water
NEW ZEALAND
The New Zealand Water & Wastes Association Waiora Aotearoa

WATER NEW ZEALAND
Good Practice Guide

NATIONAL ASBESTOS CEMENT PRESSURE PIPE MANUAL

Volume Two

TECHNICAL/SUPPORTING DATA

Second Edition | February 2017

Contents

1   INTRODUCTION

This volume provides a detailed understanding of asbestos cement (AC) condition assessment, highlighting the advantages and limitations of the techniques, assumptions made and provides background and supporting documentation to the User Guides presented in Volume 1.

This volume contains the following sections:

- Asbestos Cement Pipe Deterioration
- Asbestos Cement Pipe Condition Assessment
- Lifetime Prediction Modelling and Charts
- Condition Grading and Charts
- Glossary of Terms and Abbreviations
- Reference Tables

2   ASBESTOS CEMENT PIPE DETERIORATION

2.1   Introduction

The depth of deterioration has been measured on 879 AC pipe condition assessment samples over the last 13 years.

The original Master Database and Lifetime Prediction Model was maintained by Opus on behalf of NZWWA (now Water New Zealand [Water NZ]). Opus continued to add data on NZWWA's behalf until this arrangement stopped in ≈ 2003. However, Opus has maintained and developed its own version of the database since 2003.

2.2   Deterioration Sequence

The lifetime predictions calculated by the Lifetime Prediction Model are based on the rate of deterioration of the pipe wall matrix being linear throughout the life of the pipe. The assumed deterioration sequence is described schematically in Figure 2-1 from a). to c).
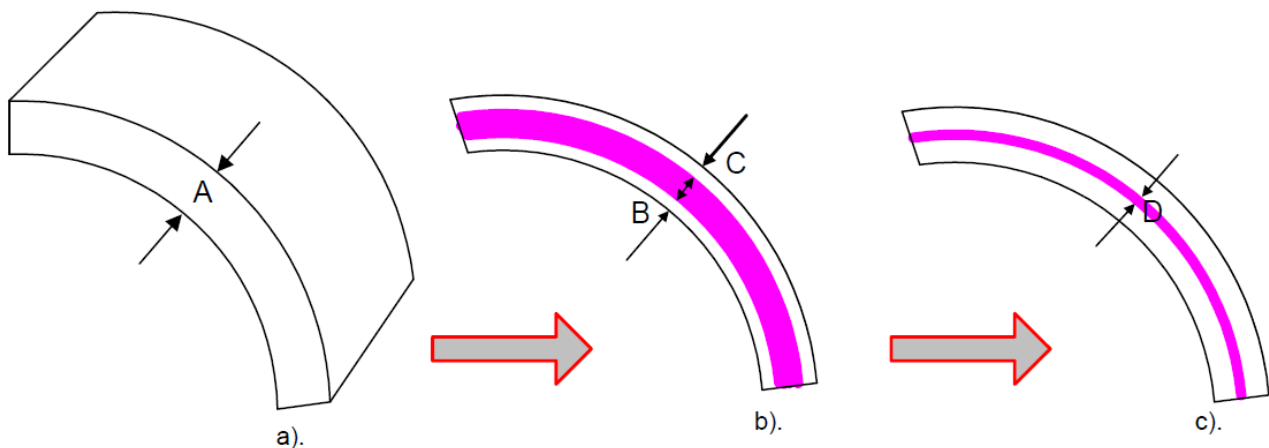
Figure 2-1 Assumed Deterioration Sequence

a) When the pipe is first laid it is assumed that there has been no deterioration of the wall, i.e. the full wall is undeteriorated (dimension A)[1].

b) When a condition assessment is conducted during a pipe's lifetime, the internal deterioration (dimension B) and the external deterioration (dimension C) are measured and combined to give the TOTAL pipe deterioration.

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[1] *This assumption cannot be made if pipe had been stored for an extended period in an area exposed to rainfall. Soft rainwater has been found to be relatively aggressive to asbestos cement pipes stored without cover.*

c) The end-of-life of an AC pipe is assumed to be the point in time when the thickness of undeteriorated pipe wall equals the "theoretical minimum undeteriorated wall thickness" (dimension D). This minimum thickness is calculated from pipe material properties, dimensions and operating pressure, using the Barlow equation.

The year that this wall thickness is predicted to be reached is calculated using the individual pipe or core sample deterioration rate calculated at the time of assessment.

2.3 Factors Influencing Deterioration of Asbestos Cement Pipes

Asbestos cement pipe production ceased in 1986 in New Zealand and Australia. Most pipes have now been in service for at least 30 years with the oldest confirmed NZ pipes in service for almost 80 years.

Many AC pipes in NZ have been bedded and backfilled with native soils often containing stones up to 80 mm diameter as this was considered standard practice for many pipelines, especially rural water supply schemes installed during the 1970's and 1980's.

There has been a perception that the later (since 1959) steam cured pipes deteriorate at a slower rate than the earlier water cured pipes but from Opus experience (supported by the Interim report Asbestos Cement Pipe Corrosion[2]) there is no marked difference in the rate of deterioration.

2.3.1 Practical Experience and Observations

Opus experience over the last 25 years has shown that AC pipes laid in high resistivity (dry, usually coarse grained and free draining) soils generally exhibit minimal external deterioration.

However, AC pipes that have been laid in heavy clays, organic, peaty, acid sulphate soils or in areas that are subjected to a high or fluctuating groundwater levels usually exhibit significant external deterioration.

Figure 2-2 has been adapted from a CIRIA Report[3]. It shows the relative aggressiveness of soils typically found in pipeline trenches and as pipe bedding.

Grain Size Criteria	Aggressiveness (Low to High)
Gravelly soils	
Sand	
Silt	INCREASING AGGRESSIVENESS
Clay	
Peat & other Organic soils	
Aggressive fill or contaminated materials	

Figure 2-2 Relative Aggressiveness of Soils[4]

2.3.2 Principal Influences on Soil Corrosiveness to Asbestos Cement Pipes

If soil and bedding sampling is undertaken, the four parameters shown in Table 2-1 could be measured.

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[2] *Interim Report – Asbestos Cement Pipe Corrosion – Water Corporation 1998 – Ben Jarvis.*
[3] *CIRIA Report 98.*
[4] *Adapted from section 8.1 of CIRIA Report 98 - 1983 – Material Durability in Aggressive Ground – D L Barry.*

Table 2-1 – Principle Parameters that Influence Natural Soil Corrosiveness

Principal Parameters	Effect
Resistivity	Resistivity is considered to be one of the most important parameters when assessing the corrosivity potential of a soil. Soils with low resistivity are considered to be highly corrosive. Soils with high resistivity are deemed to be virtually non-corrosive, although other soil parameters may contribute towards corrosion potential.
Moisture Content	Clay and organic rich soils have higher moisture contents than most other soils. Soils of higher moisture content are also likely to have higher concentrations of mobile ions and a lower pH than other soils.
pH Value	In general, as the pH decreases, corrosion rates increase, however, the pH value, in itself, is a poor indicator of aggressiveness.
Sulphates	Sulphates in solution react with cement. The reactions can produce a larger volume which can induce swelling (cracking) and delamination.

Analytical data on soils do not, in themselves, define potential corrosiveness because there can be numerous physical and chemical factors that combine to create the overall potential problem. There can be large variations in soil types along any pipeline and reasonably large numbers of sampling sites would be needed to obtain a reliable assessment of corrosiveness potential.

CT scanning of pipe samples shows in great detail the variation in deterioration depth around the pipe samples circumference as well as along its length[5].

Soil sampling is not considered to be necessary for condition assessments as the results of the soil and bedding environment are plainly evident on the pipe exterior e.g. softening of the surface and depth of deterioration.

2.3.3 Water Quality and How it Influences Deterioration of AC Pipes

International experience with AC pipes shows that the deterioration / corrosion processes is complex and the current state of knowledge is still quite limited[6].

The Aggressivity Index[7] (AI, related to the Langelier Saturation Index) is a measure of the corrosivity of the reticulated water and is frequently used to indicate its relative aggressiveness towards AC pipes, however, as yet there is no way of reliably predicting the long term effects of the reticulated water on the pipe wall.

Bruelow et al[8], reported that the AI of the water cannot be used as a predictor of fibre release or even surface deterioration as water constituents including iron, magnesium and silica are likely to be as important to the surface life of AC pipe as simple calcium carbonate equilibria models.

The variation of internal deterioration around the circumference of uncoated AC pipe (as determined in great detail by CT scanning) is generally a lot less than that observed on the pipe exterior. While there is some variation in the internal deterioration depth, an average range of less than 1 mm has been found on water supply pipes.

There can be a significantly greater variation in the internal deterioration of wastewater pressure mains due to H_2S attack.

It should be noted that the bitumen dipped pipes exhibit wide variations in deterioration depth both externally and internally.

Pipe sampling and condition assessment provides a real measure of the effects of the soil environment and reticulated water (or sewage) on AC pipe samples. The measured deterioration depth is used in the Lifetime Prediction Model to estimate the AC pipes remaining life.

The cost of soil sampling and water quality investigations (that are often inconclusive) may be more effectively spent on obtaining additional pipe samples for condition assessment.

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[5] A New Development in Asbestos Cement Pipe Condition Assessment Black et al – NZWWA Conference 2007.
[6] WRF Report #4480 – Development of an Effective Management Strategy for Asbestos Cement Pipe – 2015, Chapter 7.
[7] ASTM C 500 – 98 Standard Test Methods for Asbestos-Cement Pipe.
[8] Bruelow et al - The behaviour of Asbestos Cement Pipe under Various Water Quality Conditions, Journal AWWA – 1980.

2.4 National Deterioration Rates – Water Supply Pressure Mains

The 2001 Lifetime Prediction Model used ≈240 watermain pipe samples from DN 50 to DN 300. The average combined deterioration rate was calculated using only those pipe samples that were within the 85th percentile (i.e. 15% of the samples were considered to be "outlier" values and were rejected). These rejections were mainly due to the perception of unreliable installation dates (where water authorities used a default age value which was often incorrect).

Since 2003, a further 790 AC watermain condition assessments have been undertaken by Opus on behalf of water authorities from the Far North to Invercargill City. The results of these assessments have been analysed to calculate a combined (external and internal) average deterioration rate as well as external and internal average deterioration rates.

Since 2007, deterioration depth measurements have been based mainly on CT Scanning.

The original 240 condition assessment deterioration results have been excluded from the latest revision as a significant proportion were considered to be in error (15%).

Table 2-2 summarises the deterioration data as well as the average deterioration rates from 2003 - 2016.

Table 2-2 – Watermain Average Deterioration Rates 2003 to 2016

AC Watermains Average Deterioration Rates	
Pipe Sample Recovery Period	2003 - 2016
Number of Pipe Samples	790[9]
Average External. Det'n Rate (2016)	0.1114 mm / yr
Average Internal. Det'n Rate (2016)	0.1230 mm / yr
Average Combined Det'n Rate (2016)	0.2344 mm / yr
Average Combined Det'n Rate (2001 ≈ 240 samples)	0.2269 mm / yr

The combined average deterioration rate is approximately 3%[10] (0.0075 mm/yr) faster than the 2001 value.

This higher deterioration rate is attributed to a combination of:

- Improvements in data collection, including more reliable installation dates.
- A significantly larger number of pipe and core samples.
- CT Scanning (which locates greater maximum deterioration than the phenolphthalein method).

It is worth noting that WRF Report #4480 (Fig. 1-4) reported an average "corrosion" rate (from phenolphthalein stain tests on a significantly smaller number of AC pipes) of 0.0085" / year[11] (0.216 mm/yr) which is within 8 % of the average of our 790 samples.

2.4.1 External, Internal and Combined Deterioration

The external, internal and combined deterioration depths have been plotted against pipe age in Figure 2-3 to Figure 2-5.

The trend lines in Figure 2-3 to Figure 2-5 show the correlation between pipe age and deterioration.

However, the coefficients of deterioration (R^2) are low to very low, 0.039 for external, 0.242 for internal and 0.215 for combined deterioration. These results indicate that the exterior deterioration is significantly more variable than the interior deterioration which is caused by drinking water.

It is clear that using the national average deterioration rate for estimating pipe condition could lead to significant under or over estimation and hence remaining life.

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[9] *AC watermain condition assessments carried out by Opus for water authorities across New Zealand.*
[10] *3% increase in the national average deterioration rate, a DN 150 Class C AC pipe operating at 90 m head would have an estimated life of ~ 44 years, compared to that of ~ 46 years based on the 2001 national average deterioration rate).*
[11] *Water Research Foundation; Report #4480:2015, Development of an Effective Management Strategy for AC pipe – Chapter 1.*

AC Water Supply Pipes - External Deterioration

Det'n Depth = 0.1114 x Age
R² = 0.0399
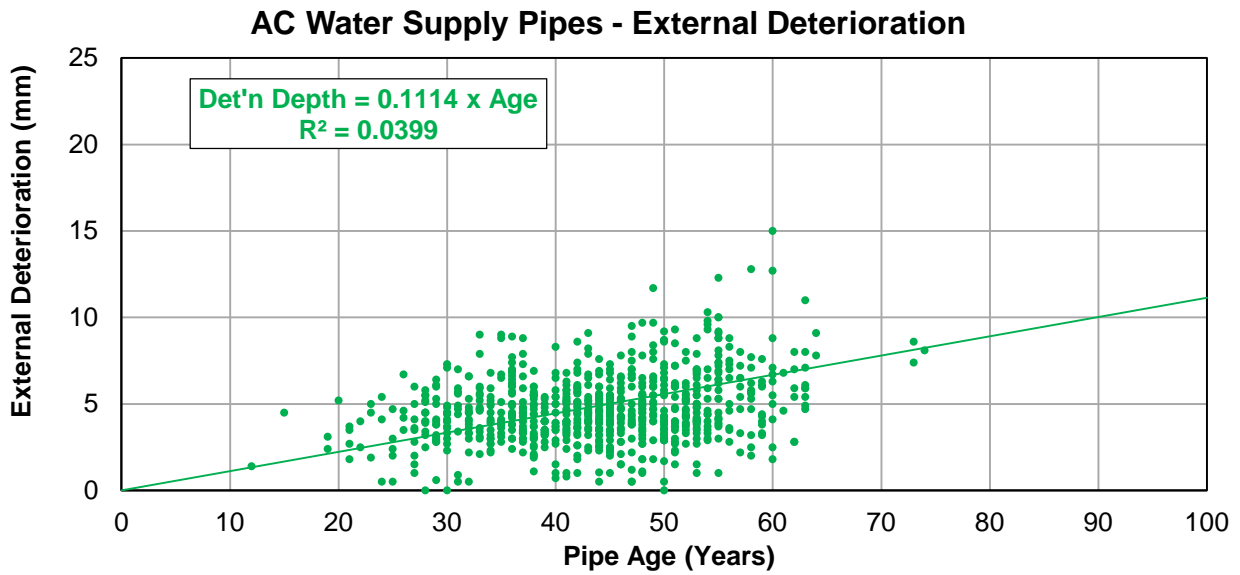
Figure 2-3 Water Supply External Deterioration Depth vs Age

AC Water Supply Pipes - Internal Deterioration

Det'n Depth = 0.1230 x Age
R² = 0.242
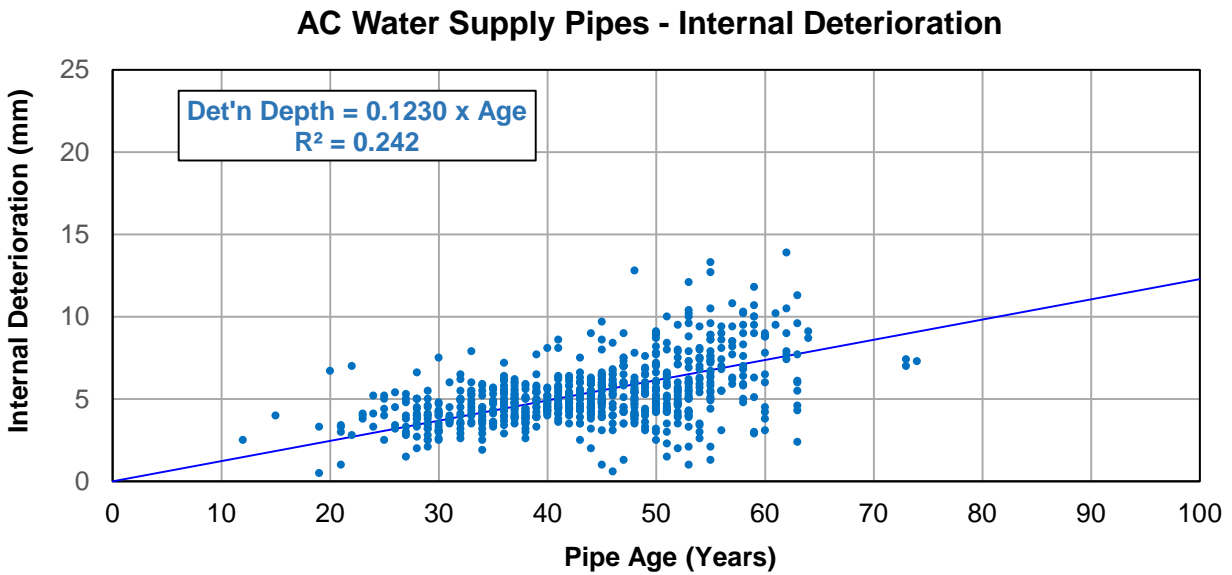
Figure 2-4 Water Supply Internal Deterioration Depth vs Age

AC Water Supply Pipes - Combined Deterioration

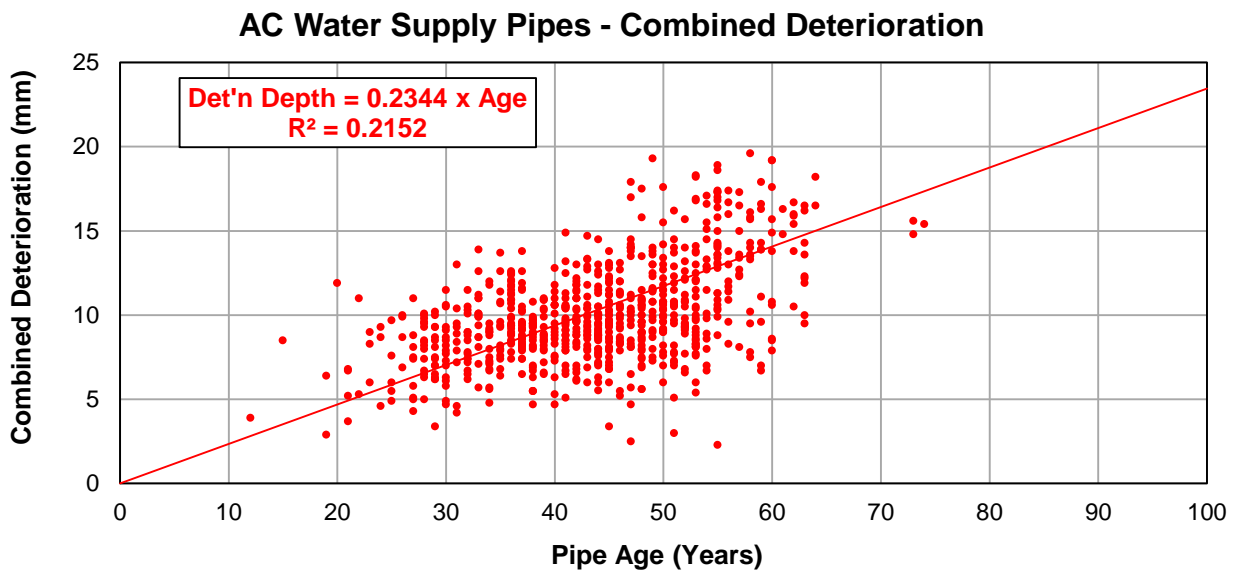Det'n Depth = 0.2344 x Age
R² = 0.2152

Figure 2-5 Water Supply Combined Deterioration Depth vs Age

2.5 National Deterioration Rates – Wastewater Pressure Mains

As part of this 2016 update, wastewater pressure mains condition assessment data has been included.

The results from 89 wastewater pressure pipe condition assessments have been analysed to calculate the external, internal and combined average deterioration rates.

Table 2-3 summarises the wastewater pressure main deterioration data.

Since 2007 the deterioration depth measurements have been mainly based on CT Scanning.

2.5.1 External, Internal and Combined Deterioration

The external, internal and combined deterioration depths have been plotted against pipe age in Figure 2-6 to Figure 2-8.

The trend lines in Figure 2-6 to Figure 2-8 show the correlation between pipe age and deterioration.

However, the coefficients of deterioration (R^2) are low to very low, 0.223 for external, 0.071 for internal and 0.141 for combined deterioration.

Table 2-3 – Wastewater Pressure Mains Deterioration Rates 2003 to 2016

AC Wastewater Pressure Mains Average Deterioration Rates	
Pipe Sample Recovery Period	2003 to 2016
Number of Pipe Samples	89[12]
Average External Det'n Rate (2016)	0.1390 mm / yr
Average Internal Det'n Rate (2016)	0.2072 mm / yr
Average Combined Det'n Rate (2016)	0.3462 mm / yr

The average external deterioration rate is ≂20% greater than for watermains (not unexpected as wastewater pressure mains are generally buried deeper than watermains and as such can be expected to be more influenced by the presence of groundwater. However, the internal deterioration rate is 70% greater than for watermains, which indicates that wastewater is significantly more aggressive than drinking water.

AC Wastewater Pressure Pipes - External Deterioration

Det'n Depth = 0.1390 x Age
R^2 = 0.223

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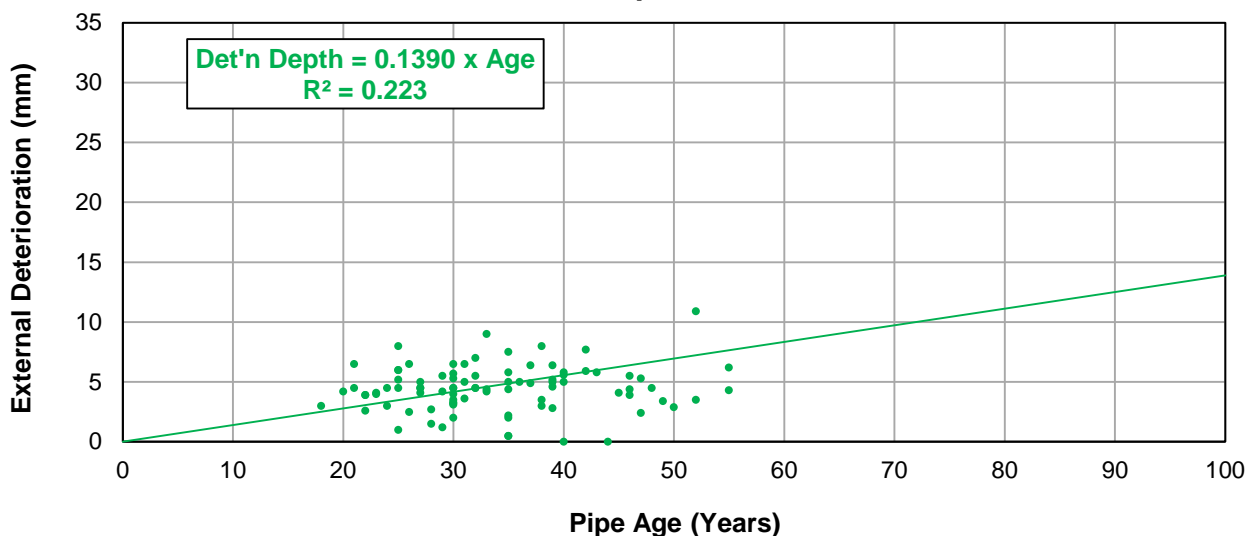
[12] AC Wastewater pressure pipe condition assessment's carried out by Opus for water authorities across New Zealand.

