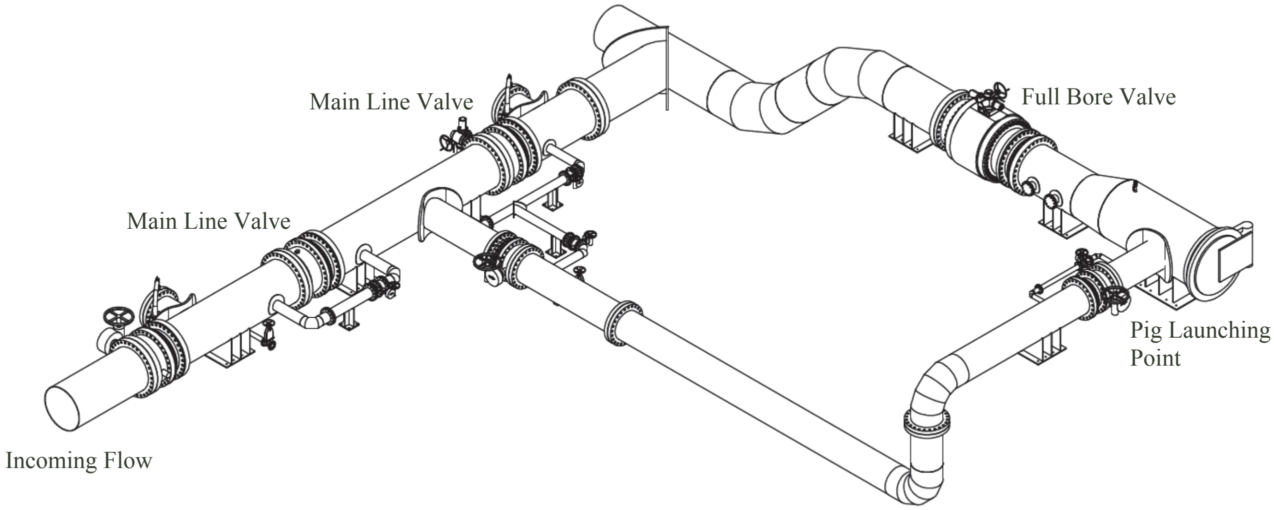



**FIGURE 8** Pig launching station example

- Assessment of corrosion defects;
- Calculation of estimated remaining service life; and
- Probability of failure calculated with various models.
- Based on the structural integrity of the pipe wall, the overall condition of the pipeline's accessories and the estimated or measured corrosion rates, the pipeline asset management plan including recommendations for refurbishment, repairs or replacement can be compiled or updated in line with the principles of proactive pipeline asset management illustrated in Figure 2.

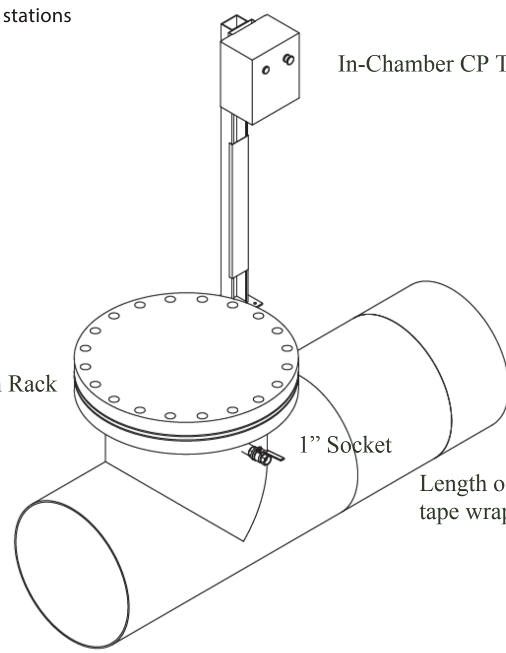
## DESIGN FOR CONDITION ASSESSMENT

The future design of pipelines should be completed in a manner where more of the available inspection tools and techniques can readily be employed on the pipeline, thereby improving the accuracy of the pipeline condition assessment and the efficiency of the pipeline's asset management over its service life.