Figure 2-6 Wastewater External Deterioration Depth vs Age

AC Wastewater Pressure Pipes - Internal Deterioration

Det'n Depth = 0.2072 x Age
R² = 0.0711

Internal Deterioration (mm) vs Pipe Age (Years)
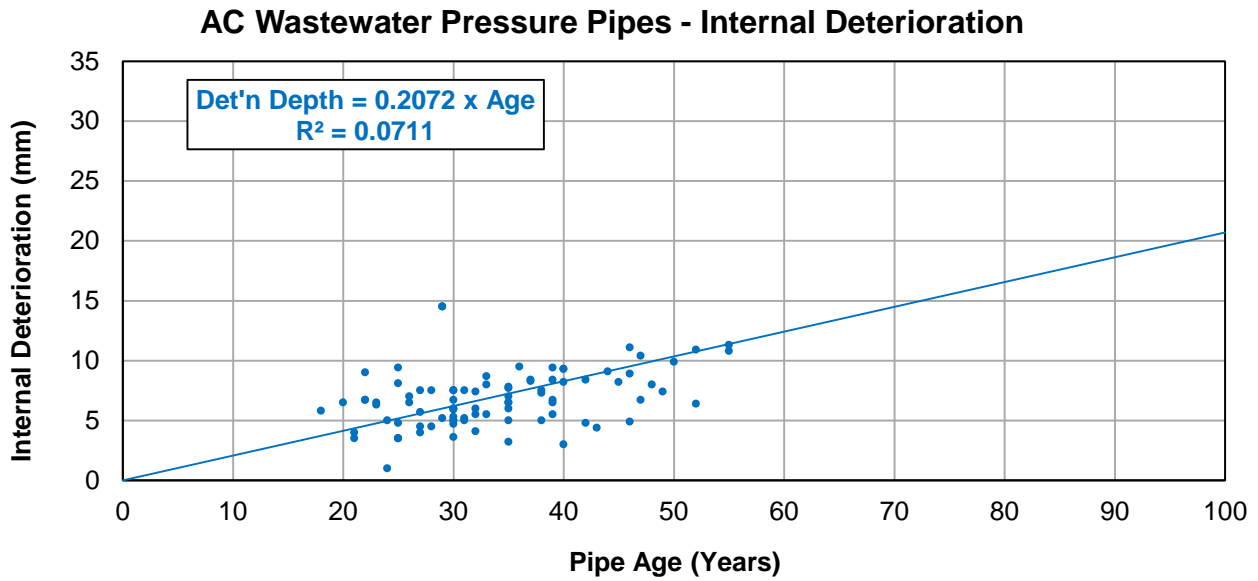
Figure 2-7 Wastewater Internal Deterioration Depth vs Age

AC Wastewater Pressure Pipes - Combined Deterioration

Det'n Depth = 0.3462 x Age
R² = 0.141

Combined Deterioration (mm) vs Pipe Age (Years)
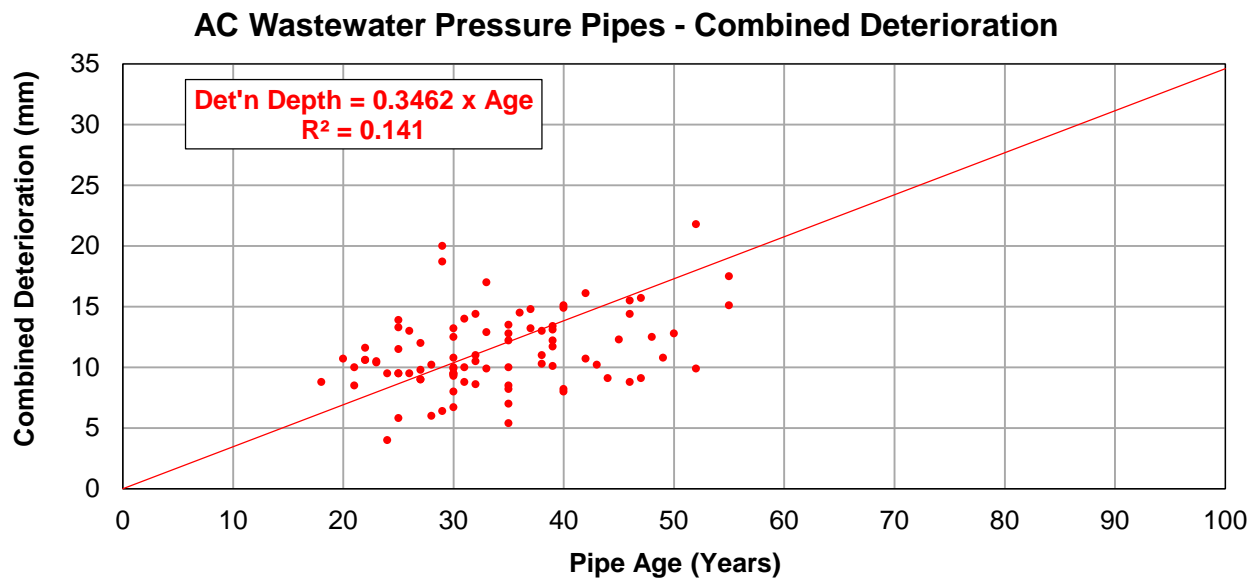
Figure 2-8 Wastewater Combined Deterioration Depth vs Age

To date, no pipe or core samples have been assessed from stormwater pressure mains. It is recommended that for stormwater pipes, Figure 2-5 is used.

2.6   Why Sample Deterioration Rates can differ from National Average

Significant differences in the deterioration rates from the national average can be due various conditions and influences. Table 2-4 provides some examples.

Table 2-4 – Causes for Differences from the National Average Deterioration Rate

Internal Deterioration		External Deterioration
Water Supply	**Wastewater**	
Aggressive (or benign) reticulated water	Aggressive (or benign) effluent	Aggressive (or benign) pipe environment (ground water / soil).
Factory applied bitumen coating (slows deterioration but can be highly variable)	Hydrogen Sulphide Attack	Extended unprotected pipe storage (exposed to the elements[13])
	Factory applied bitumen coating (slows deterioration but can be highly variable)	Factory applied bitumen coating (slows deterioration)
• Earlier manufacturing (typically pre 1960) pipes where often bitumen dipped. The coating and lining is usually inconsistent in thickness (and quality) along the length of a pipe.		
• Manufacturing tolerances allowed for a substantial variance in the wall thickness.		
• Incorrect installation year (sometimes GIS records use a default year) e.g. GIS = 1976, Actual = 1963. Therefore the average deterioration rate changes from 0.3106 mm / yr to 0.2344mm / yr.		
• The pipe sample may not represent the condition of the whole pipeline. I.e. it may have been taken from a section of pipe that has been used for repairs to a pipe burst or installed as part of a new connection (this has been found on several occasions).		

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[13] *Rainwater has been found to be aggressive to the cement in AC pipes that were stored in stacks (without protection from the elements) and the exterior deterioration rates can exceed the average for buried pipes.*

3   ASBESTOS CEMENT PIPE CONDITION ASSESSMENT

3.1   Pipe and Core Sampling

This section is aimed at achieving consistency of pipe and core sample recovery across the water industry.

The pipe sample recovery contractor is responsible for preparing and implementing appropriate Health and Safety Plan(s), road opening notices (working in a road corridor), obtaining consents etc. for any physical works.

Obtaining wherever possible, the pipe or core sample should be representative of the in-situ condition of the pipe.

Refer to Section 5 of Volume 1 for the Health and Safety requirements, notably Section 5.7 for safe working practices, when planning and undertaking any work with or near AC pipes.

Site Preparation & Excavation

Prior to the commencement of excavation, contact all other utilities and service providers to determine if there are other services in the area and ensure they are marked out and protected during the work.

Notify consumers of the impending shut down or reduction in service in accordance with the asset owner's standard procedures.

Ensure that all plant, machinery and equipment, including appropriate pipe fittings that are dimensionally compliant with the in-ground pipe, etc. are on site before commencing work.

Carry out all work in accordance with the contractor's and asset owner's established policies and procedures and those of other controlling authorities e.g. NZTA, as appropriate.

Carry out the excavation in a safe manner in accordance with the contractor's approved Health and Safety Plan and the approved code of practice for safety in excavations and shafts for foundations.

Figure 3-1 Shows a Well-Planned Excavation

During excavation, take care in exposing the pipe, so the pipe bedding can be observed and recorded, the presence of rocks or other deleterious materials and / or voids under the pipe can be observed and photographed.

In the event of recovering a pipe sample following a pipe break / burst event, follow the asset owner's procedures for an emergency shutdown and isolate the pipeline. Pipe burst events will usually wash out the native soil and bedding material.

3.2   Observations and Recording Data

Once the pipeline is exposed and before removing the pipe or core sample, carry out the following preparation work:

- Carefully wet clean the pipe exterior, taking care to avoid damaging the pipe or removing any softened asbestos cement.
- Examine the exposed pipe and record:
    - o   Details of any external coating e.g. bitumen or a PE sleeve.
    - o   Any manufacturer's markings (take a sharply focused photograph).
    - o   Any damage to the pipe e.g. gouging or scoring and comment whether this damage is likely to have occurred during the current works or if it happened earlier.
- When a full section of pipe is recovered for assessment, mark the top of pipe "as laid" before cutting the pipe. Use a paint spray can / dazzle or if the pipe is wet, use a wax crayon, alternatively, a small hole, 5 – 6 mm diameter can be bored in the top of the pipe.
- For a core sample, note the location (clock face) where the core sample is recovered from, as viewed in the principal direction of flow (if known, or record the assumed direction of flow).
- Take a photograph of the exposed pipe, refer to Section 3.8, Table 3.4 of Volume 1.
- Record the GPS co-ordinates of the pipe or core sample location.
- Record any other features that may be present (such as leakage, scouring of the pipe wall, joint type, etc.).
- Measure depth of cover.
- Measure depth to ground water level (if present).
- Mark the location for cutting the pipe (if taking a full sample) or, fit a stainless steel off-take clamp or tapping band[14] (refer to Figure 3-2) in preparation for the recovery of a core sample.
- Collect a representative sample of pipe bedding (≅2 handfuls), seal it in a plastic bag so it retains the in-situ moisture content.
- Write the bedding sample site description on the bag with a permanent marker and where it was recovered from, e.g. under pipe, haunching, top of pipe, etc.
- Turn off the water supply and / or pumps and ensure the pipeline has been isolated and drained before cutting into the pipe. Core samples can be recovered from an operating pipeline using under pressure tapping equipment (Section 5, Table 5-4 of Volume 1).

3.3   Recording Pipe Sample Data

Pipe Sample Recovery Report Form

Complete a pipe sample recovery report form for each pipe or core sample. The essential information needed for a condition assessment is:

- Location / asset ID / pipe purpose
- Year installed
- Year sample recovered
- Operating pressure
- Pipe OD
- Pipe ID
- Minimum wall thickness

The form should be completed in as much detail as possible by the contractor. Any relevant data that is not readily available to the contractor is to be provided by the asset owner, e.g. year installed (as determined from as-built records, building permits, subdivision records, contract documentation or local knowledge etc.) and the maximum operating pressure, (e.g. a pressure log recorded at 1 second intervals).

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[14] *When recovering a core sample and the risk of pipe failure is unacceptably high, a stainless steel off-take clamp is strongly recommended (instead of a tapping band) as this can be fitted to cover any notches used for exterior deterioration measurements. Also if the pipe fractures axially at the core sample point, the clamp will prevent leakage.*

A copy of the completed form should be photographed and the hard copy sealed in a plastic bag. The asset owner should also retain a copy.

Examples of pipe sample recovery report forms are presented in Appendix A1 and A2.

3.4   In-situ Condition Assessment

A site specific Health & Safety Plan for in-situ condition assessment is necessary. Only appropriately trained, competent and experienced personnel with full PPE may enter the work area.

Level 2 condition assessment testing of in-service pipes is possible (or Level 3 if an under pressure core sample is recovered). Once the pipe has been exposed, cleaned, photographed and the OD measured and recorded, the exterior can be assessed in-situ by any of the following methods.

Note that an exposed pipe joint can identify the pipe manufacturer and the approximate year of installation, or the likely year of installation if the manufacturer's markings are still visible, assuming that the pipe was installed in the year of manufacture (most were).

Level 2 Assessment Methods

Exterior Deterioration and Softening

Deterioration of AC pipes results in softening of the surface. The degree of softening can vary around the circumference and in extreme cases the surface can be very soft and fibrous, not dissimilar to wet cardboard.

A sharp metal probe (e.g. a bradawl) can be used to penetrate the pipe wall to the maximum possible with hand impact. The depth of deterioration is roughly equal to the depth of penetration. Measure the depth of penetration around the pipe circumference (at the crown, underside and sides of the pipe as a minimum).

A notch can be chiselled or filed in the pipe surface (using a sharp knife, file or wood chisel) until undeteriorated AC material is encountered. Ensure appropriate working practice is used (e.g. by spraying and keeping the working area wet) to prevent creating airborne asbestos fibres. Be careful not to cut into the undeteriorated pipe by more than one millimetre.

A colour and hardness change occurs at the deteriorated / undeteriorated interface. The use of phenolphthalein indicator and a magenta colour change is the preferred method to confirm the deteriorated / undeteriorated interface.

The depth of deterioration at the chiselled or filed notch can be measured using callipers fitted with a straight edge or by the method described in Appendix C. At least 4 measurements should be made around the pipe circumference to determine the maximum depth of deterioration (which is usually greatest at the underside of the pipe).

Unless a core or full ring sample is taken, it is not possible to know the pipe wall thickness (needed to determine the pipe pressure class) or to measure the interior deterioration depth.

Without the pipe wall thickness and internal deterioration depth, the assessment confidence level will be reduced. The pipe pressure-class may have been entered in the GIS or asset register, though this has not been common practice and may not be reliable. Alternatively, the default pressure class in this manual can be used (Section 3.2.4, Table 3-1 of Volume 1). The interior deterioration depth can be estimated from previously recovered pipe samples of similar age and transporting similar quality water. Alternatively, the national average internal deterioration rate can be used.

All equipment used in the preparation and assessment of deterioration and softening shall be "controlled equipment", refer to Section 5.8, Tables 5-1 to 5-4 of Volume 1.

3.5   Recovery of Pipe Sample

Pipe samples should generally be between 250 – 350 mm long unless a pipe joint is being recovered or specific testing (e.g. crushing test) is required.

- If a pipe joint has been uncovered, the pipe should be cut approximately 100 – 200 mm each side of the joint and the complete joint recovered for condition assessment.

- If a crush test is required (e.g. > DN 300 pipes which cannot be reliably CT Scanned) the asset owner will advise the contractor. The pipe sample should be cut square to the pipe axis and preferably be between 295 and 305 mm long.

3.6   Recovery of a Core Sample

A core sample can be taken from a pipeline to minimise / eliminate unacceptable disruption to customers which would occur if a full pipe sample were to be taken.

A core sample may reduce the overall risks of recovering a pipe sample and be cost effective, however, it does not provide the same level of confidence as a full pipe sample. However, when combined with multiple exterior deterioration depth measurements it will usually give an acceptable indication of the pipe deterioration for condition assessment.

Provided the core sample has not delaminated at the interior, the core thickness and the interior deterioration depth can be measured. The core (wall) thickness can be used to calculate the pipe ID (pipe OD – 2 x core thickness = pipe ID). This can be checked against the manufacturing standard and the pipe pressure-class determined. The deterioration depth measured at the core interior can be taken as the average internal deterioration depth as it is relatively constant around the pipe circumference in most water supply pressure pipelines.

The following process, provides guidance for recovery of a core sample:

- Carefully clean the pipe exterior to remove any native soil, bedding material or other debris. Take care not to damage the surface of a softened pipe or to remove any manufacturer's markings that may still be visible.
- Accurately measure and record the circumference (OD) of the pipe barrel to the nearest 0.5 mm preferably using a diameter tape (π tape). The pipe circumference can be measured with a flat steel tape and the OD calculated by dividing by π. The pipe OD is particularly important when recovering a core sample.
- Core samples should (preferably) be at least 40 mm in diameter. Care is required to avoid causing the core to delaminate during recovery.
  Note that core samples can fall out of the hole saw and be lost inside the pipe, the risk of this happening can be minimised by fixing the take-off clamp or tapping band horizontally or at 45° (see Figure 3-2).

Figure 3-2 Recovery of an AC Core Sample

Handling, Temporary Storage and Transportation Guidance

The following steps are related to recovery of pipe or core samples that have to be transported for condition assessment (e.g. to a safe handling facility).

- Pipe samples do not need to be completely cleaned as the pipe OD will be measured accurately off-site and small amounts of native soil or bedding material adhering to the pipe sample can be useful.

- Wastewater pipe samples should be carefully washed and disinfected in a solution of chlorine bleach for a period of 2 hours before preparing for measurement (depending on the safety protocols adopted by the off-site assessors). A suitable disinfecting solution can be made by mixing 200 ml of household bleach into 10 litres of water.

- Prior to placing the pipe (and bagged and labelled soil sample) in a heavy plastic bag (at least 120 µm thickness) and sealing with tape to maintain in-situ moisture, remove any sharp edges on the pipe sample and use bubble wrap to avoid puncturing the plastic bags during transport and handling.

- Attach an asbestos warning label, see Appendix D for examples (these images can be copied and printed on sticky labels).

- Make sure that any small tears or punctures in the plastic bag are repaired with duct or packaging tape to maintain the seal.

- If the bag is torn, either replace it or add another bag.

- Place the first bag inside a second bag and include the completed (and bagged) pipe sample recovery report form before sealing the second bag.

- Write the pipe or core sample location on the outer plastic bag with a permanent marker pen.

- Attach a second asbestos warning label if the second bag is not clear plastic or the previously attached warning label is not easily visible.

- Pipe samples can be transported individually wrapped in corrugated cardboard (to protect the plastic wrapping from damage) or several can be enclosed inside cardboard boxes or in a wooden packing crate.

- Custom made crates can be used but the total weight for such crates should not exceed 80 kg (two man lift).

- It is not necessary to attach asbestos warning labels to the outer packaging as the AC pipe samples are securely double wrapped and if the outer packaging does get damaged, there will be adequate warning of the contents

Figure 3-3 A Well Wrapped AC Pipe Sample

This is an example of a well wrapped AC pipe sample. The asbestos warning label is clearly visible as well as the pipe sample recovery report and Asset ID. Note also the bubble wrap at the pipe sample ends.

Section 5.3 of Volume 1 provides guidance regarding Health and Safety and Asbestos Management plans for working with ACMs.

3.7   Recovered Pipe Sample – Inspection and Condition Assessment

Recovered pipe and core samples can only be opened and assessed in a safe handling facility for AC pipes (the facility).

Asbestos Cement Pipe Safe Handling Facility

A purpose built facility, complying with all Health and Safety requirements requires at least the following:

- Controlled equipment to undertake wet cutting of AC pipes (alternatively this part of the process can be out-sourced to a suitability qualified contractor with appropriate controlled equipment and health and safety procedures).
- Three compartments:
    o Clean change room – where personnel change into disposable overalls prior to moving through the dirty change room into the work area.
    o Dirty change room – where personnel remove potentially contaminated overalls after a work session.
    o Workshop room – where pipe inspection, testing and condition assessment is carried out.
- The clean change room can be used to store cleaning products & equipment, heavy plastic bags of various sizes to suit pipes, packaging / duct tape etc.
- The dirty change room and workshop area are likely to have asbestos cement residue and dust, so it is essential that they operate under negative pressure to eliminate the possibility of dust escaping into the environment.
  An industrial extractor fan discharging through a High Efficiency Particulate Air (HEPA) filter is necessary and suitable pressure gauges to monitor any increase in pressure across the filter which will signify clogging.
  Testing of air discharged through the filter is required annually or after approximately 100 pipe or core samples (whichever occurs first).
- To avoid creating dust when cleaning the facilities floors, only wet mopping is acceptable.

Health & Safety

A site specific Health and Safety and Asbestos Management Plan for the facility is necessary, refer to Sections 5.3.1 and 5.3.2 of Volume 1 respectively.

Only appropriately trained, competent and experienced personnel with full PPE may enter and use the facility.

Contamination

Only unpack double bagged (and sealed) pipe and / or core samples in the workshop room of a facility.

Carefully unwrap the pipe and / or core samples to minimise the likelihood of releasing particles, chips of AC or generating dust. Recover the sealed bedding sample and pipe sample recovery report form.

Place the inner pipe sample bag in a suitable rubbish bag ready for safe disposal when the bag is ½ to ¾ full.

Undamaged outer bags can be recycled and used as the inner bag for further testing or disposed of safely.

Clean all pipes carefully so as not to damage the pipe or release dust. This may require washing to remove all traces of adhered clay.

Disposal of any contaminated wash water should be via a connection to the reticulated wastewater network.

Inspection and Data Recording

The cleaned pipe sample is then carefully inspected, measured, photographed and the results recorded. The key details to be recorded are as shown on the example *"Pipe and Core Sample Inspection Record"* form in Appendix A3.

General comments should include observations such as damage, evidence of delamination, scratches, gouges, splits, blow outs or holes in the pipe wall e.g. direct tapping of service pipes and general comments regarding potential likely cause(s) of the feature(s) photographed.

Pipe Bedding Material Assessment

Reference can be made to the following publications for guidance on identifying soils.

- New Zealand Geotechnical Society's "Field Description of Soil and Rock"
  http://www.nzgs.org/publications/guidelines/soil_and_rock.pdf
- New Zealand Geotechnical Society's "Rock Field Guide Sheet"
  http://www.nzgs.org/Publications/Guidelines/soil_and_rock_field_guide.pdf

Note that some asset owner's pipe bedding specifications required the use of pea or rice gravel, scoria or reject sealing chips. These are not adequately described by the field description of soil and rock for engineering purposes guidelines.

Further Testing or Safe Disposal

Double bag and seal the pipe and / or core samples after inspection, measuring and any testing in the facility has been carried out, before being removed from the facility for further testing (e.g. CT Scanning) or safe disposal.

3.8   Condition Assessment Techniques

To assess the condition of the pipe, determine the maximum depth of both the external and internal deterioration of the pipe wall. The two principal methods of measuring deterioration depth are:

- Applying a phenolphthalein solution (Level 2 and 3 Condition Assessments).
- Computed tomography (CT) scanning (Level 3 Condition Assessment).

In addition to the depth of deterioration, a crushing test may also be undertaken to determine the residual (remaining) strength of the pipe.

Level 2 and 3 condition assessment processes are illustrated in Sections 3.3 and 3.4 of Volume 1 respectively and detail where the various techniques are used.

3.8.1 Phenolphthalein Testing

Phenolphthalein is a chemical powder that is dissolved in alcohol and is mixed with water to produce a colourless liquid that changes to a magenta colour (refer to Figure 3-4) when applied to sound cementitious material that has a pH > 8.3.

Phenolphthalein testing provides a useful method for determining the depth of deterioration of a pipe or core sample. This can be performed in the field by properly trained operatives during planned maintenance and repair works.

This test method may be used on any diameter and pressure class of AC pipe, and is useful where the diameter or wall thickness exceeds the limitations of a CT scanner.

Preparation

In order to achieve reliable results, the phenolphthalein solution needs to be applied on a freshly cut or prepared section of AC pipe.

Appropriate measures need to be taken to minimise the release of fibres during the preparation of the pipe.

Applying Phenolphthalein Solution

Before applying the phenolphthalein solution, ensure the freshly cut or prepared surface is wiped clean of any asbestos cement slurry or dust generated from the preparation process. Failure to clean the surface can result in false deterioration depths being observed and recorded.

The phenolphthalein solution is best applied as a fine spray. To avoid potential running of the solution and migration of any remaining asbestos cement surface dust, the prepared surface should be laid flat and no more spray than necessary applied.

Figure 3-4 Phenolphthalein Solution Applied to a Freshly Cut Pipe Sample End

Deterioration Measurements and Data Collection

Where the phenolphthalein has come in contact with sound cementitious material (>8.3 pH) it will have changed to a magenta colour.

Using digital callipers, measure the depth of deterioration to the nearest 0.1 mm in accordance with the methodology described in Appendix C. On a full pipe cross section the minimum number of deterioration depth measured is six both externally and internally, ensure the maximum deterioration depth is recorded.

With the external and internal deterioration depths measured, a worst case (maximum) deterioration rate (mm / year) can be determined, assuming the year installed is either known or has been reliably estimated.

Once the deterioration depth measurements have been recorded, the pipe or core sample, can be double bagged for CT scanning if the phenolphthalein results are inconclusive, or for a crushing test (pipe only) or for safe disposal once the pipe or core sample is no longer required.

3.8.2 CT Scanning and Analysis

Computed Tomography (CT) Scanning can be used on AC pipe samples up to DN 300 with a wall thickness ≤ 25 mm.

CT Scanning provides the most accurate deterioration depth measurements. A 300 mm long pipe sample, scanned at 2 mm intervals provides ~ 150 cross sectional images for assessment.

This number of cross-sectional images provides the assessor with a greater understanding of the overall deterioration of the pipe wall, compared to the phenolphthalein tests typically applied to each end of the pipe sample (i.e. only two cross-sections).

Background

The 2001 Manual briefly covered radiographic examination of AC pipes using conventional X-ray techniques with photographic plates. This technique was impracticable and has been superseded by CT scanning.

A CT scanner uses X-rays to scan an object in detail (in this case a pipe or core sample). Computer software then produces cross sections of the scanned object as close together as 0.6 mm intervals.

The scanner detects small density changes in the pipe wall which have been found to agree closely with phenolphthalein stain tests, as well as scanning electron microscopy and petrographic analysis.

The depth of deterioration can be measured using the custom software to an accuracy of ± 0.2 mm or less.

These images can be enhanced by software to produce defined boundaries between deteriorated and undeteriorated AC.

Each cross sectional image can be a file of up to 1 MB, so, scanning a pipe sample that is 300 mm long (or more) can generate over 150 MB of data.

A paper on the use of CT scanning was presented at the 2007 NZWWA (now Water NZ) conference.[15]

CT Scan Limitations

CT scanners have limitations and it is recommend to check the scan images to confirm that sufficient detail is being achieved.

- A pipe sample should not be more than 20 Kg in weight, (ideally less than 10 kg from a manual handling perspective).
- Pipe wall thickness should not exceed ~ 25 mm (typically greater than 25 mm is likely to provide noisy images and potentially unreliable / indeterminate results).

CT Scanning

The double bagged pipe sample (or core) with the top "as laid" marked is placed on the CT scanner bed ready for scanning.

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[15] *A New Development in asbestos cement pipe condition assessment, Black, DeRuyter & Morris.*

Figure 3-5 shows some pipe samples loaded on the scanner table prior to being scanned.

Figure 3-5 CT Scanner (Siemens SOMATOM) Loaded with AC Pipe Samples

Deterioration Measurements

Using the scanner software package, run through the scan sequence and select one (or more) of the most deteriorated images to measure in detail. Then measure both external and internal deterioration depths as well as the pipe ID, OD and wall thickness.

3.8.3 Crushing Test

The findings of WRF Report #4480[16] was that "little evidence could be found that [Eastern Bays Municipal Utilities Districts (EBMUD)] breaks were directly correlated to material strengths". This may mean that the results of this test are of limited value.

However, crushing is a simple test that can be used to relate the strength of a recovered pipe sample to the minimum requirement of the contemporary standard (for a new pipe).

It is worth noting that it was common for new pipes to comfortably exceed the standards minimum requirements and the crushing test results can still be greater than that of the standard after many years in service. Pipes that show significant deterioration can still exceed the minimum requirement for a new pipe, which suggests that the crushing strength might be a poor indicator of the pipes in service performance and supports the Report #4480 statement (as above).

However, if the crushing strength of a pipe has reduced to 80% (or less) of the minimum required strength of the contemporary standard, the in-service performance is likely to be seriously compromised. Further study is required to prove this and until confirming information is obtained (which may take some time) crushing tests are only recommended when the pipe is too big or the pipe wall is too thick to be CT scanned.

Preparation

Place the double bagged and sealed pipe sample on a compression machine with the top of pipe "as laid" uppermost (if known).

Crushing Test Method

The crushing test should be carried out in accordance with NZS 3202:1977, Appendix D Crushing Strength Test. Note that the earlier standard (BS 486:1956) crushing test requirements are similar.

Calculate the ultimate crushing strength (MPa) and compare with the minimum requirement for a new pipe as defined in the standard.

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[16] *WRF Report #4480 – Development of an Effective Management Strategy for Asbestos Cement Pipe – 2015,*

3.8.4 Non Destructive Condition Assessment Overview

There are various non-invasive, non-destructive pipe condition assessment methods currently available to Asset Owners such as *"inverse transient analysis"* and *"high resolution acoustic inspection"*.

These methods are promoted as being capable of carrying out pipe condition assessment of pipelines over many km's. To date, only limited results of surveys of this type on AC pipes were available during the preparation of this second edition of the manual. Therefore no comment on their effectiveness has been made.

Until proven otherwise, these technologies should be considered as a first-cut assessment method that may assist the Asset Managers to focus on areas for in-situ or pipe sampling condition assessment methods.

3.9   Safe Disposal

Section 5.9 of Volume 1 refers to the safe disposal of asbestos pipes, PPE and decontamination of the work area.

4   LIFETIME PREDICTION MODEL

4.1   Lifetime Prediction Model

It is strongly recommended that pipe or core sample(s) are recovered for condition assessment from any pipeline programmed for replacement. This will provide a greater level of confidence (based on the pipe samples condition being a typical reflection of the pipeline) than is possible using the charts and "average" deterioration rates.

Sampling of pipelines before replacement can occasionally show that pipes are of different materials or are in better condition than anticipated.

The working database and the Lifetime Prediction Model *http://www.waternz.org.nz/ACManual* uses the individual pipe or core sample appraisal results and the operating pressure to estimate the "time to deterioration failure in years".

*Note: Lifetime Prediction Charts (Section 5) have been produced as part of the Level 1 Condition Assessment, (Section 3.2 of Volume 1) to allow the user to estimate the remaining life[17] of an AC pipeline that has **not been sampled or a condition assessment carried out**.*

Working Database and Lifetime Prediction Model

In order to make best use of the working database and Lifetime Prediction Model the minimum key data necessary is presented in Table 4-1.

Table 4-1 – Key Data for the Lifetime Prediction Model

Key Data Required				
Local Authority	Pipe Sample Recovery Location	Pipe DN	Pipe OD (Mean)	Year Recovered
Minimum Wall Thickness	Maximum External Deterioration (mm)	Maximum Internal Deterioration (mm)	Year Installed	Year Assessed

Fixed Values

Within the working database some parameters have fixed values, these being the national average deterioration rate (mm / yr) and the operating pressure surge factor. The fixed parameter values are presented in Table 4-2.

Table 4-2 – Working Deterioration Model – Fixed Values

Working Deterioration Model	Value / Unit	Date
Deterioration Rate (Water / Stormwater)	0.2344 mm / yr	July 2016
Deterioration Rate (Wastewater)	0.3462 mm / yr	July 2016
Operating Pressure Surge Factor	1.5 (Factor of Safety)	July 2016

The pipe wall matrix strength (minimum tensile strength as required by the manufacturing standard) is dependent on the year installed and the model automatically chooses the correct minimum strength as presented in Table 4-3.

Table 4-3 – Installation Period and Minimum Tensile Strength

Installation Period	Minimum Tensile Strength
1937 – 1955	15.5 MPa
1956 – 1976	22.1 MPa
1977 – 1986	23.5 MPa

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[17] *Remaining life is the calculated year of first pressure related failure due to deterioration. It does not necessarily mean the whole pipeline will catastrophically fail and require full replacement.*

These values are relatively conservative as pipe samples tested almost invariably met (and exceeded) the minimum required strength.

Alternatively, the minimum tensile strength can be "user defined" by manually entering a value.

These key assumptions give an appropriately conservative remaining lifetime for critical pipelines and those with high to very high consequences of failure.

In the working deterioration model spreadsheet, the individual pipe and core sample deterioration rates are compared with the national average deterioration rate for watermains or wastewater pressure mains. *(This gives the user an indication of whether the pipes sampled are deteriorating significantly faster or slower than the national average and frequently points to incorrect date of installation or other issues)*.

The peak operating pressure is defined as the static pressure obtained by subtracting the pipe elevation from the top water level in the reservoir or the steady pumping pressure in the pipeline. This value will change along a pipeline as the elevation of the ground changes.

Where pressure / transient records are recorded at one second intervals or less (e.g. milliseconds) that extend over a significant time period and cover most of the likely operating conditions in a network are available, they may allow for a lower surge factor to be used.

Factors Not Considered in the Model

The lifetime prediction model does not allow for the following factors:

- The deteriorated part of the pipe has some remaining strength and well-consolidated bedding and back-filling will also provide some resistance to internal pressures (*the model assumes that there is no strength in the deteriorated material, bedding or backfill)*.
- If the maximum measured deterioration depths (externally and internally) do not coincide the predicted result will be an under estimate of the remaining life.
- The tensile strength of the AC wall matrix is equal to the minimum value of the relevant manufacturing standard.

Note, some examples of extremely softened pipes have still been capable of resisting low to moderate internal pressures even though it has been possible to crush the wall under hand pressure.

Generally failures due to deterioration of the pipe wall alone are predictable, whereas failures due to other causes can be virtually random events that may or may not be directly related to pipe deterioration. Table 4-4 provides some examples.

Table 4-4 – AC Pressure Pipe Cause of Failure

Pressure Pipe Failure Mechanism	Comments / Mitigation
Sections of pipeline poorly installed and lacking uniform support.	May be highly localised and not normally a cause for total replacement.
Loss of pipe bedding support (third party services installation).	Usually highly localised and not normally a cause for total replacement.
Settlement, ground instability and seismic movement.	May require replacement of a defined area.
Specific pipe fitting(s) failure.	May be localised and not normally a cause for total replacement.
Earth pressures and bending caused by wetting and drying of expansive clays.	Can be localised or widespread along a pipeline. Expansive clays are not very common in New Zealand.
Excessive pressure surges caused by failure of control systems, incorrect operation of valves or pumps etc.	Usually preventable by changing operating practices.

Table 4-4 – AC Pressure Pipe Cause of Failure – Cont'd

Pressure Pipe Failure Mechanism	Comments / Mitigation
Over-pressurisation, usually due to the wrong pressure class of pipe being installed or due to increased pump capacity without considering the consequences.	May be preventable by improved pressure management system(s) or by replacing the overloaded section(s) of pipeline.
Unusual imposed pipe loads (e.g. vibration, earthmoving or construction traffic, reduced cover etc.).	Usually only a localised area affected and short in duration. Not normally a cause for total replacement. Mitigation measures can be put in place to prevent / minimise damage.
Growth of tree roots exerting bending forces on pipes.	Mitigation may be delayed until failure occurs (depending on consequences) and the pipe line diverted around the tree using a flexible pipe material.
Pipe manufacturing defects or pipes damaged before or during installation.	May be difficult to identify, likely to only affect a single pipe.

It is important that the nature of the failure (and cause if possible), is recorded so that it can be compared with the deterioration of the pipe and the relative importance of the deterioration to the failure can be estimated. The nature and perceived cause of failure should be recorded as part of the pipe data collection process.

Pipe bursts are the best predictor of future breaks. A pipe that has burst two or more times is likely to break again with the interval between breaks becoming shorter and shorter.

Some pipe break / burst can be due to causes other than deterioration e.g. installation damage, but in general the predictability of subsequent breaks appears to be independent of the pipe age and other factors[18].

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[18] *Water Research Foundation; Report #4480:2015, Development of an Effective Management Strategy for Asbestos Cement Pipe.*

5   LIFETIME PREDICTION CHARTS

5.1   Lifetime Prediction Charts

These charts are intended to give Asset Managers a **desk-top method** of assessing the likely remaining life of AC pressure pipes where **no physical sampling** and **condition assessments** have been carried out.

The lifetime prediction charts include asbestos cement pressure pipes of all available pressure classes used for water supply and wastewater, in sizes ranging from DN 50 to DN 600.

These charts are based on the range of minimum and maximum pipe wall thickness (allowed for in the manufacturing standards) for each pressure class, the national average pipe deterioration rate and an operating pressure surge factor range from 1.1 to 1.5. The water supply lifetime prediction charts may also be used for asbestos cement pressure pipes used for stormwater.

This desk-top procedure is heavily dependent on the reliability of the asset data records or GIS system. If any data is unknown or is suspected to be unreliable, pot-holing and in-situ testing (level 2 condition assessment) or pipe sampling (level 2 or level 3 condition assessment) is recommended. Experienced maintenance operatives can frequently assist with some of this information.

The key data needed is:

- Pipe purpose (water supply, wastewater, stormwater).
- Pipe diameter (if not known pot holing is recommended).
- Operating pressure (if known, or estimate, e.g. reservoir TWL – GL @ pipe).
- Pipe pressure class (use default value from Section 3.2.4, Table 3-1 of Volume 1).
- Year installed.

It is highly likely that there is a level of uncertainty with most of the above. If the risks associated with incorrect data are acceptable, select the most appropriate Lifetime Prediction Chart (pipe diameter, class and purpose).

5.1.1 Lifetime Prediction Charts Fixed Values

The key parameters / assumptions used in preparing the charts are:

- NZSS 285:1959 standard applies for pipe dimensions, ($\approx$65% of the AC pressure pipe samples assessed to date were manufactured to this standard. NZS 3202:1977 shares the same dimensions.
  2" and 2¼" pipes have been combined as 50 / 60 mm *(there are probably few of these pipe still in service). 3" diameter pipes have been soft-metricated to DN 80 as per NZS 3202:1977).*
- All pipe classes have a wall thickness between the minimum and maximum manufacturing standard *(from Opus' experience this is mostly conservative, for larger pipes).*
- Pressure Surge Factor value of 1.5 times peak operating pressure.
- Tensile strength of the undeteriorated portion of the wall is 22.1 MPa *(as per NZSS 285:1959).*

5.1.2 Limitations of Lifetime Prediction Charts

The charts show a range of lifetimes. For critical pipelines (where failure consequences are high) sampling and the use of the lifetime model is recommended. A first-cut remaining lifetime can be made by using the most conservative chart.

5.2   How to Use the Lifetime Prediction Charts

1. Plot the operating pressure on the Y axis of the chart and extend until it intersects with the banding representing the pipe pressure class.
2. Based on the pipe data available estimate the remaining life time from the banding and read the predicted years to deterioration failure on the X axis. Refer to Section 3.2.3, of Volume 1 regarding the use of the banding.

3. Add this number to the year installed. This represents the estimated year of first deterioration failure. Note that it is possible for this date to be earlier than the current date which indicates that:

    *   The pipeline is in very poor condition.
    *   The installation date is incorrect.
    *   The pressure class is wrong.
    *   The deterioration rate is actually slower than the national average.

4. Subtract the current year to determine the calculated remaining life.

Note:

If the confidence in the data accuracy is low, the results of a desk-top study may be of limited value, but may help to target areas for level 2 and 3 condition assessments.

The Lifetime Prediction Charts are based on national average deterioration rates and in some cases pipes will fail earlier and some will exceed the calculated remaining life.

If the likelihood of failure of the pipeline cannot be tolerated (e.g. trunk watermain feeding the water treatment plant), then a level 2 or 3 condition assessment should be carried out to confirm the actual condition.

LIFETIME PREDICTION CHARTS – WATER SUPPLY (DN 50 to DN 600)
FOR USE WHEN A PHYSICAL PIPE OR CORE SAMPLE IS NOT AVAILABLE
Lifetime Prediction Chart - DN 50 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

* Default Pressure Class AF, Volume 1, Section 3, Table 3-1
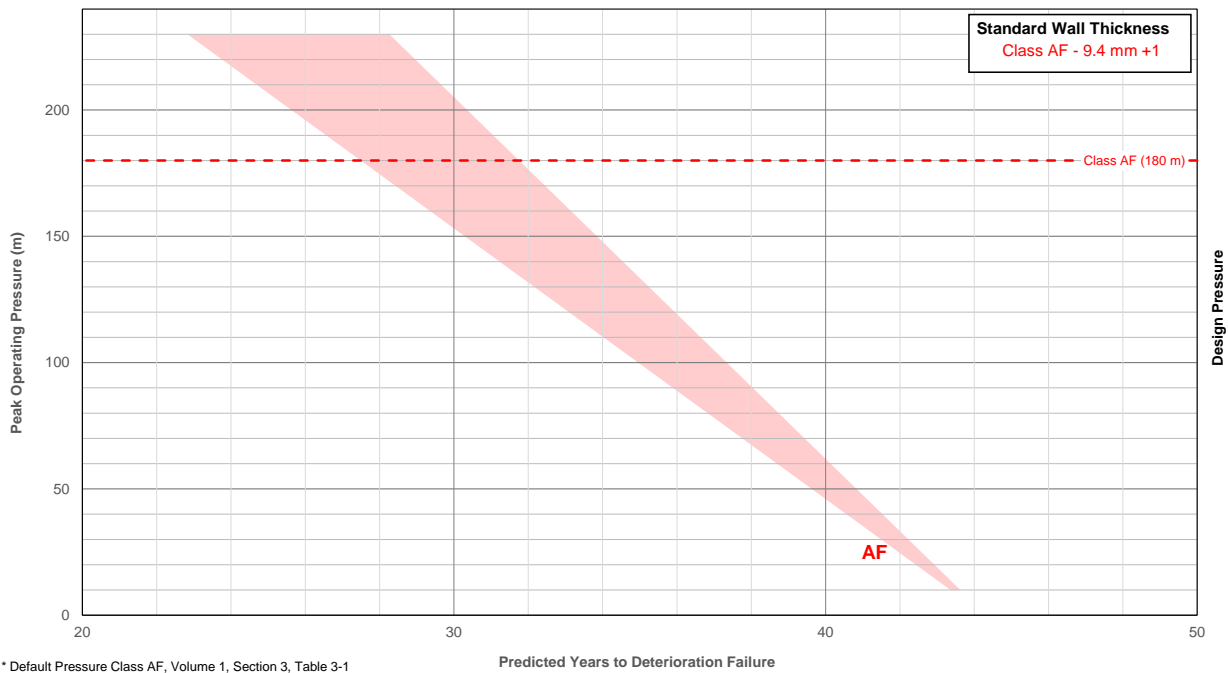
Lifetime Prediction Chart - DN 75 / DN 80 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

* Default Pressure Class CD, Volume 1, Section 3, Table 3-1
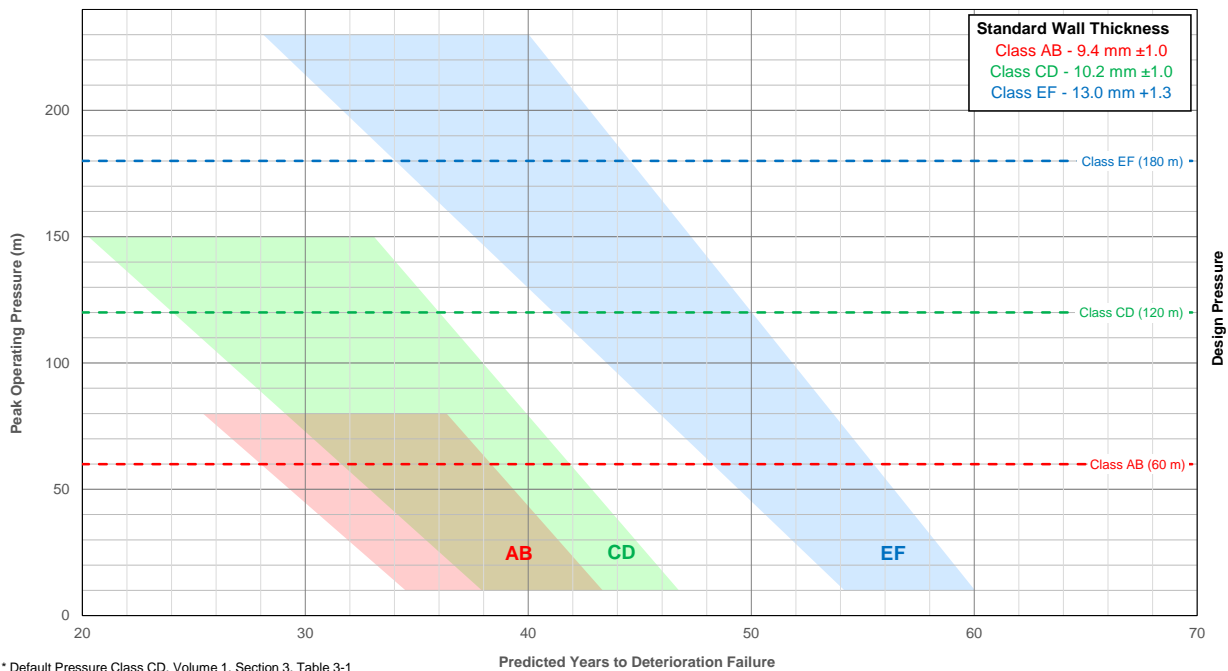
Note: Class EF is based on NZS 3202:1977

Lifetime Prediction Chart - DN 100 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class AB - 10.4 mm ±1.0
Class CD - 12.7 mm ±1.3
Class EF - 16.5 mm +1.5

* Default Pressure Class CD, Volume 1, Section 3, Table 3-1

Note: Class EF is based on NZS 3202:1977
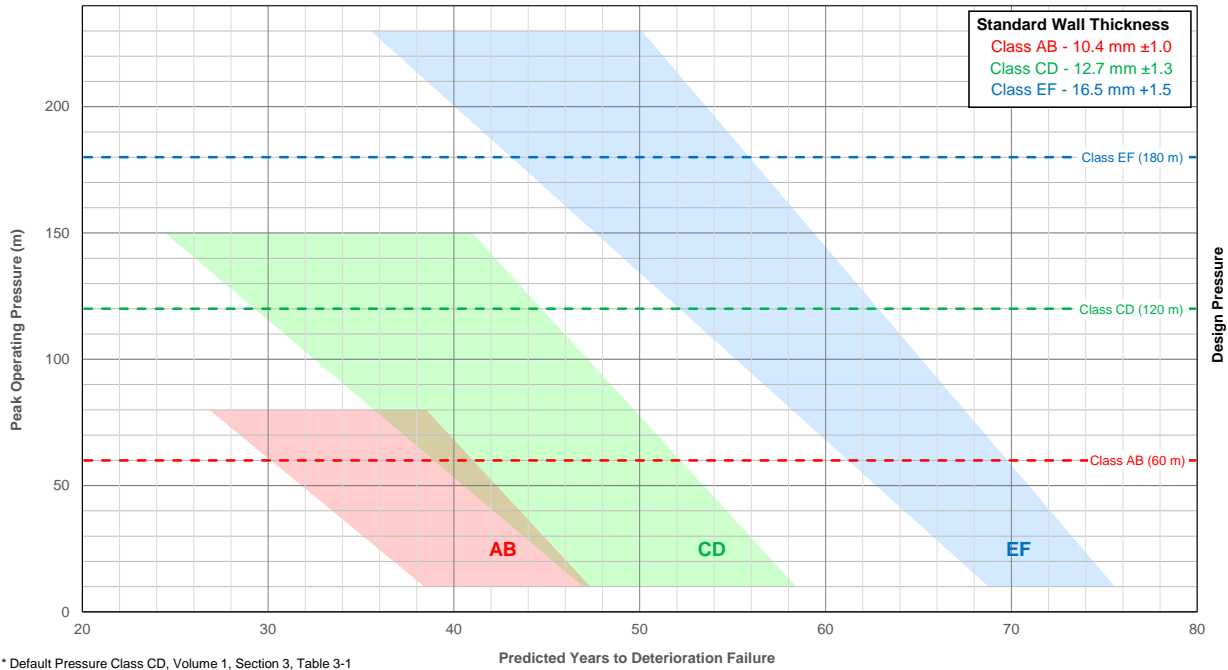
Lifetime Prediction Chart - DN 150 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class AB - 11.4 mm ±1.0
Class C - 15.5 mm ±1.5
Class D - 17.8 mm ±1.5
Class E - 19.1 mm +1.5
Class F - 21.9 mm +1.8

* Default Pressure Class C, Volume 1, Section 3, Table 3-1

Note: Class E and F are based on NZS 3202:1977
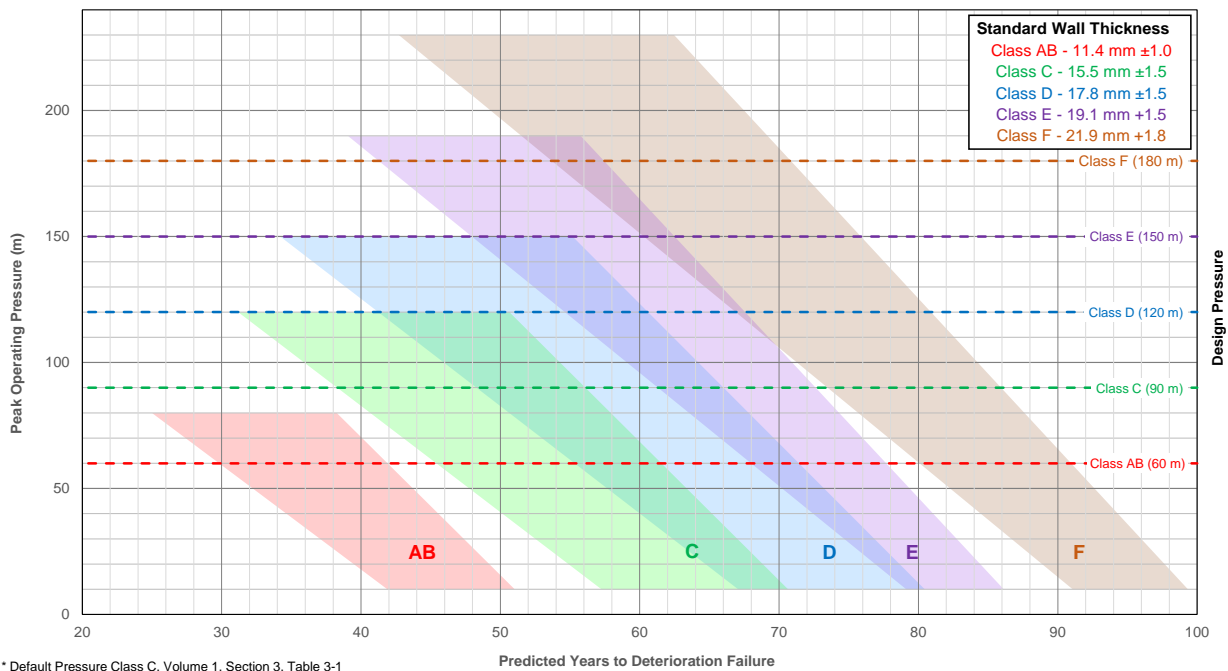
Lifetime Prediction Chart - DN 200 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 12.0 mm ±1.3
Class B - 14.5 mm ±1.3
Class C - 18.3 mm ±1.5
Class D - 22.9 mm ±1.8

* Default Pressure Class C, Volume 1, Section 3, Table 3-1
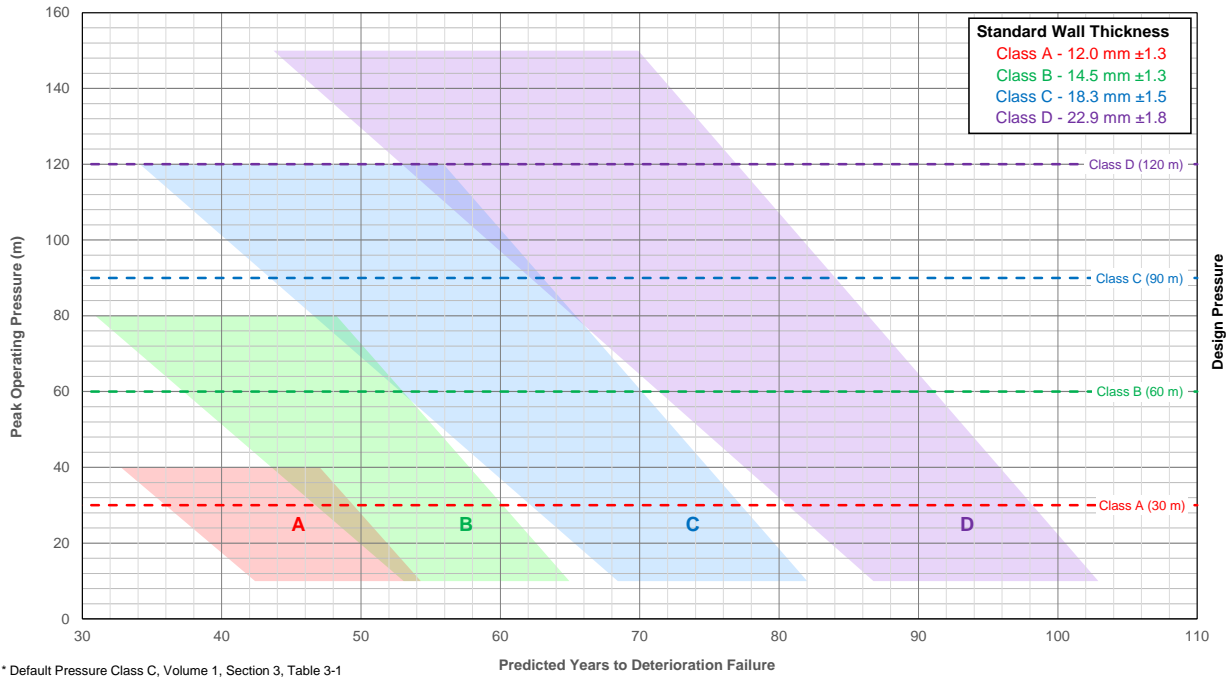
Lifetime Prediction Chart - DN 225 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 12.7 mm ±1.3
Class B - 15.3 mm ±1.5
Class C - 20.1 mm ±1.8
Class D - 24.9 mm ±2.0