Together with the rapid development in technology and the realisation of some of these developments in the pipeline inspection tool kit, it is recommended to construct bulk water pipelines and more specifically ferrous bulk water pipelines to be "piggable". It is firmly believed that these technologies will become more accessible in the near future. The following changes and additions to traditional pipeline designs are required to make the pipeline "piggable":

- Custom designed and installed pig launching and receiving stations;
- Full bore isolation valves (i.e. gate valves and ball valves in lieu of butterfly valves);
- Long radius pipeline bends;
- Guide bars at air valve tees, off-takes and access points; and
- No pipeline restrictions such as reducers, reduced diameters and non-return valves.

**FIGURE 9** Integrated pipeline monitoring stations



An example of a recent design of a pig launching station on a bulk water pipeline is provided in Figure 8.

Together with the design of the pipeline to be "piggable", pipeline access points with a nominal spacing in the range of 600 m is recommended (until the newer long range CCTV inspection tools become more readily available in South Africa) and pipeline monitoring stations are also recommended to be included in the design. These pipeline monitoring stations are recommended to have the following components integrated into a pipeline access chamber:

- Internal corrosion coupons;
- An uncoated pipe length wrapped with a petrolatum tape that can be readily removed and reinstated to allow for detailed inspection of the pipe wall integrity, utilising test methods such as ultrasonic pipe wall measurements (i.e. internal corrosion measurements);
- Quarter inch to one inch sockets with isolating valves for the installation of pressure gauges and pressure transducers; and
- In-chamber cathodic protection test posts with electrical connection to the pipeline or coupons outside of the chamber.

The design of such a chamber is illustrated in Figure 9. The spacing and number of these monitoring stations is dependent on the length of the pipeline and impact of pipeline failure (i.e. pipeline importance).

## CONCLUSION

Effective pipeline asset management can only take place if there is adequate and accurate data on which to base decisions. The condition assessment of a pipeline provides this data during the maintenance, operation, rehabilitation and extension phases of the asset's service life.

To accurately assess a pipeline is a challenging task whereby a representative sample of the high failure risk areas are identified and assessed in detail. In order to identify these high risk areas various field investigations utilising a combination of pipeline inspection tools and techniques are required. There is however a myriad of pipeline inspection tools and techniques, not all of which are applicable to every pipeline. A phased approach is therefore recommended, consisting of four phases, namely: a desktop study and preliminary investigations, field investigations, detailed pipe integrity assessments and condition assessment post processing. Each of the phases provides direction to the next phase in terms of the selection of the appropriate condition assessment tools and techniques from the various options available. Furthermore it is recommended to structure the project where the desktop study and preliminary investigations can be conducted on a bulk main or water supply system independently of the further phases in order to correctly define the scope and methodology of the remainder of the condition assessment.

Additionally, a number of pipeline design changes and additions are recommended to allow for simpler implementation of future pipeline condition assessments. These changes and additions include: designing the pipeline to be "piggable", providing access points every 600 m and providing pipeline monitoring stations.

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## LAND OF THE RISING YOUNG ENGINEERS

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## ABSTRACT

In September 2015, five young Municipal Engineers were awarded a scholarship to Japan to learn about Japanese technology and their approach to water and wastewater engineering solutions. The Scholarship was a partnership between the South African Department of Science and Technology and Hitachi Ltd. The trainees spent two months in Japan and visited numerous sites across the country. The goal of the scholarship was to impart Japanese knowledge and experience onto the South African Engineers, which they would bring home to help build technical capacity in South Africa.

The major gains in experience were not in learning about radical new technology, but rather in exposure to successful implementation of these technologies on a large scale. Innovative approaches to problem solving were shared by fellow engineers who are developing products to tackle the municipal engineering challenges faced throughout the world. It was also fascinating to live in a city that services 18 million people every day with little to no service interruptions and a Non-Revenue Water (NRW) percentage of 2.5%.