* Default Pressure Class C, Volume 1, Section 3, Table 3-1
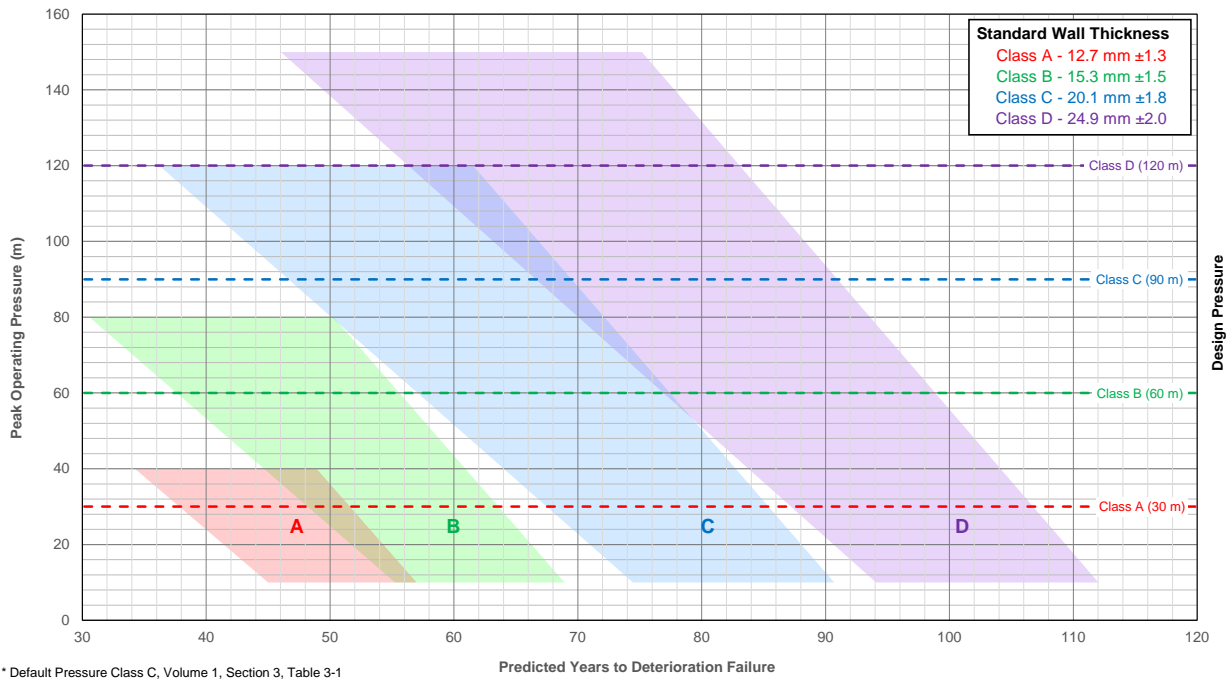
Lifetime Prediction Chart - DN 250 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 13.2 mm ±1.3
Class B - 16.3 mm ±1.5
Class C - 21.3 mm ±1.8
Class D - 27.5 mm ±2.0

Default Pressure Class C, Volume 1, Section 3, Table 3-1
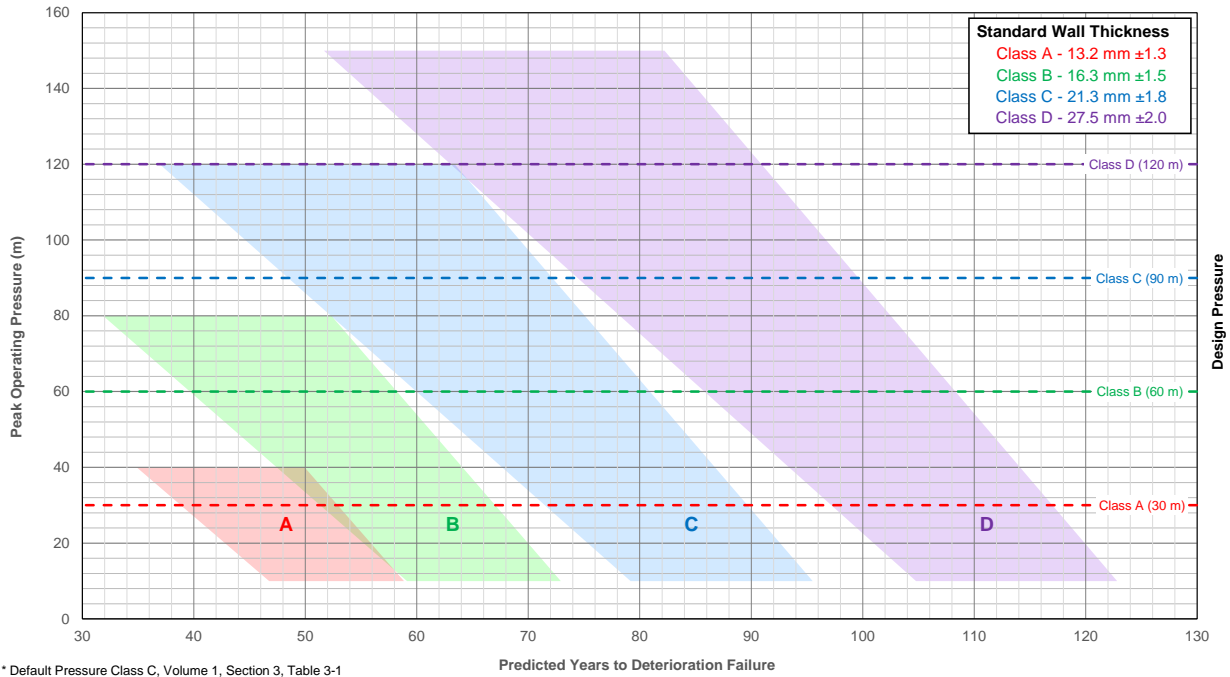
Lifetime Prediction Chart - DN 300 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 14.5 mm ±1.3
Class B - 17.3 mm ±1.5
Class C - 25.4 mm ±2.0
Class D - 33.0 mm ±2.3

Default Pressure Class C, Volume 1, Section 3, Table 3-1
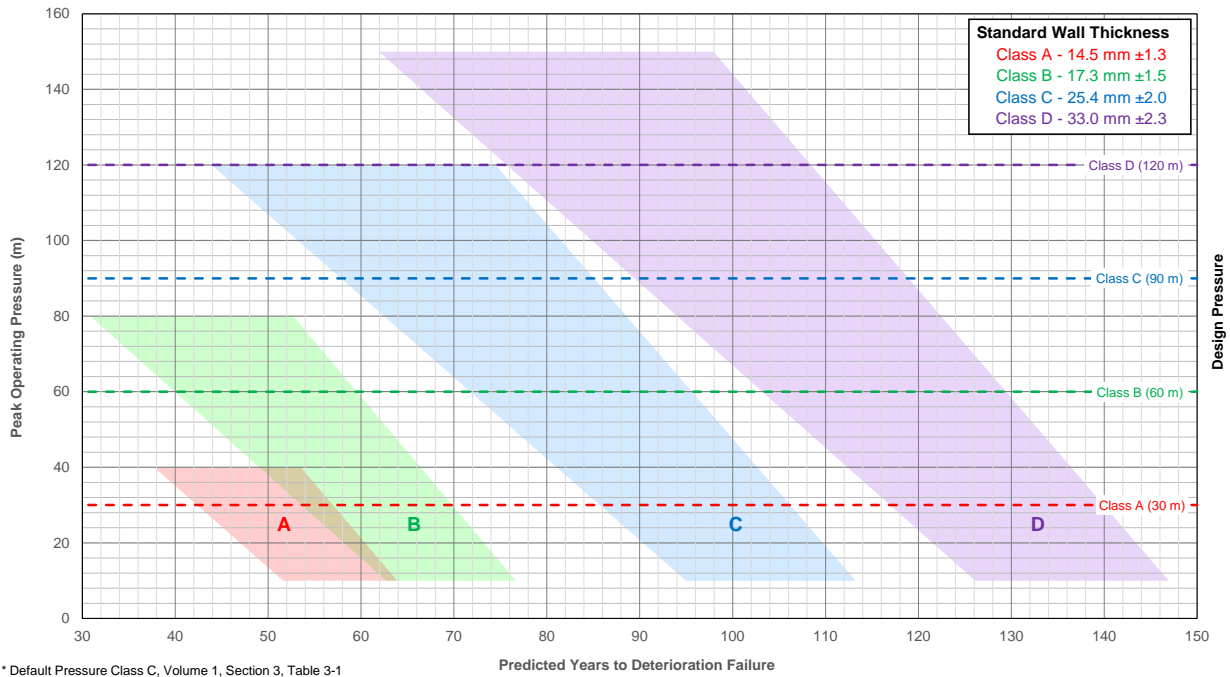
Lifetime Prediction Chart - DN 375 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

* Default Pressure Class C, Volume 1, Section 3, Table 3-1
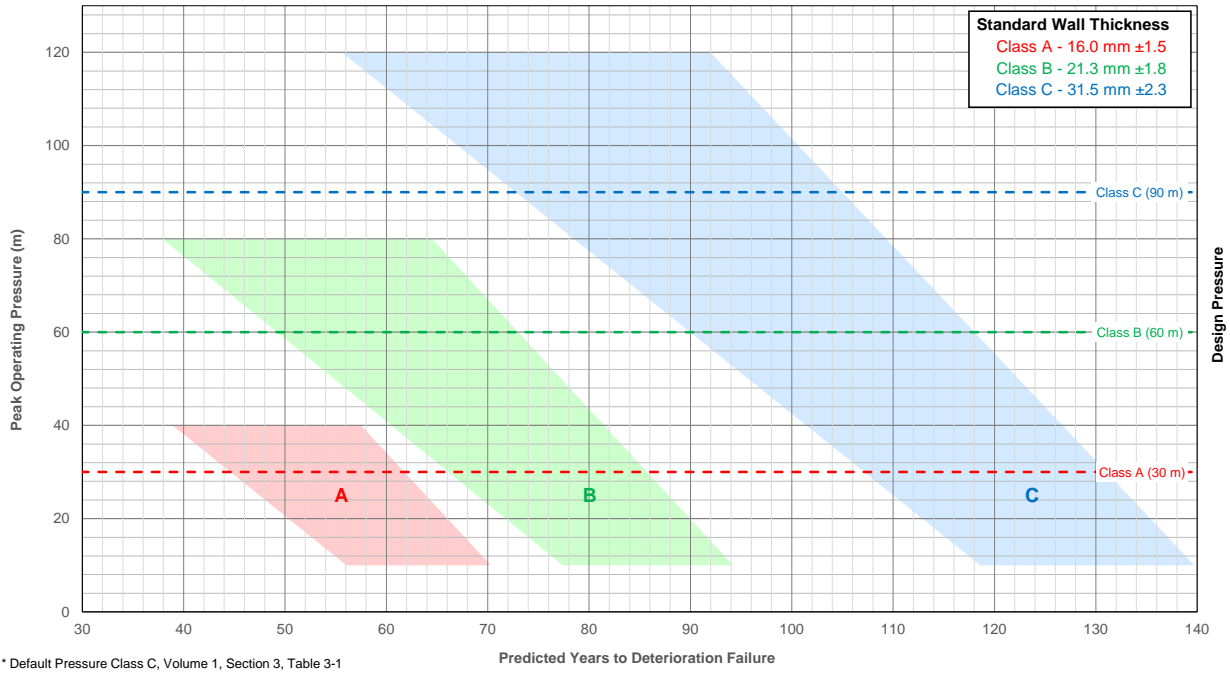
Lifetime Prediction Chart - DN 450 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

* Default Pressure Class B, Volume 1, Section 3, Table 3-1
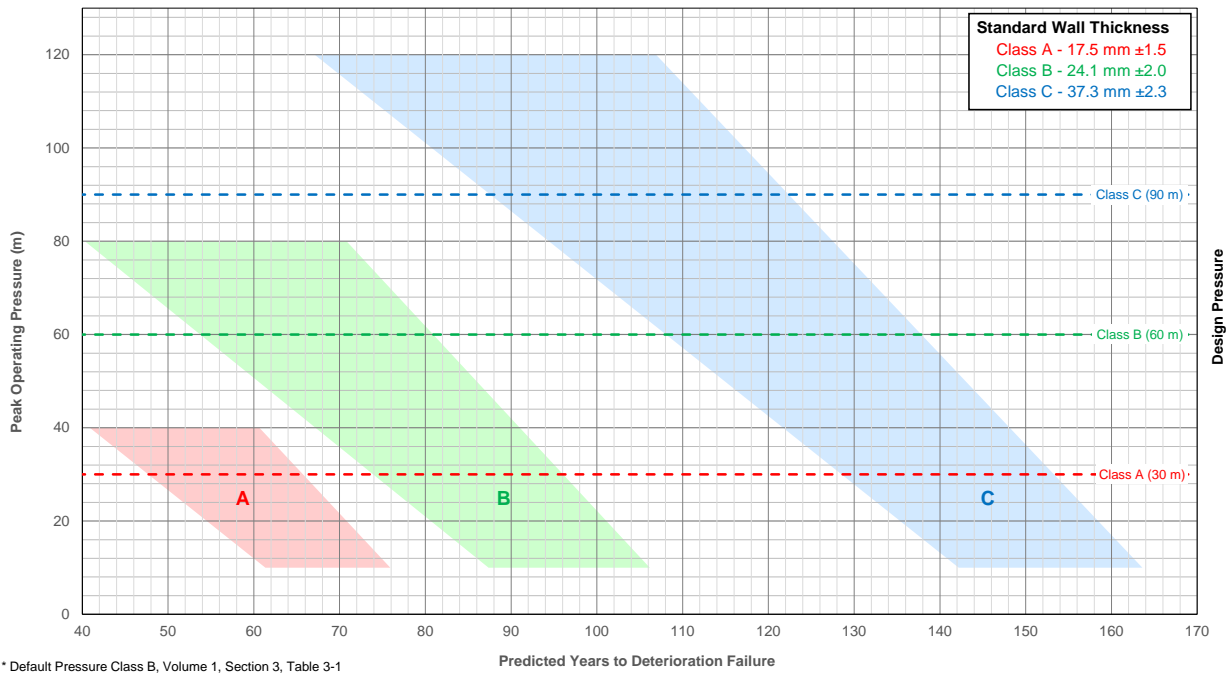
Lifetime Prediction Chart - DN 525 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 19.1 mm ±1.5
Class B - 27.9 mm ±2.0
Class C - 40.6 mm ±2.5

* Default Pressure Class B, Volume 1, Section 3, Table 3-1
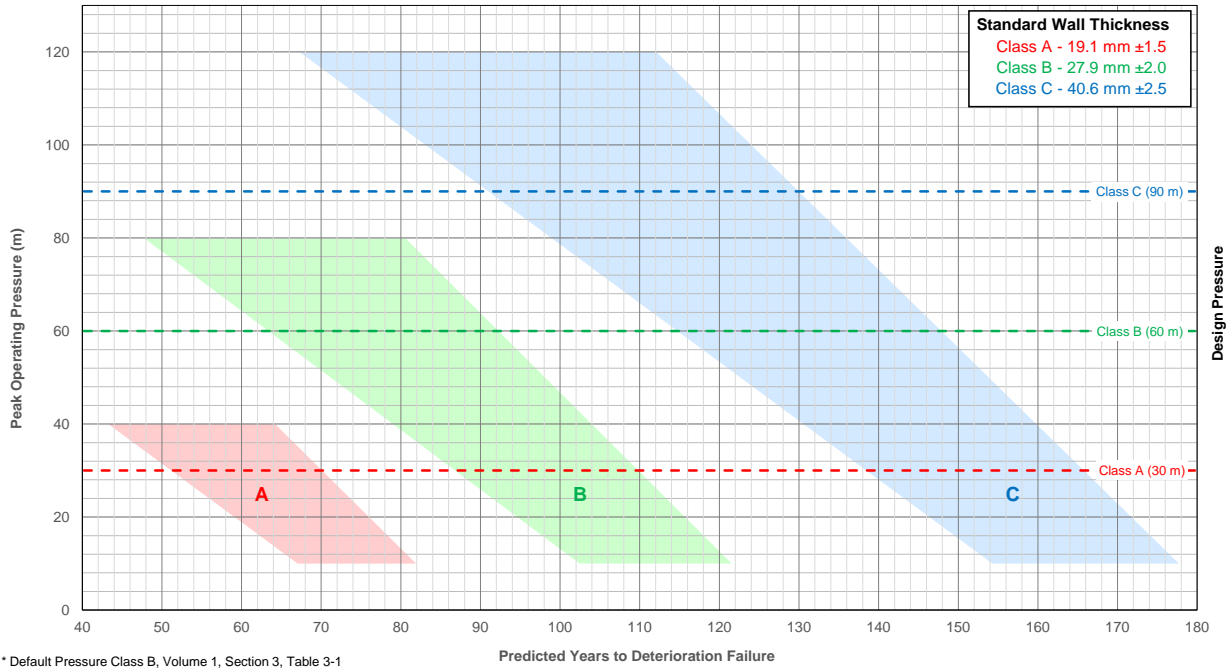
Lifetime Prediction Chart - DN 600 (Water)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 20.3 mm ±1.8
Class B - 31.7 mm ±2.3
Class C - 45.7 mm ±2.5

* Default Pressure Class B, Volume 1, Section 3, Table 3-1
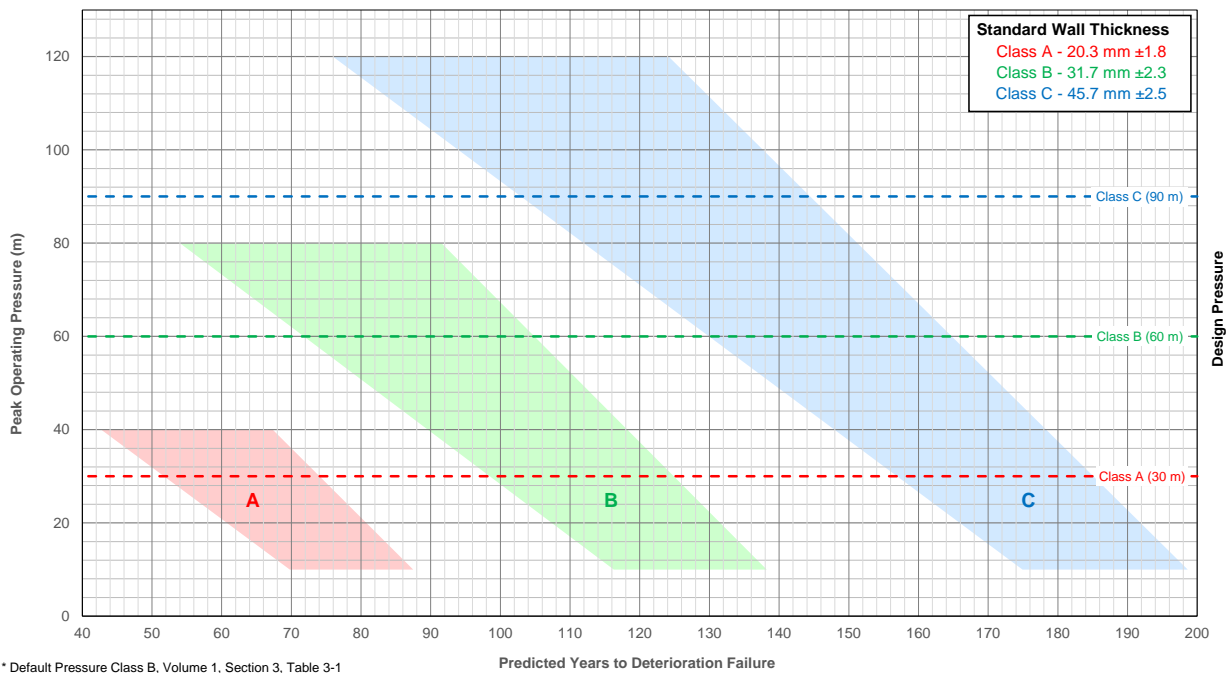
LIFETIME PREDICTION CHARTS – WASTEWATER DN 50 to DN 600
FOR USE WHEN A PHYSICAL PIPE OR CORE SAMPLE IS NOT AVAILABLE

Lifetime Prediction Chart - DN 50 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

* Default Pressure Class AF, Volume 1, Section 3, Table 3-1
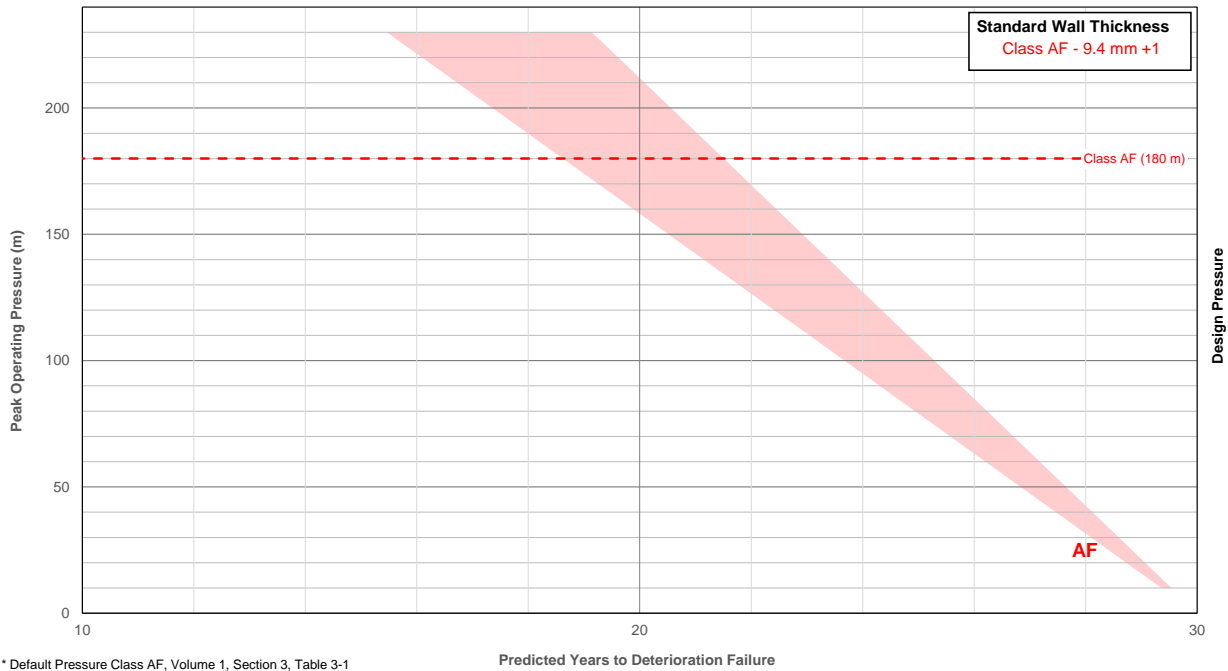
Lifetime Prediction Chart - DN 75 / DN 80 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

* Default Pressure Class CD, Volume 1, Section 3, Table 3-1
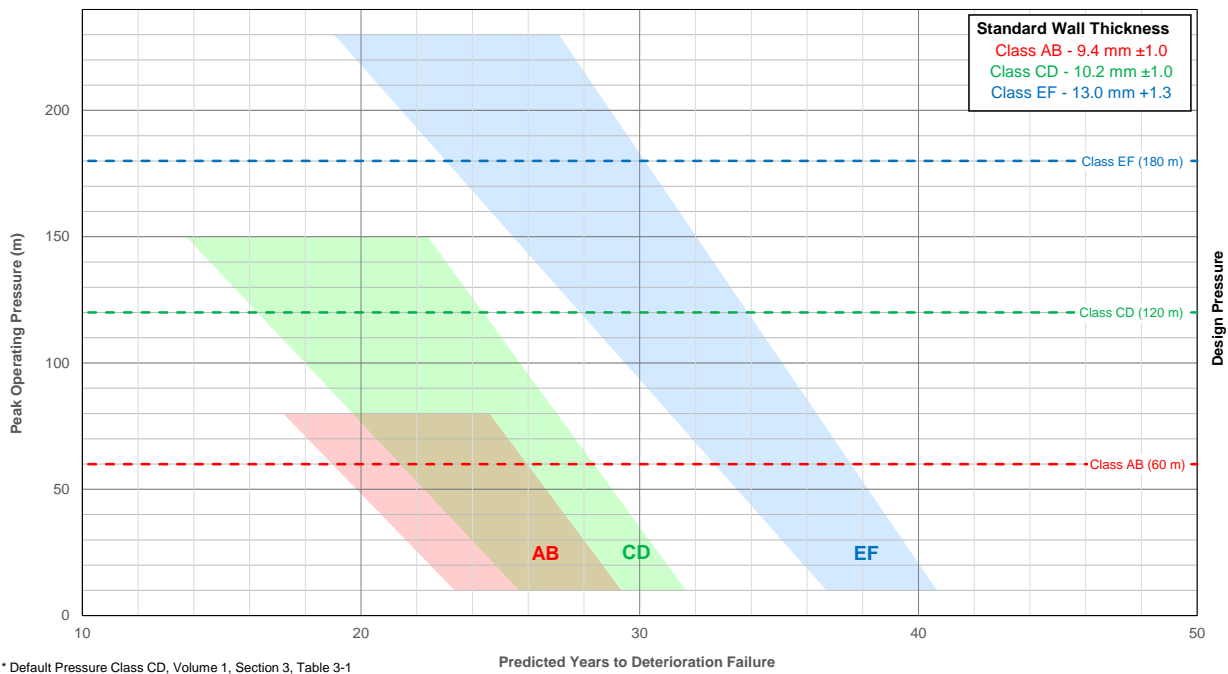
Note: Class EF is based on NZS 3202:1977

Lifetime Prediction Chart - DN 100 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

* Default Pressure Class CD, Volume 1, Section 3, Table 3-1

Note: Class EF is based on NZS 3202:1977
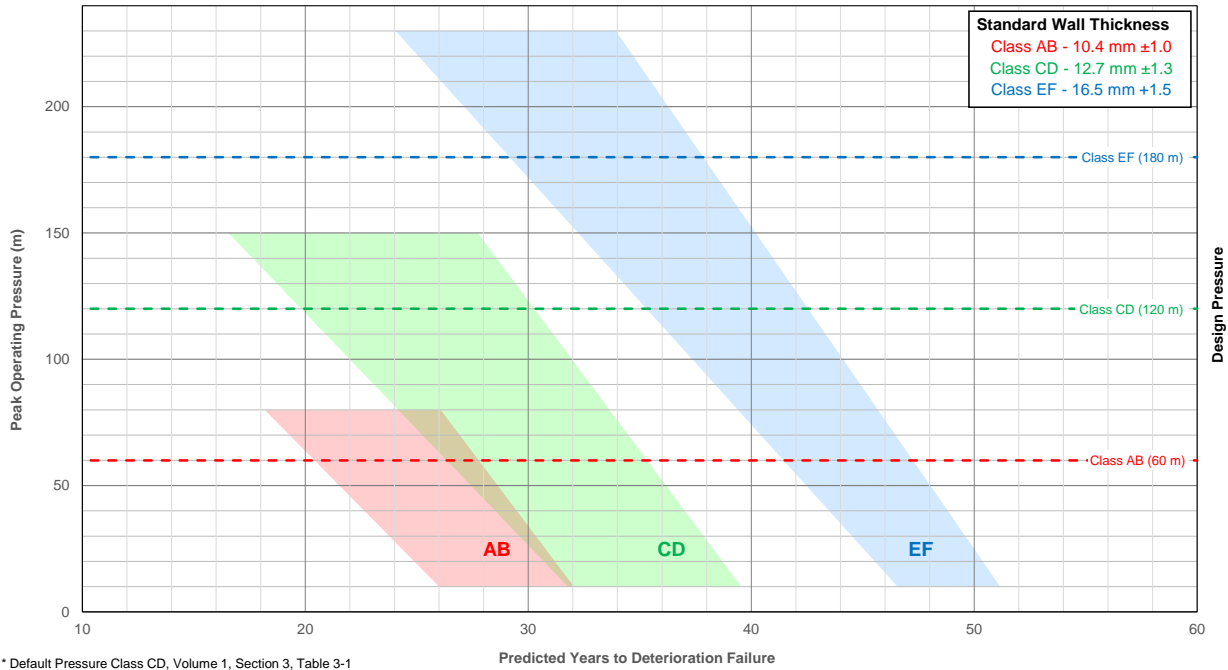
Lifetime Prediction Chart - DN 150 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

* Default Pressure Class C, Volume 1, Section 3, Table 3-1

Note: Class E and F are based on NZS 3202:1977
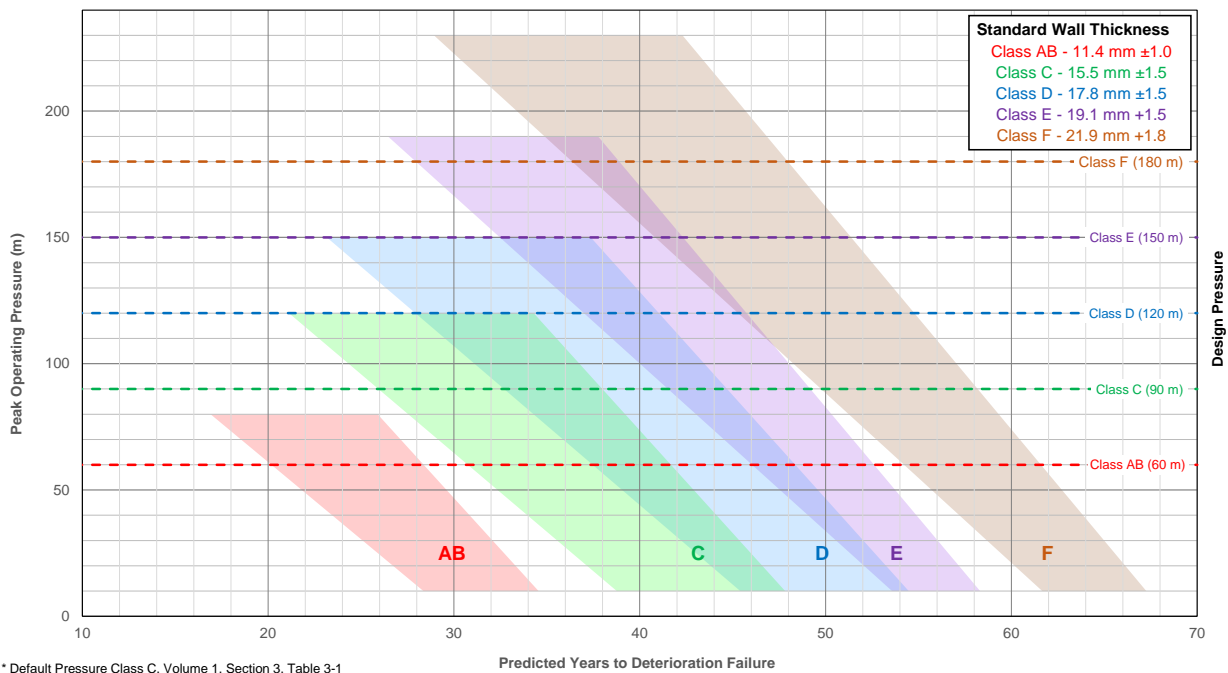
Lifetime Prediction Chart - DN 200 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 12.0 mm ±1.3
Class B - 14.5 mm ±1.3
Class C - 18.3 mm ±1.5
Class D - 22.9 mm ±1.8

* Default Pressure Class C, Volume 1, Section 3, Table 3-1
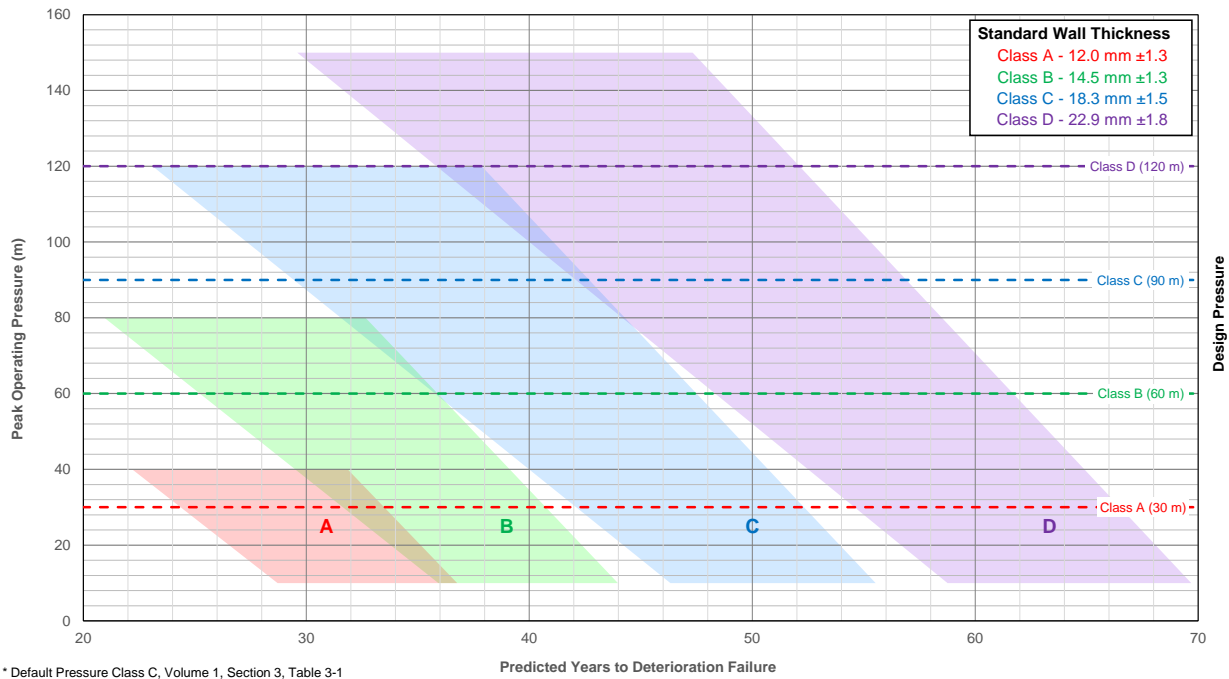
Lifetime Prediction Chart - DN 225 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 12.7 mm ±1.3
Class B - 15.3 mm ±1.5
Class C - 20.1 mm ±1.8
Class D - 24.9 mm ±2.0

* Default Pressure Class C, Volume 1, Section 3, Table 3-1
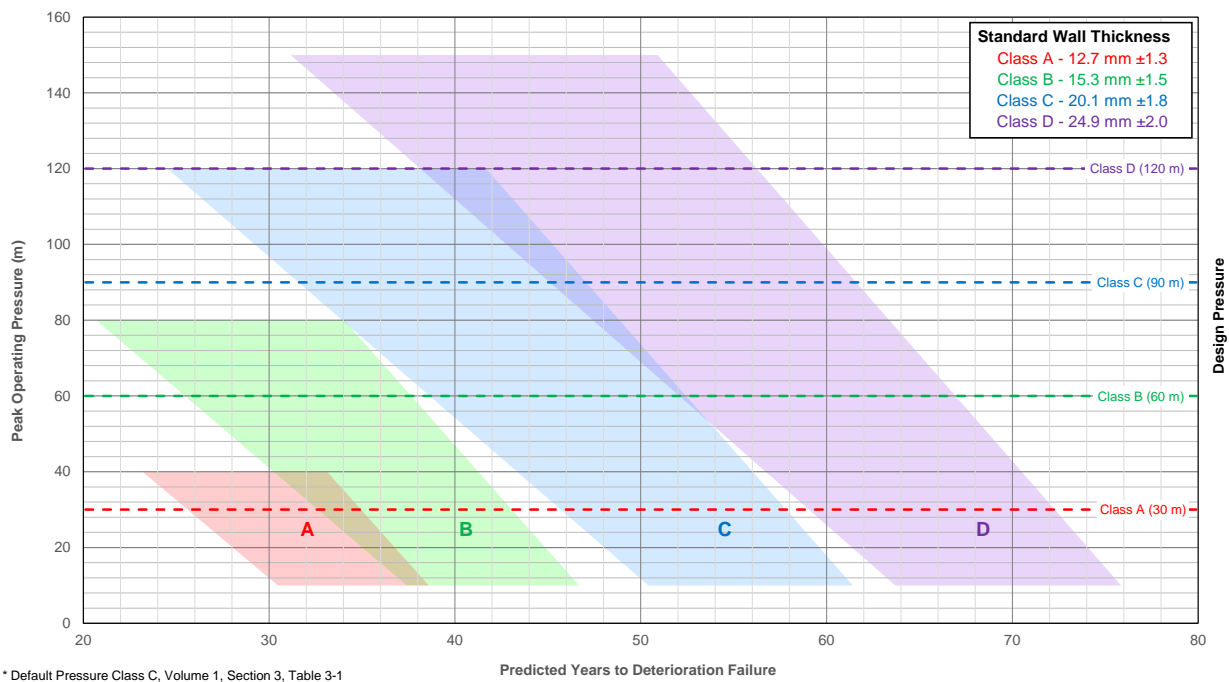
Lifetime Prediction Chart - DN 250 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 13.2 mm ±1.3
Class B - 16.3 mm ±1.5
Class C - 21.3 mm ±1.8
Class D - 27.5 mm ±2.0

* Default Pressure Class C, Volume 1, Section 3, Table 3-1
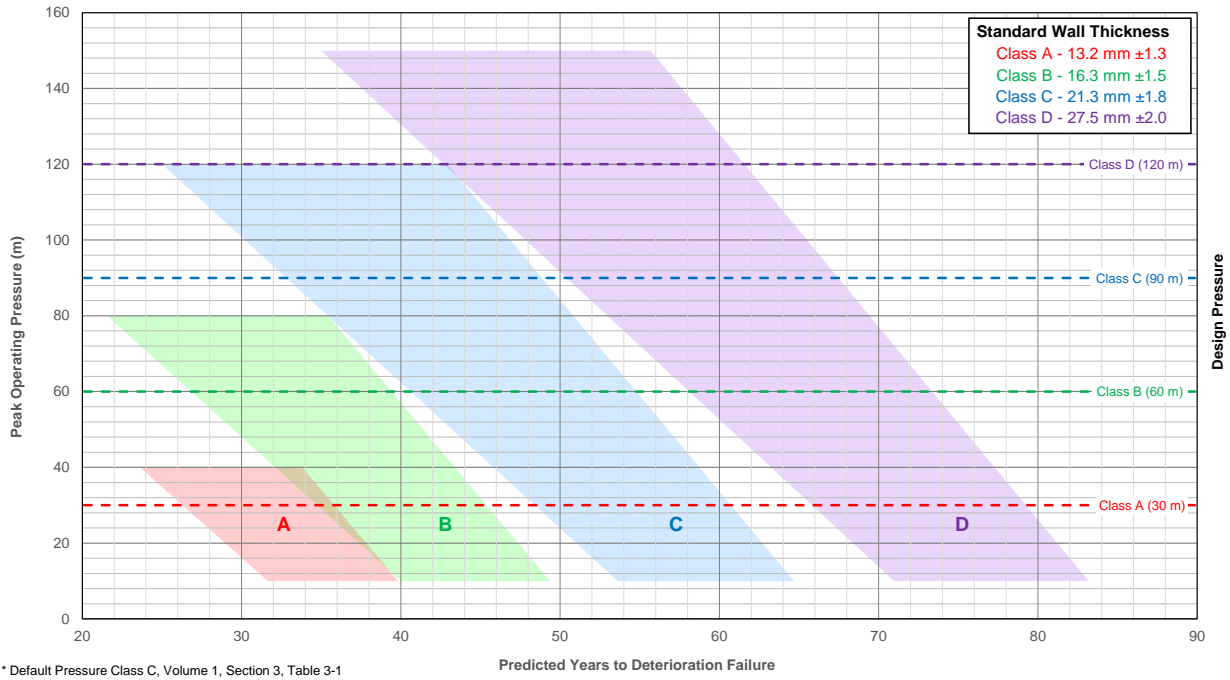
Lifetime Prediction Chart - DN 300 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 14.5 mm ±1.3
Class B - 17.3 mm ±1.5
Class C - 25.4 mm ±2.0
Class D - 33.0 mm ±2.3

* Default Pressure Class C, Volume 1, Section 3, Table 3-1
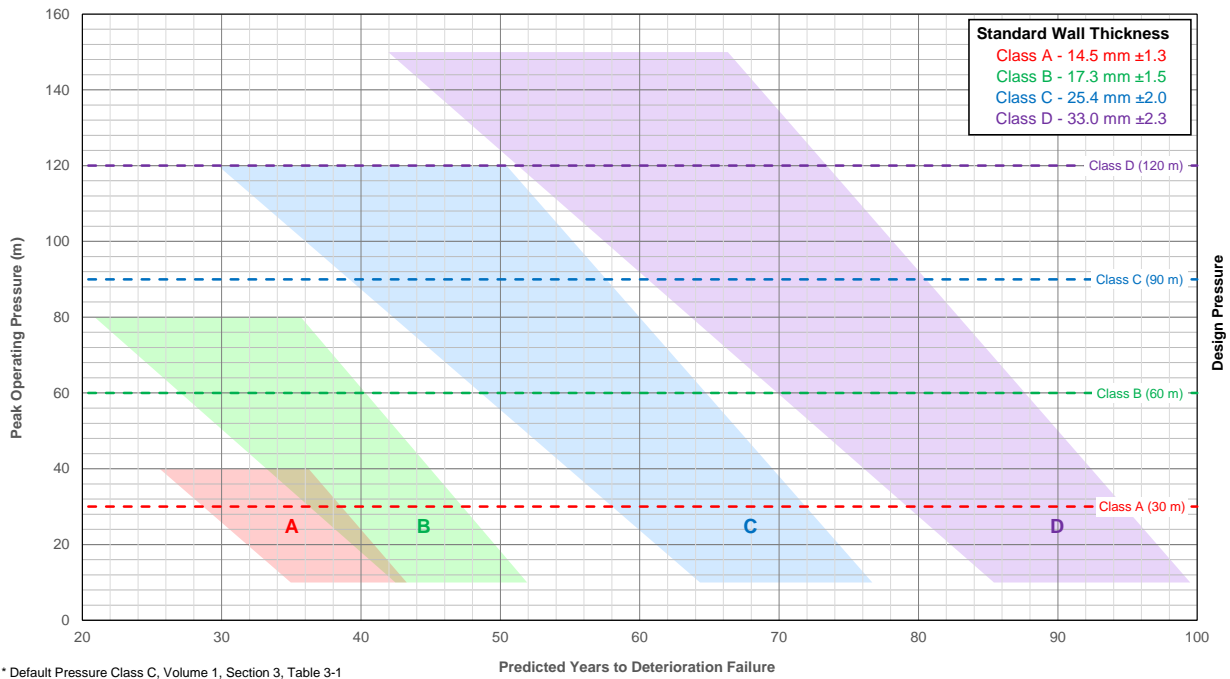
Lifetime Prediction Chart - DN 375 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 16.0 mm ±1.5
Class B - 21.3 mm ±1.8
Class C - 31.5 mm ±2.3

Peak Operating Pressure (m)

Design Pressure

Class C (90 m)

Class B (60 m)

Class A (30 m)

A   B   C

Predicted Years to Deterioration Failure

* Default Pressure Class C, Volume 1, Section 3, Table 3-1
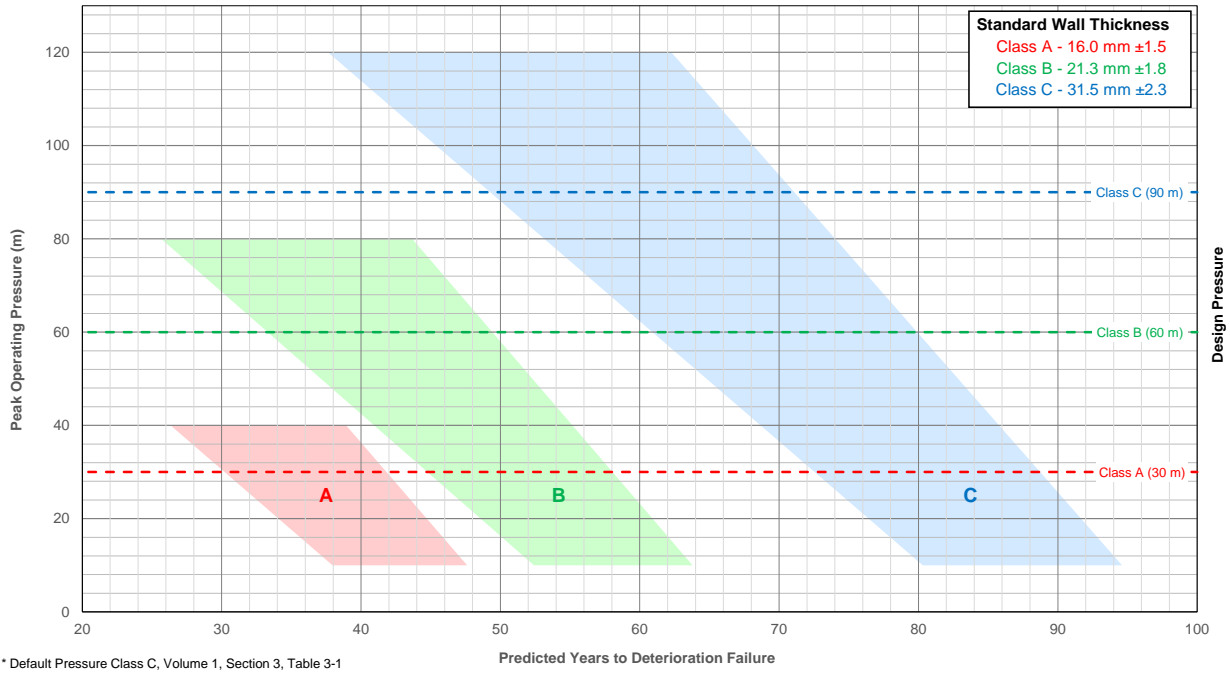
Lifetime Prediction Chart - DN 450 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 17.5 mm ±1.5
Class B - 24.1 mm ±2.0
Class C - 37.3 mm ±2.3

Peak Operating Pressure (m)

Design Pressure

Class C (90 m)

Class B (60 m)

Class A (30 m)

A   B   C

Predicted Years to Deterioration Failure

* Default Pressure Class B, Volume 1, Section 3, Table 3-1
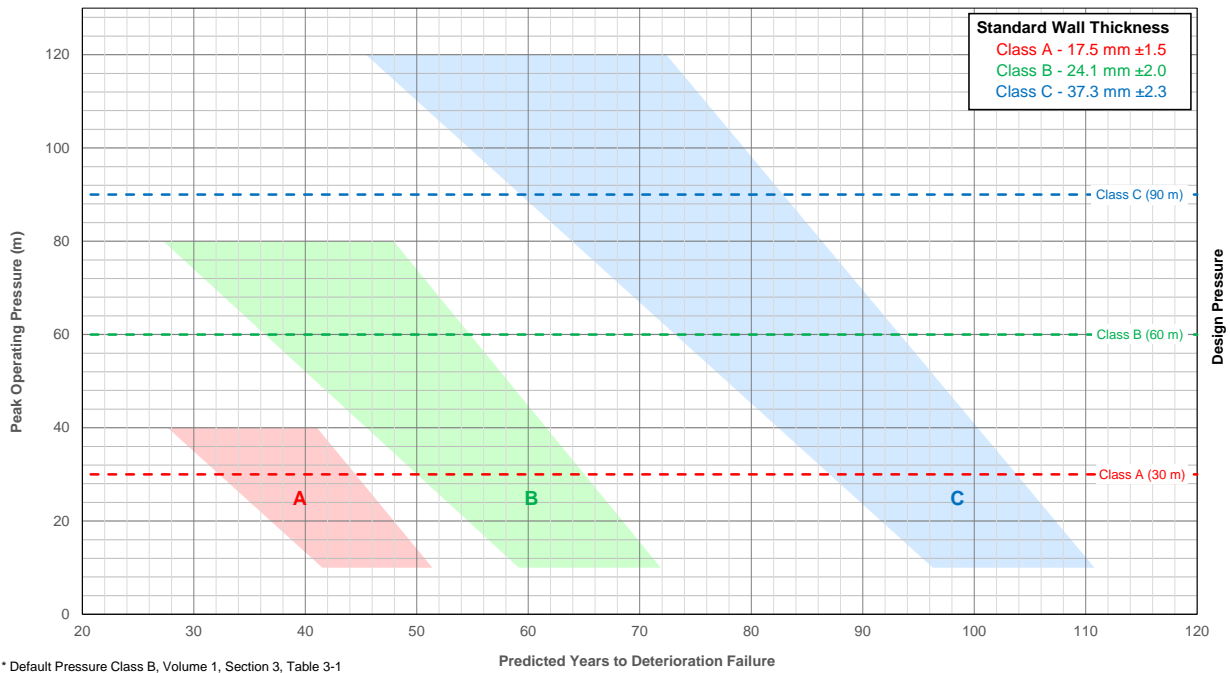
Lifetime Prediction Chart - DN 525 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 19.1 mm ±1.5
Class B - 27.9 mm ±2.0
Class C - 40.6 mm ±2.5

* Default Pressure Class B, Volume 1, Section 3, Table 3-1
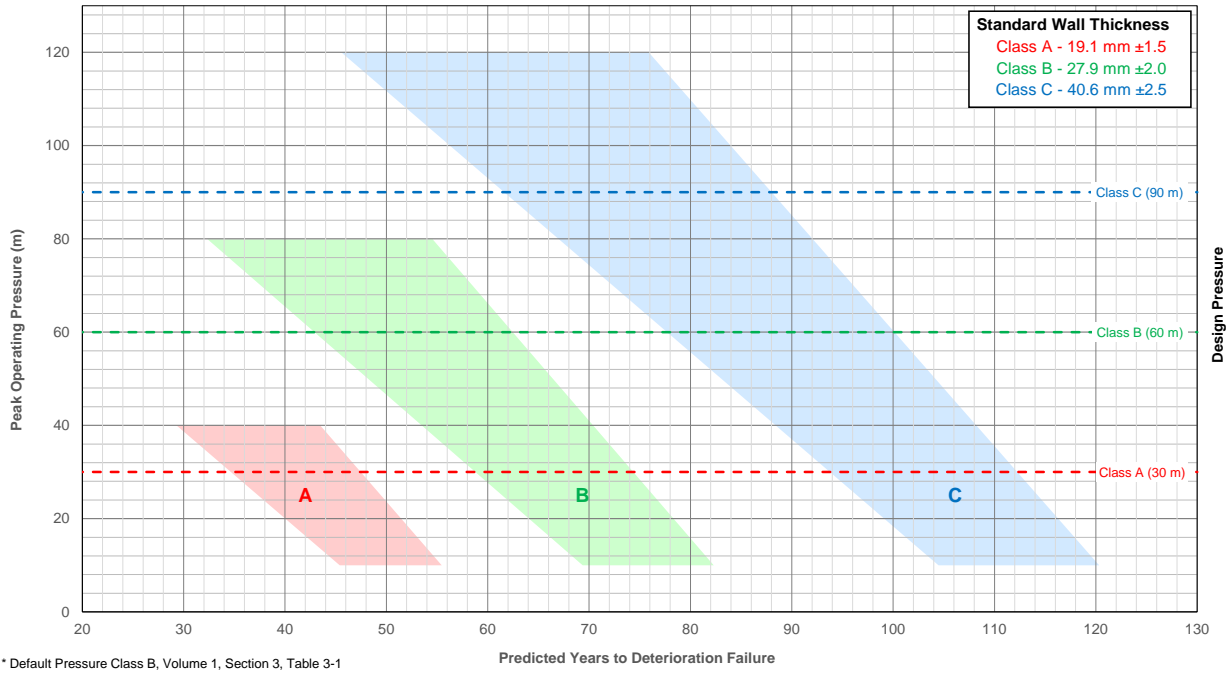
Lifetime Prediction Chart - DN 600 (Wastewater)

Level 1 Desktop Condition Assessment (No Pipe Samples Recovered)

Standard Wall Thickness
Class A - 20.3 mm ±1.8
Class B - 31.7 mm ±2.3
Class C - 45.7 mm ±2.5

* Default Pressure Class B, Volume 1, Section 3, Table 3-1
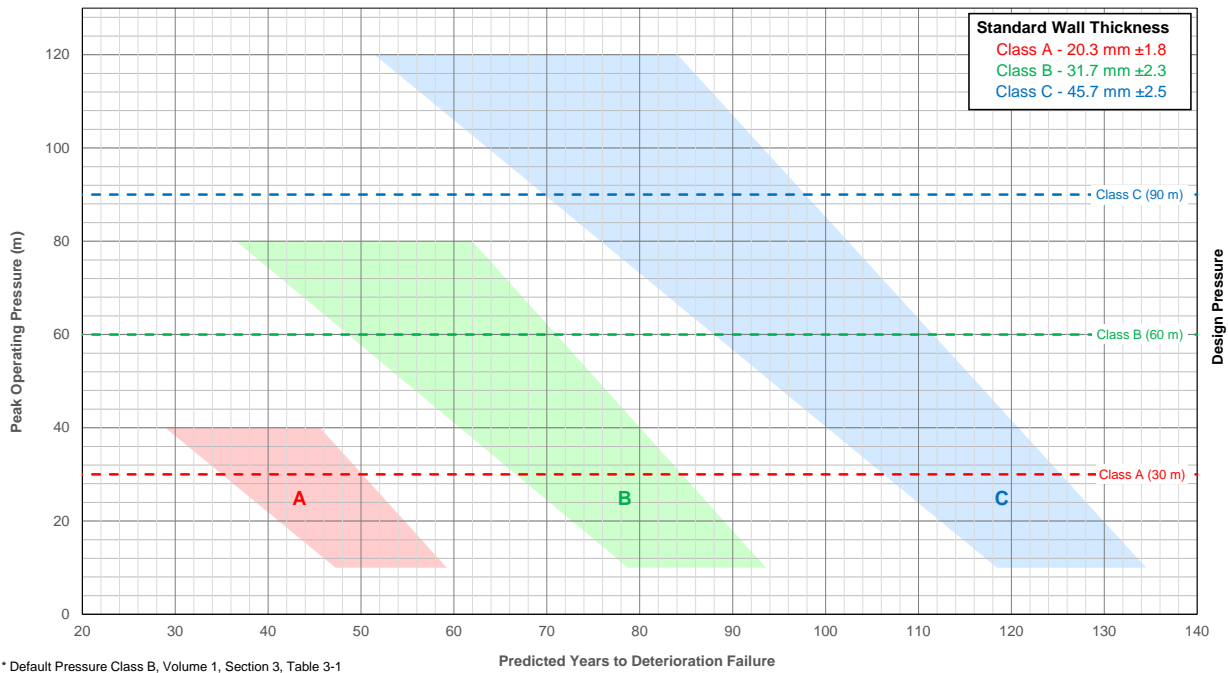
6   ASBESTOS CEMENT PRESSURE PIPE CONDITION GRADING

6.1   Introduction

This manual covers watermains from DN 50 to DN 600, and wastewater pressure pipes from DN 50 to DN 600 although to date only one condition assessment of a DN 600 wastewater pipe has been performed.

Consistent condition grading for AC pressure pipes is possible using the results from the working database and Lifetime Prediction Model.

This grading may then be applied to other pipes within a network that are of similar age and assumed condition.

6.2   Condition Grading

The condition grading system provides for 5 grades as per the New Zealand Infrastructure Asset Grading Guidelines. The grading is related to the probable remaining life of the pipeline so that there is no need for a qualitative judgement regarding the pipe condition.

The condition grades used for AC pipes and their definitions are presented in Table 6-1.

Table 6-1 – Condition Grades for AC Pressure Pipes and the Definitions

Condition Grade	Definition
1	**Very Good:** At least 75 % of the life of a new AC pipe remaining.
2	**Good:** Between 50 % and 75% of the life of a new AC pipe remaining.
3	**Moderate / Adequate[19]:** 25 % to 50 % of the life of a new AC pipe remaining.
4	**Poor:** Less than 25 % of the life of a new AC pipe remaining.
5	**Very Poor:** Pipe failure due to deterioration can be expected within a few years, some pipe failures may have already occurred.

The condition grading is based on the calculated remaining lifetime (as determined using the working database and Lifetime Prediction Model).

Note that the model sometimes identifies pipes that could have been at risk of failure for some time but have not yet failed.

6.3   How to Use the Condition Grading Charts

1. The pipe condition grade can be estimated by plotting a line at the operating pressure and a line at the calculated remaining life on the Condition Grading Chart for the appropriate pipe purpose, diameter and pressure class.
2. The Intersection of these two lines will fall within one of the shaded areas allowing the condition grading to be read (e.g. Grade 5, 4, 3, 2 or 1).

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[19] *"Adequate" is the definition proposed in the current draft MetaData Standards.*

CONDITION GRADING CHARTS – WATER SUPPLY20 (DN 50 to DN 600)

Condition Grading - DN 50 Class AF (Water)
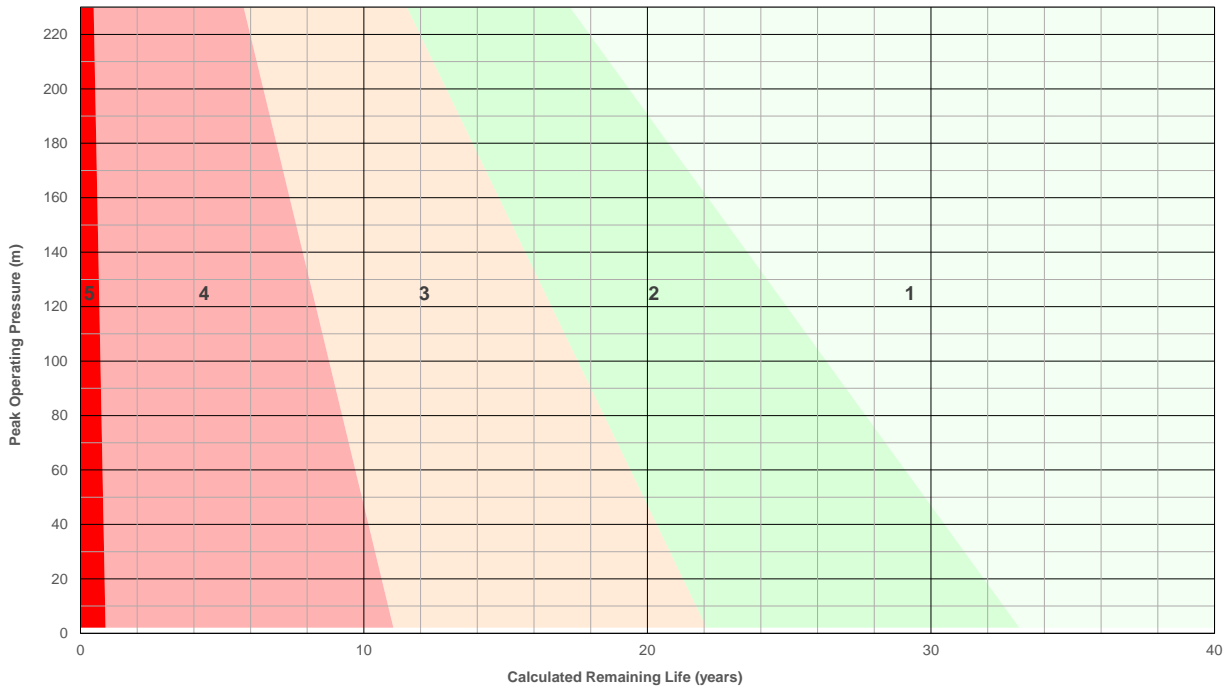
Note: Class E and F are based on NZS 3202:1977

Condition Grading - DN 75 Class AB (Water)

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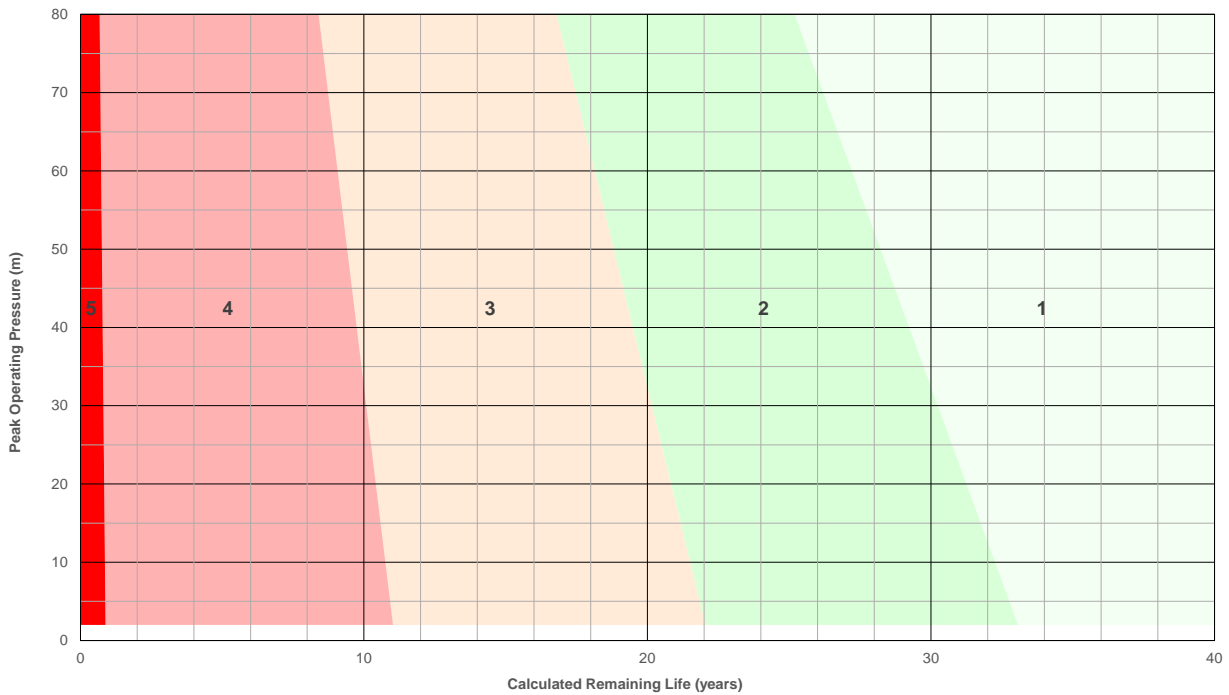
[20] The water condition grading charts may be used for stormwater asbestos cement pressure pipes.

Condition Grading - DN 75 Class CD (Water)
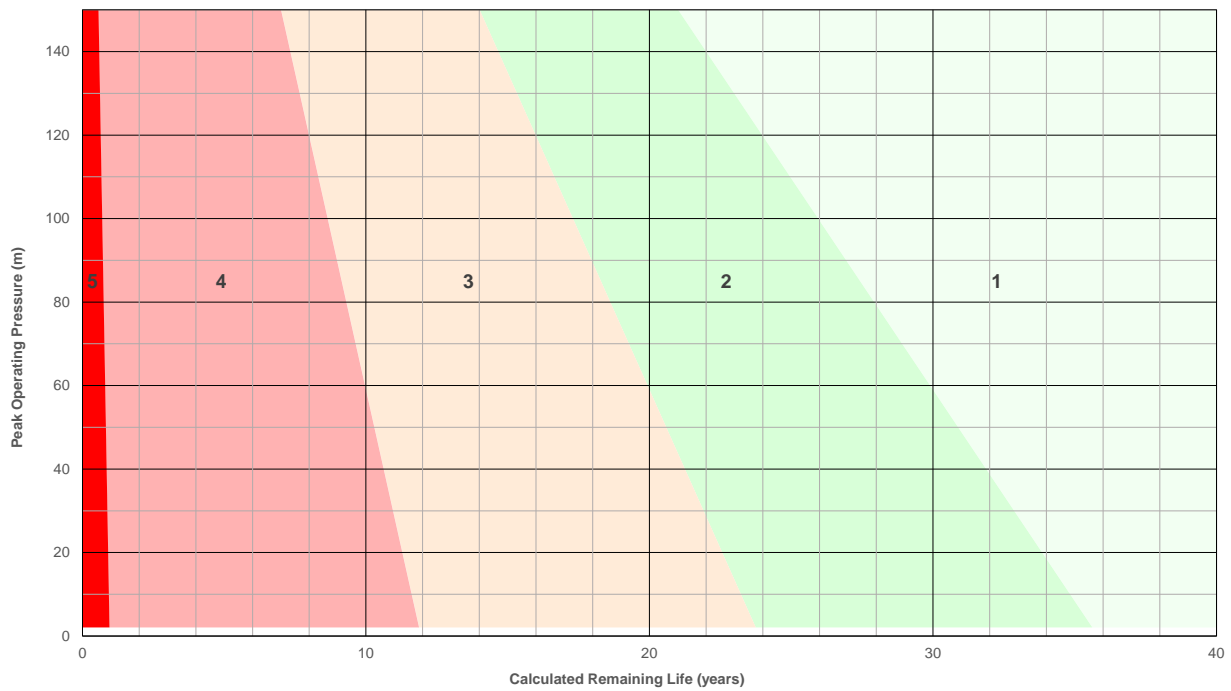
Condition Grading - DN 80 Class EF (Water)
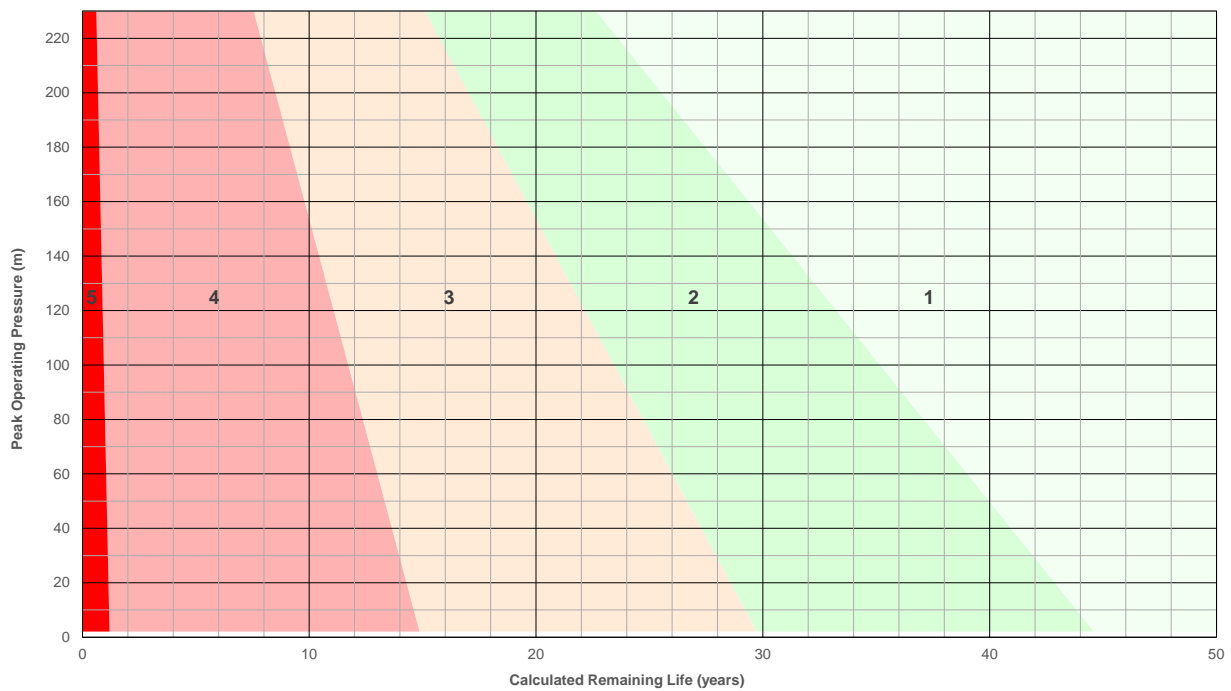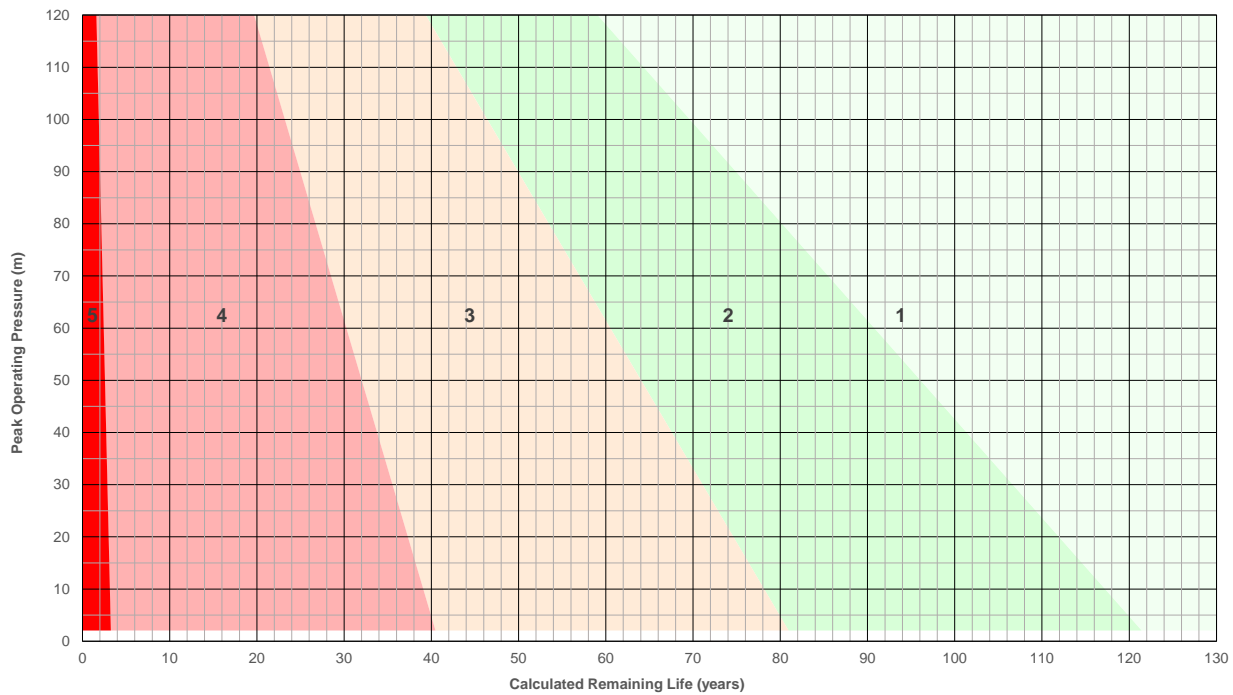

Note: Class E and F are based on NZS 3202:1977

Condition Grading - DN 100 Class AB (Water)
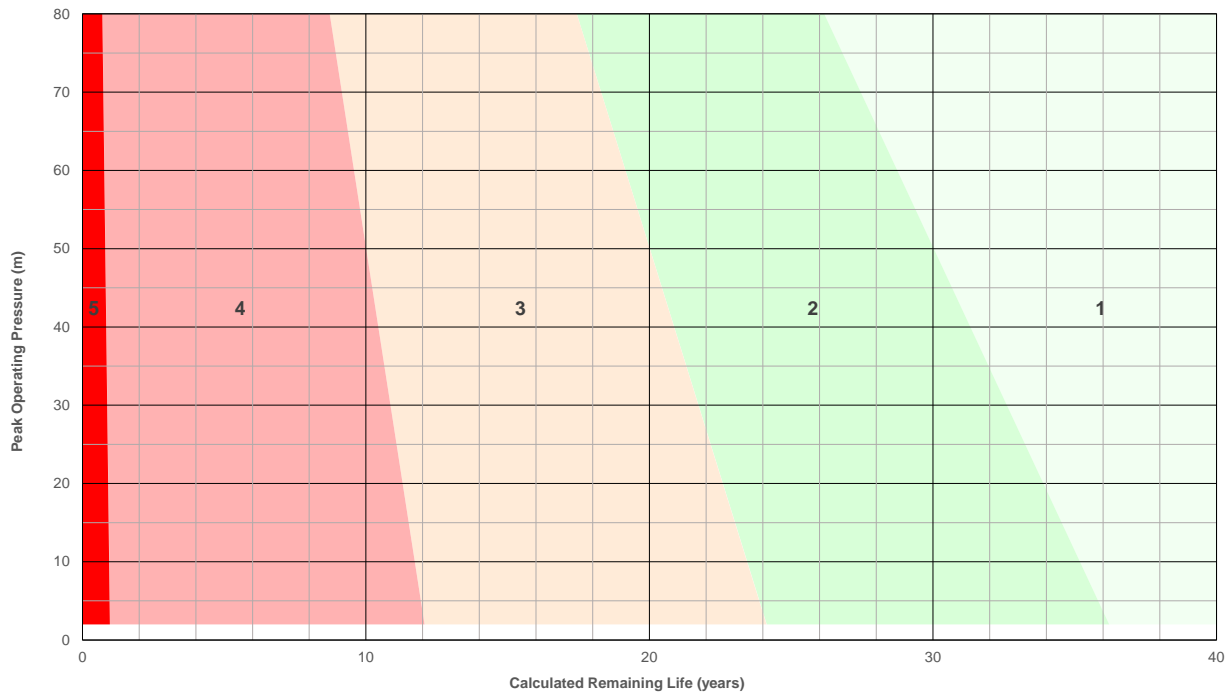
Condition Grading - DN 100 Class CD (Water)
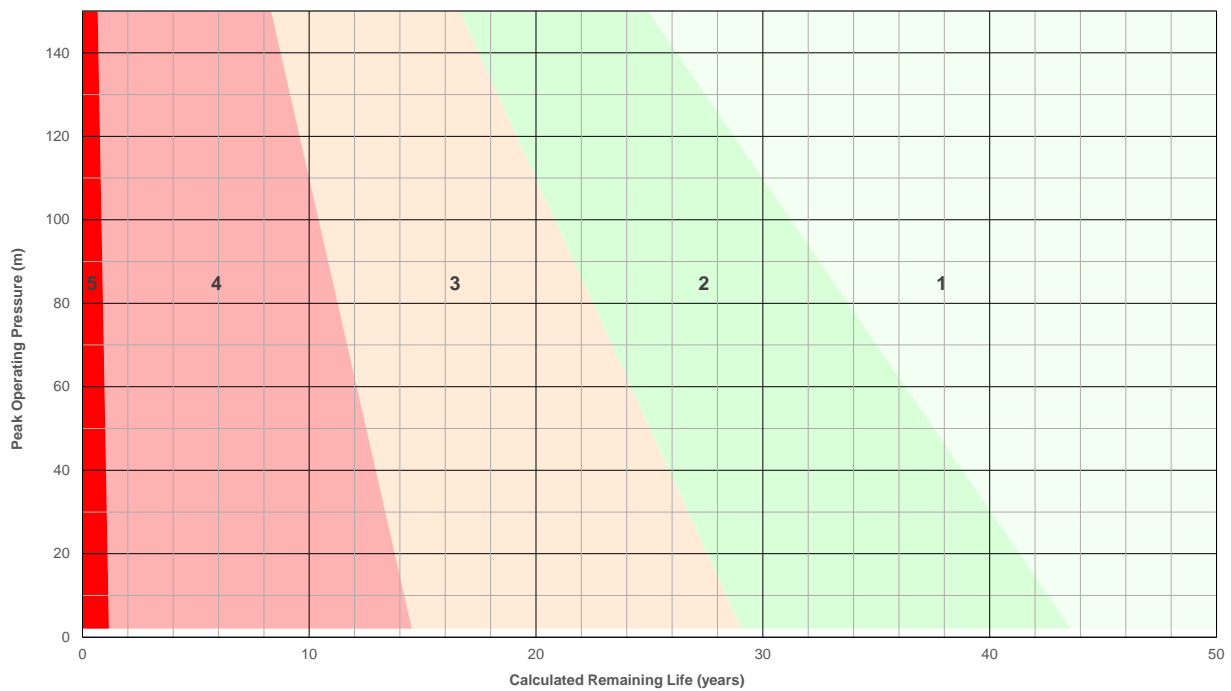
Condition Grading - DN 100 Class EF (Water)
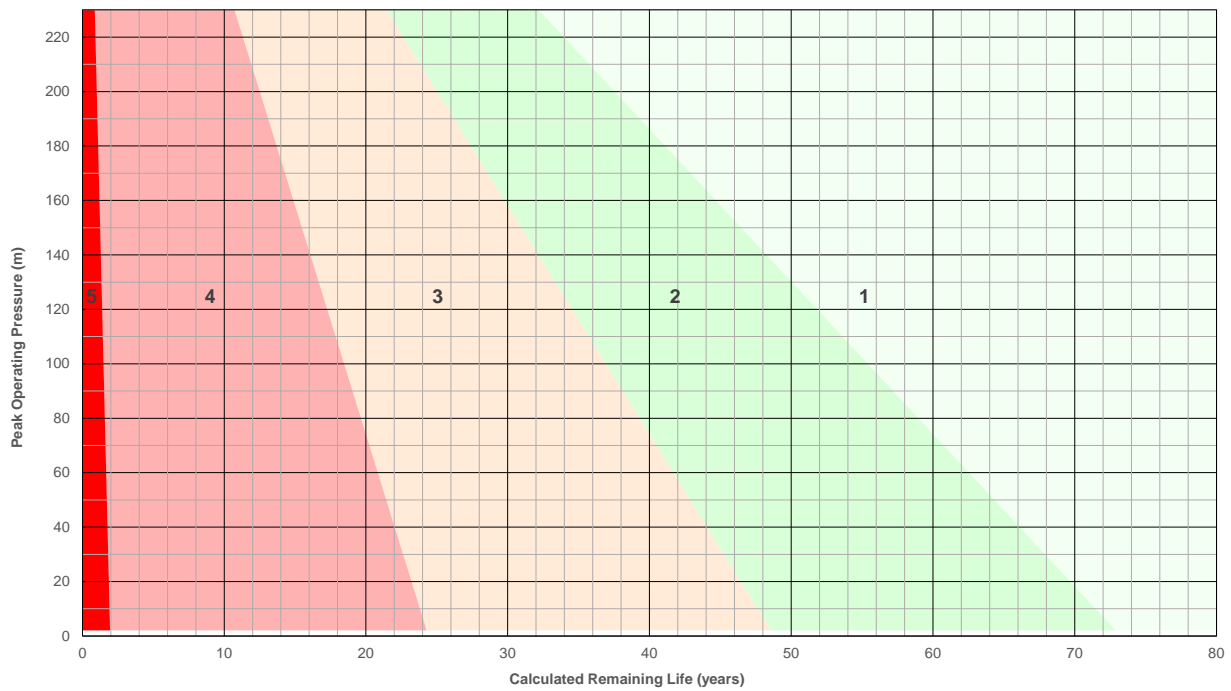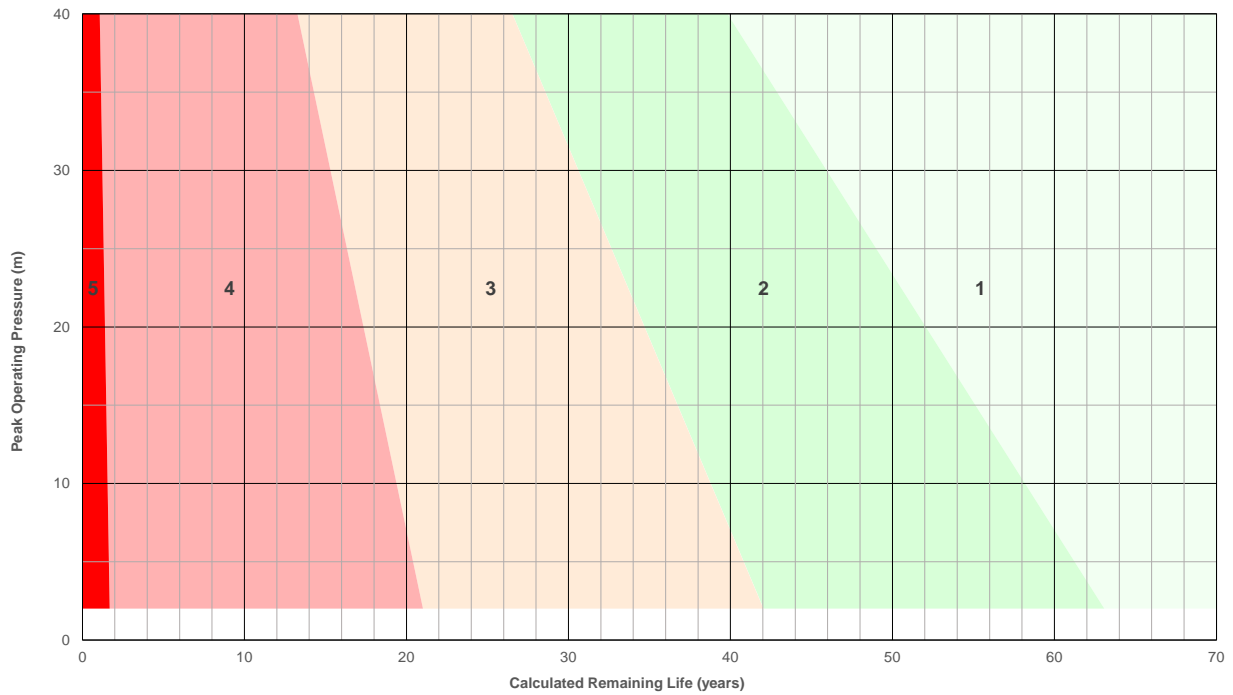

Note: Class E and F are based on NZS 3202:1977

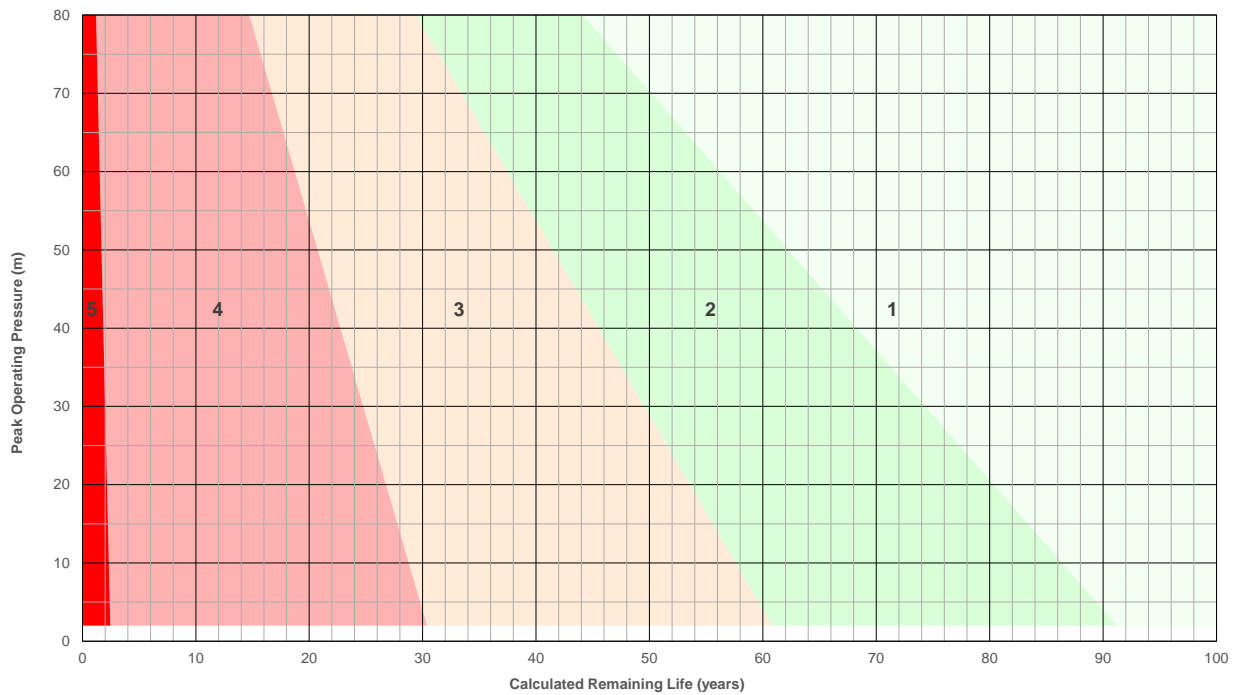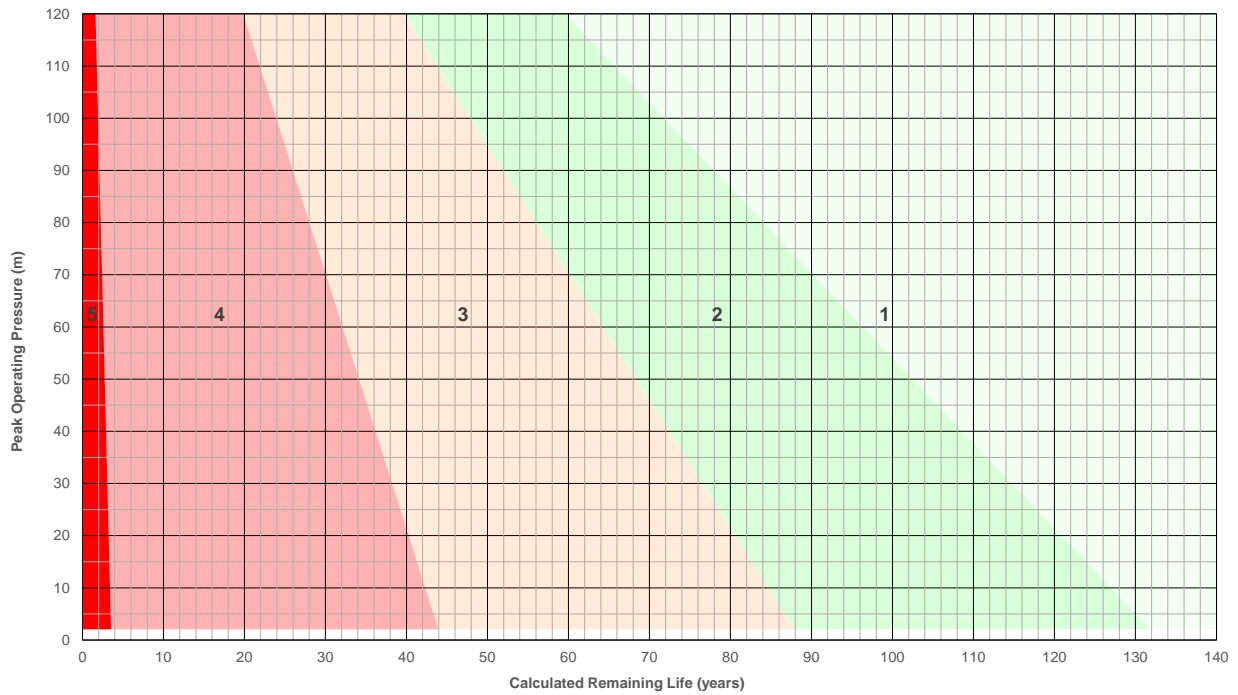**Condition Grading - DN 150 Class AB (Water)**
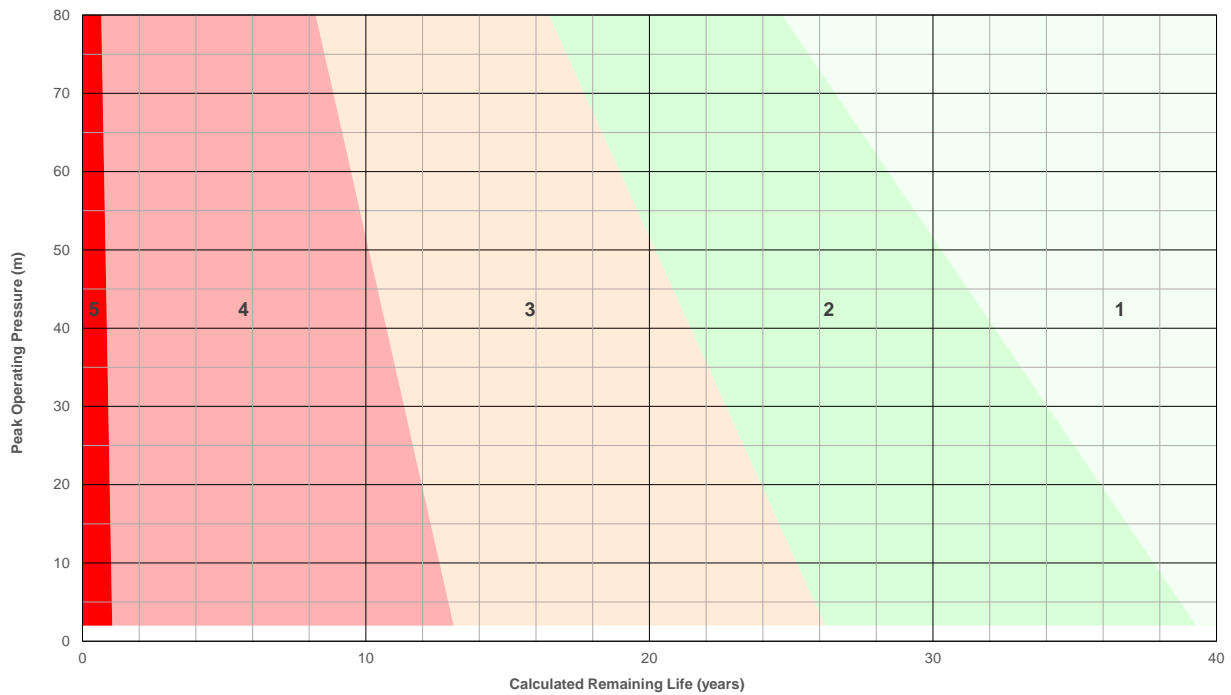
Condition Grading - DN 150 Class C (Water)
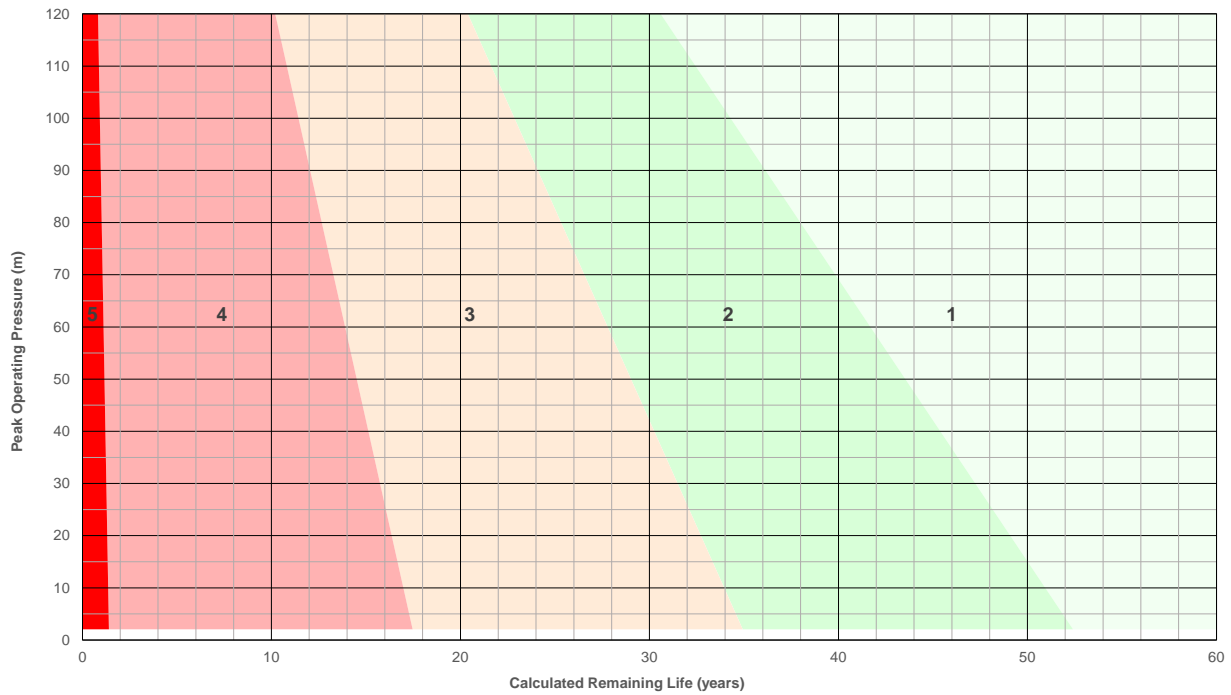
Condition Grading - DN 150 Class D (Water)
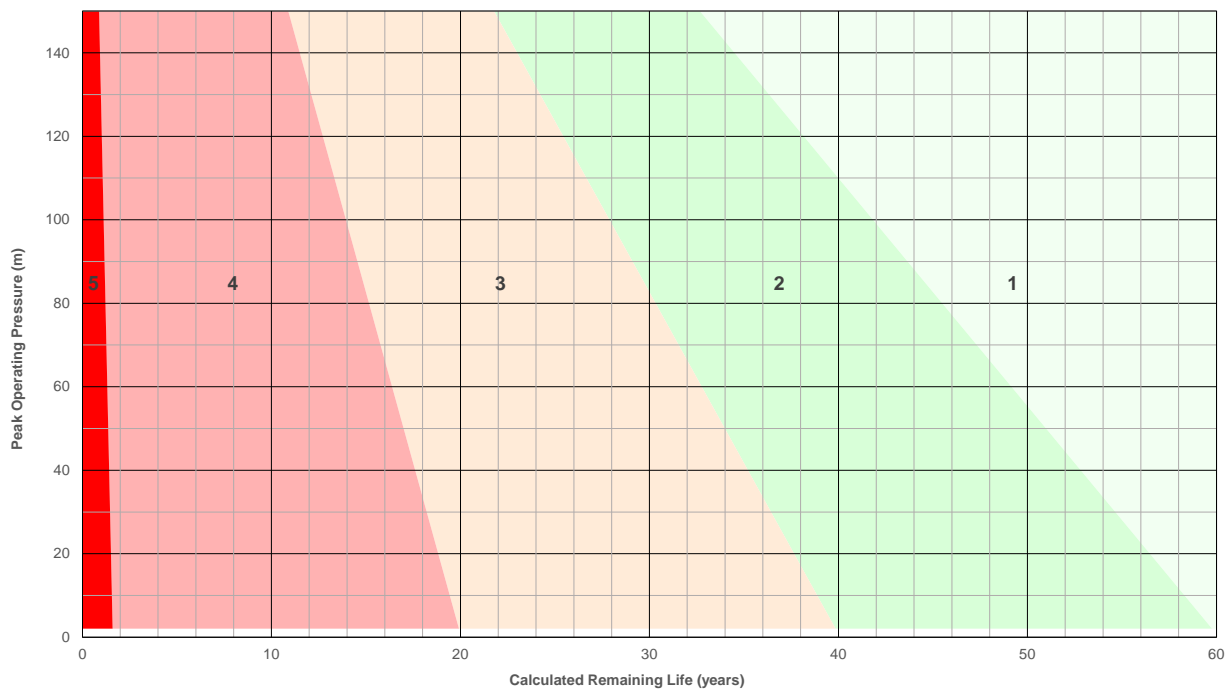
Condition Grading - DN 150 Class E (Water)
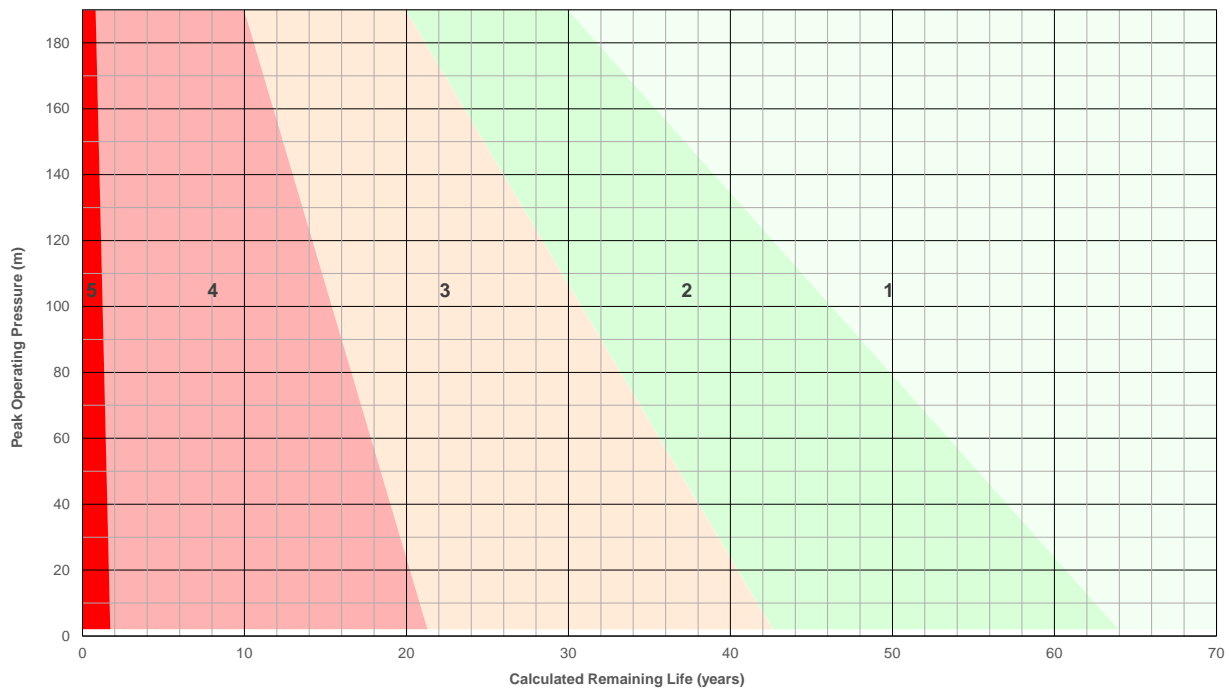
Note: Class E and F are based on NZS 3202:1977

Condition Grading - DN 150 Class F (Water)
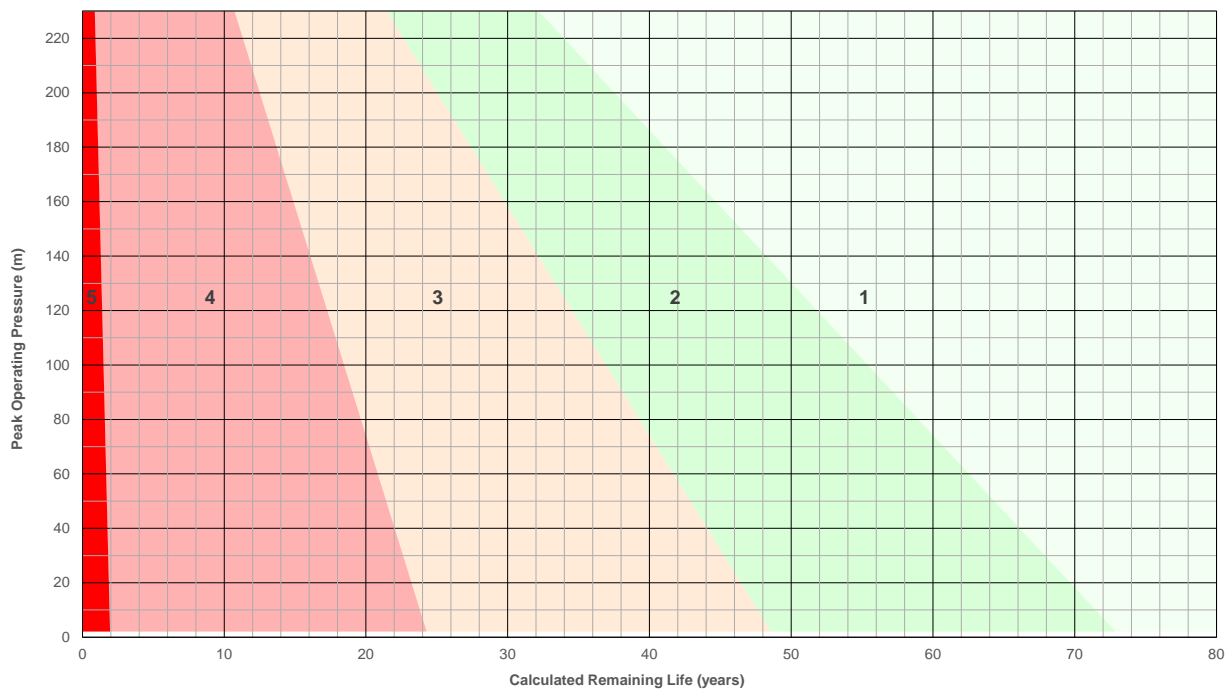
Note: Class E and F are based on NZS 3202:1977

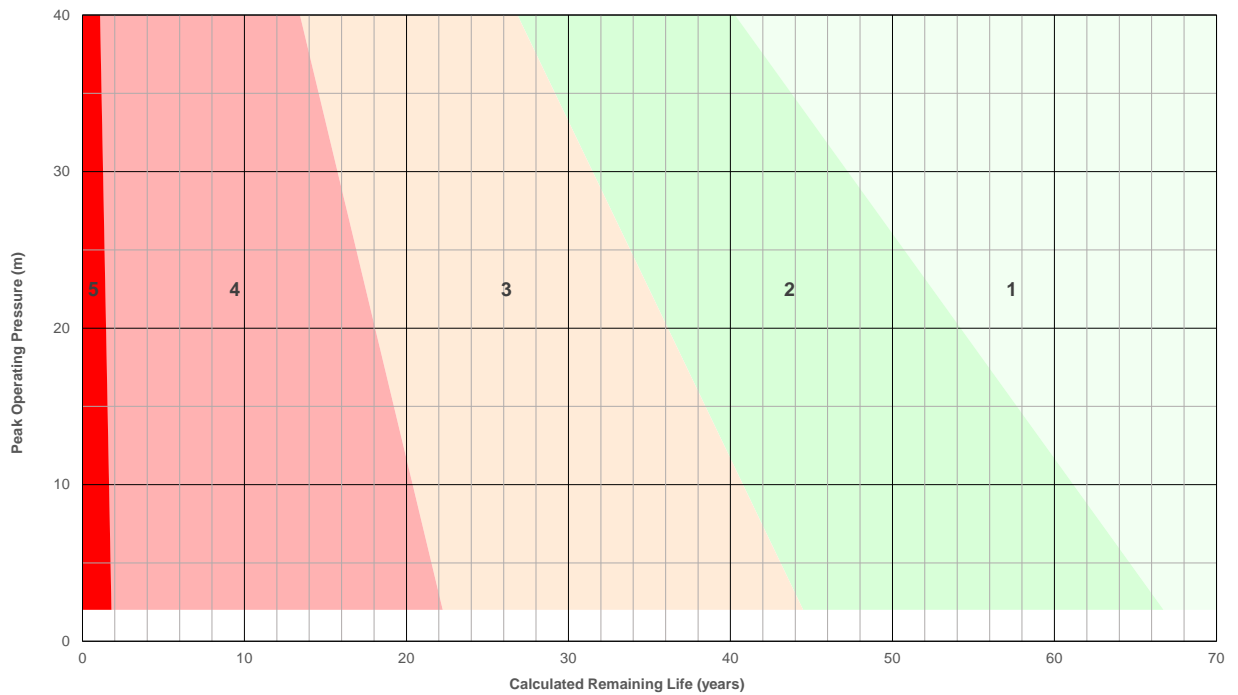**Condition Grading - DN 200 Class A (Water)**
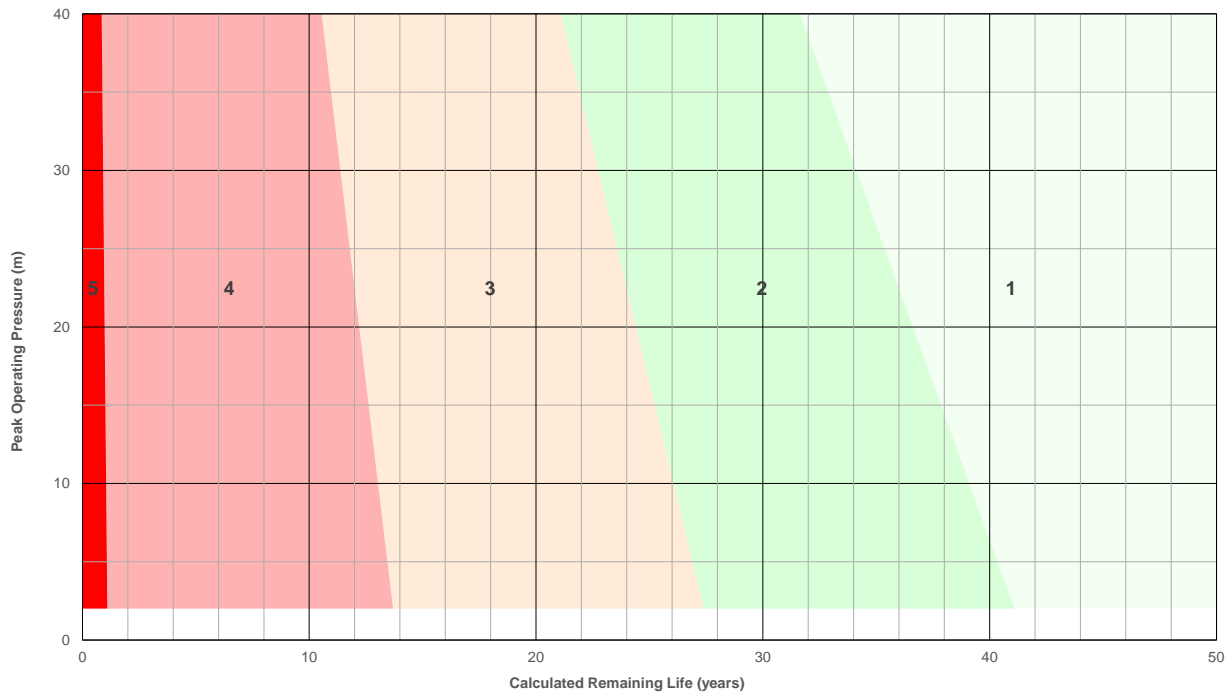
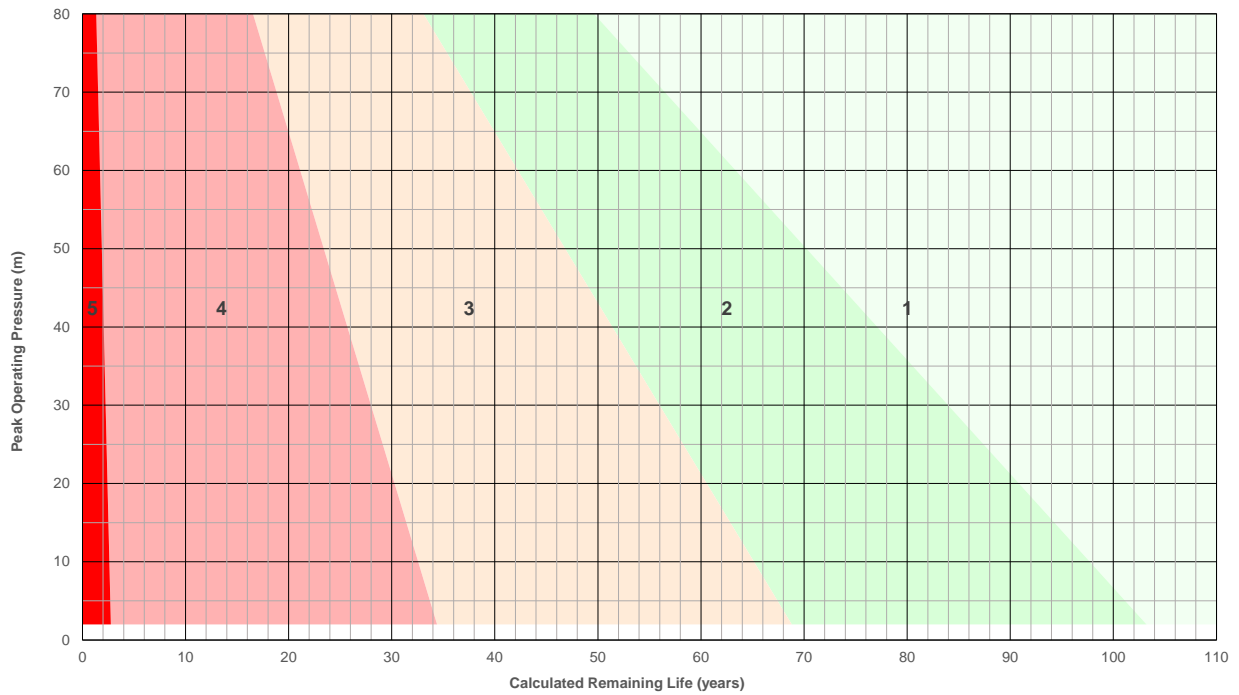**Condition Grading - DN 200 Class B (Water)**
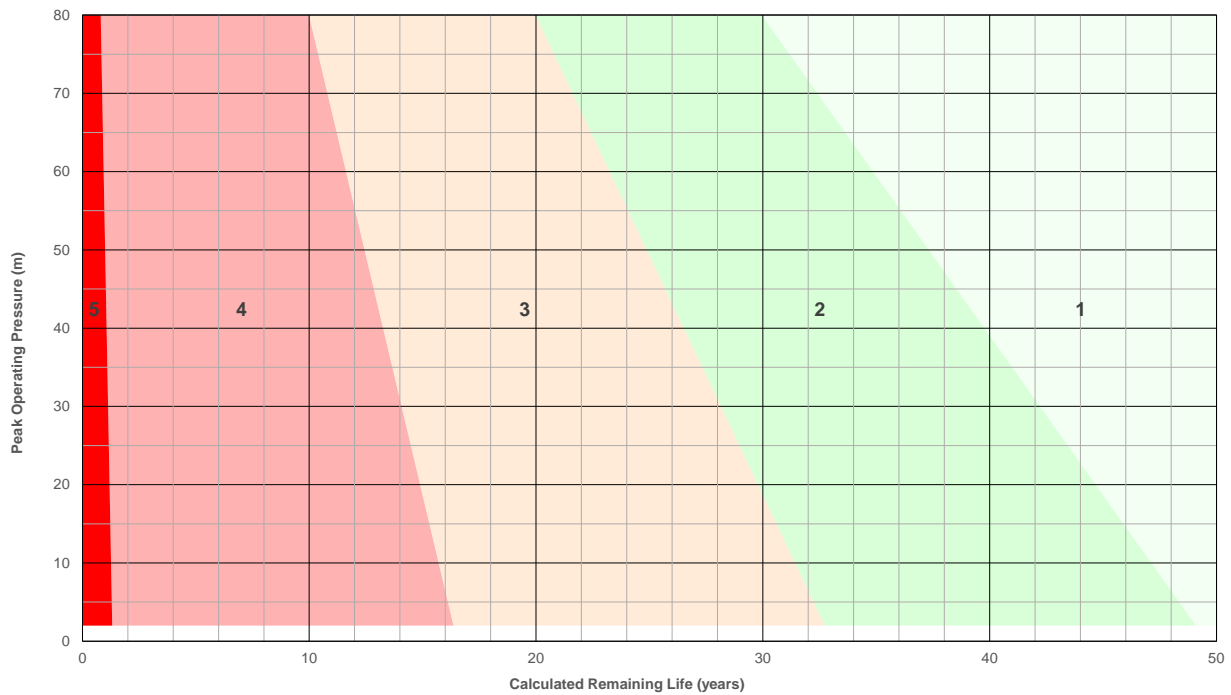
Condition Grading - DN 200 Class C (Water)
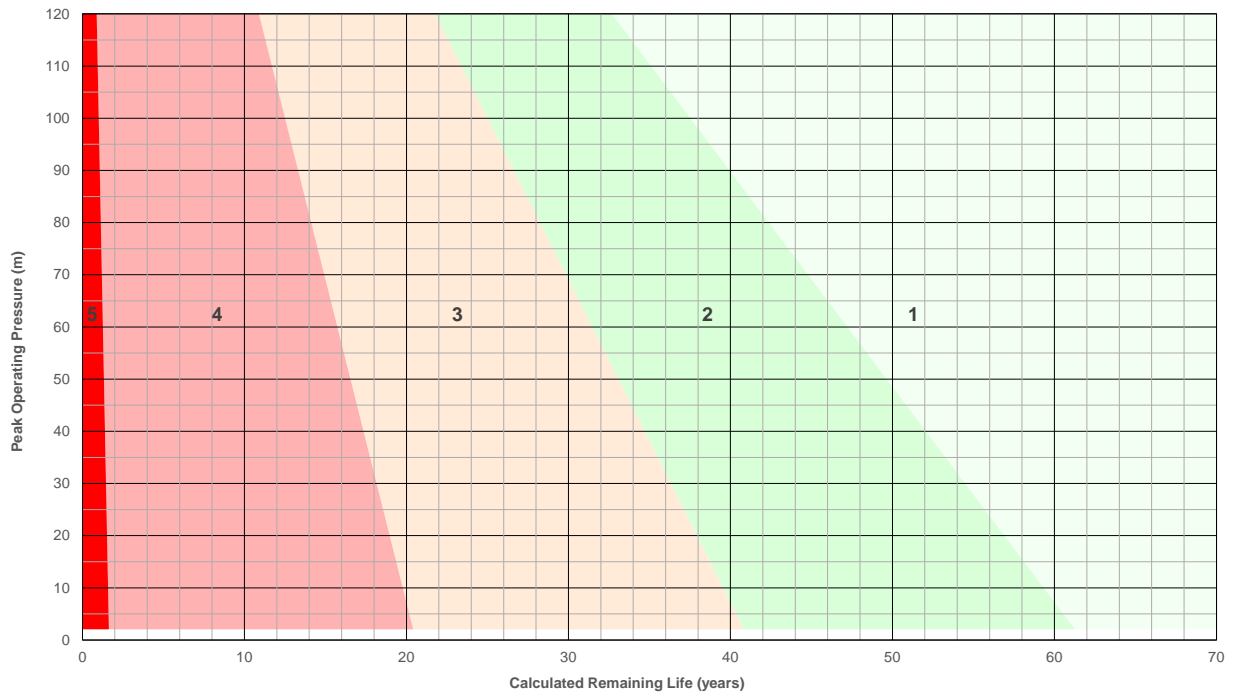
Condition Grading - DN 200 Class D (Water)
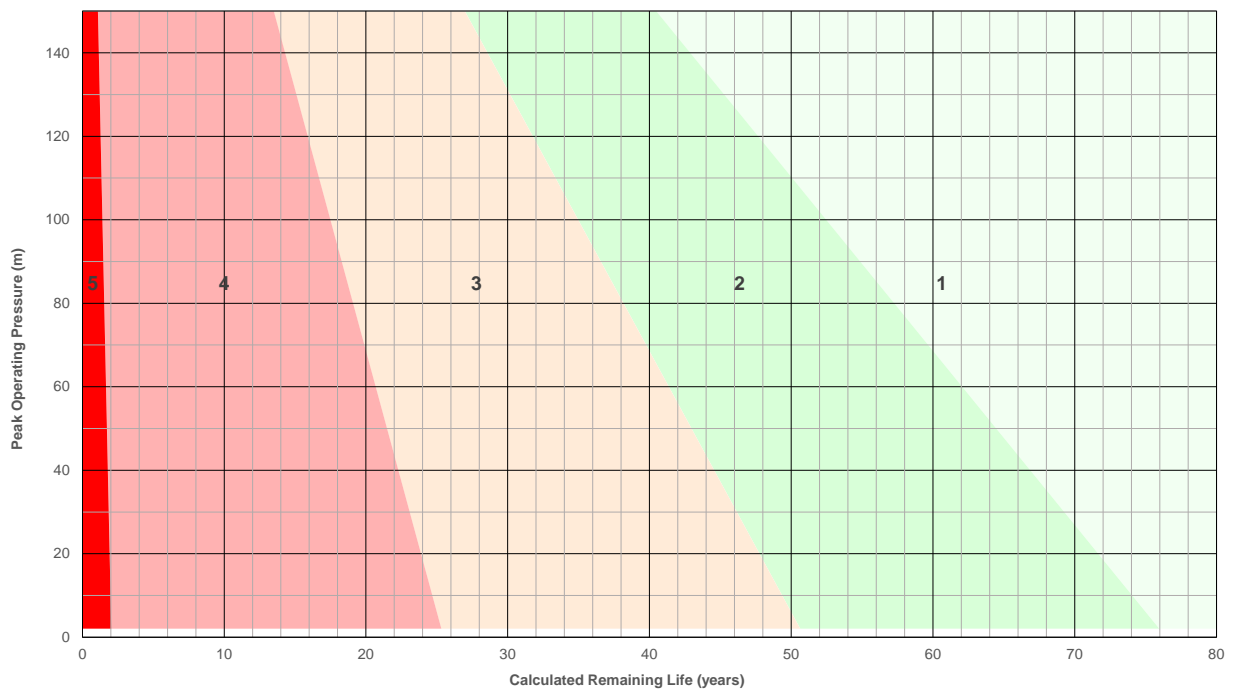
Condition Grading - DN 225 Class A (Water)
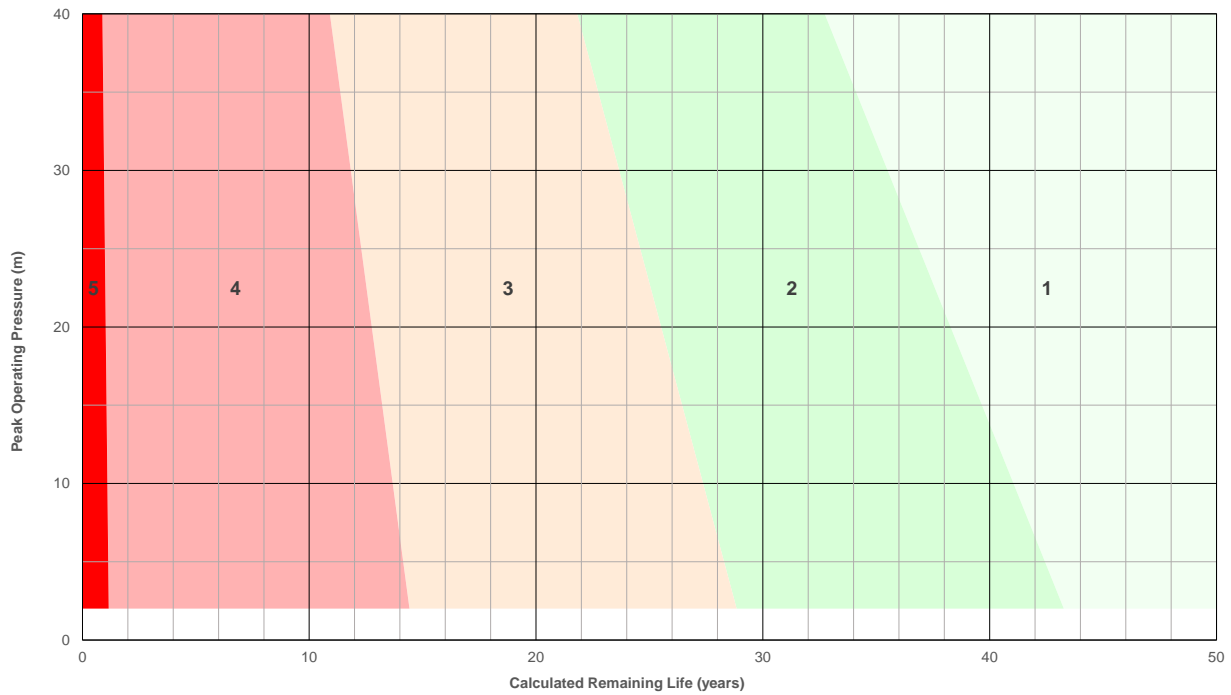
Condition Grading - DN 225 Class B (Water)
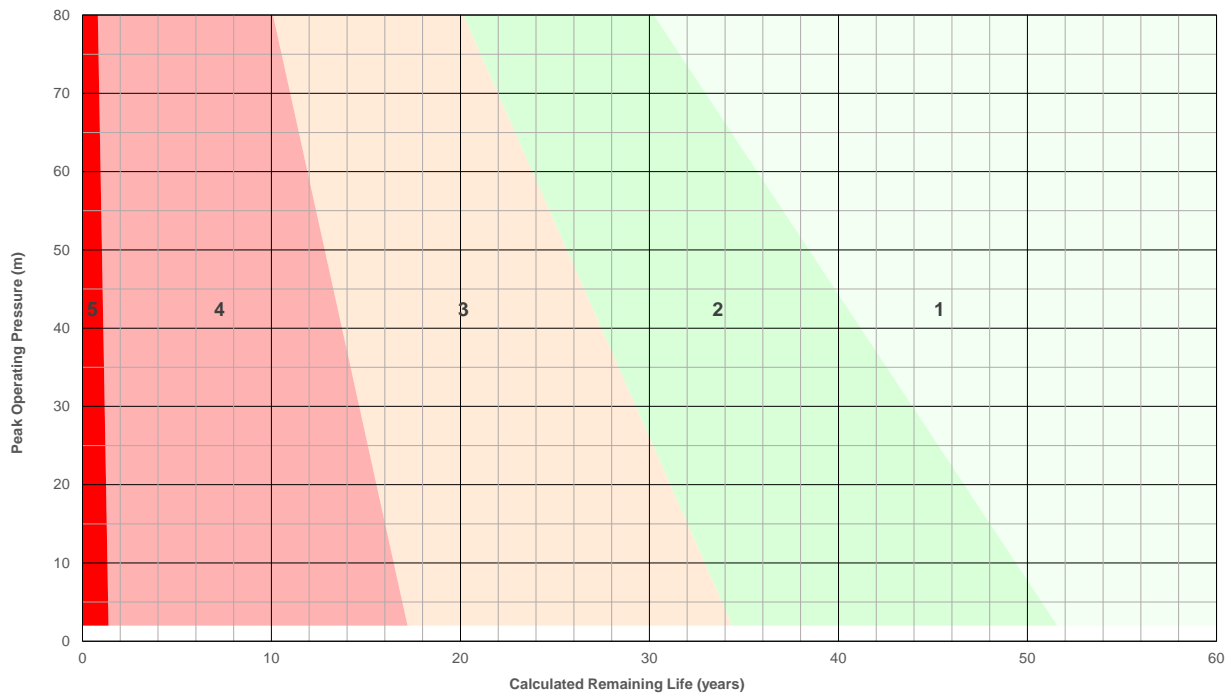
Condition Grading - DN 225 Class C (Water)
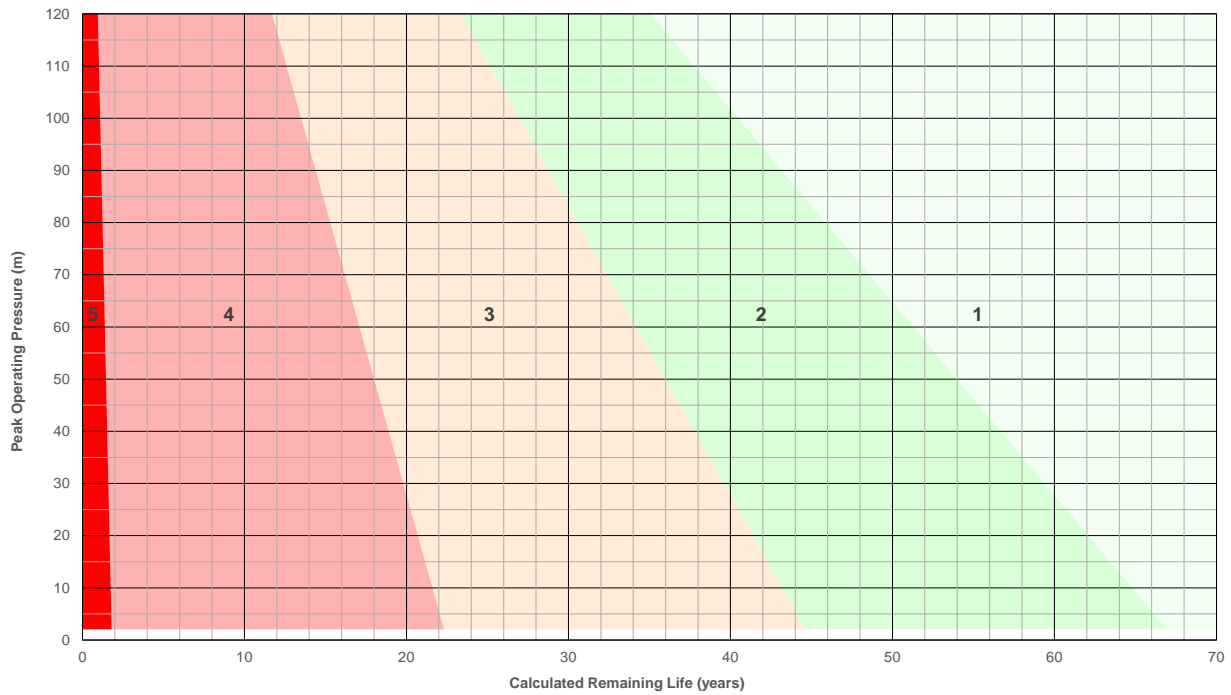
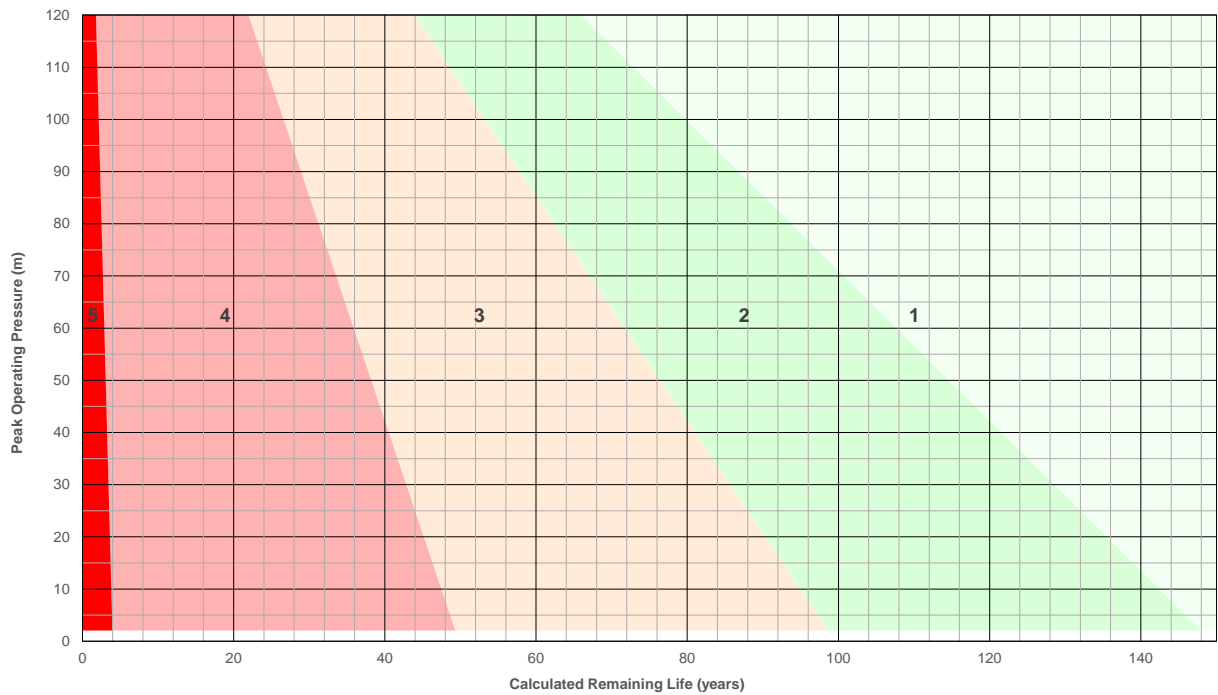**Condition Grading - DN 225 Class D (Water)**
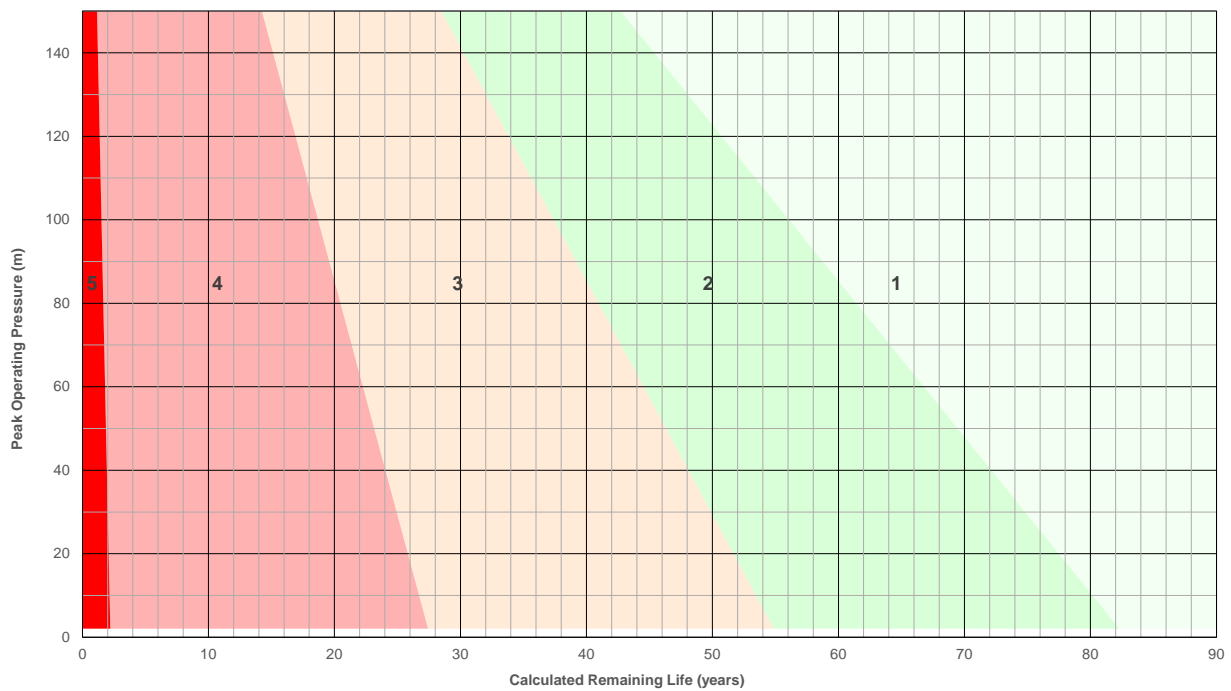
Condition Grading - DN 250 Class A (Water)
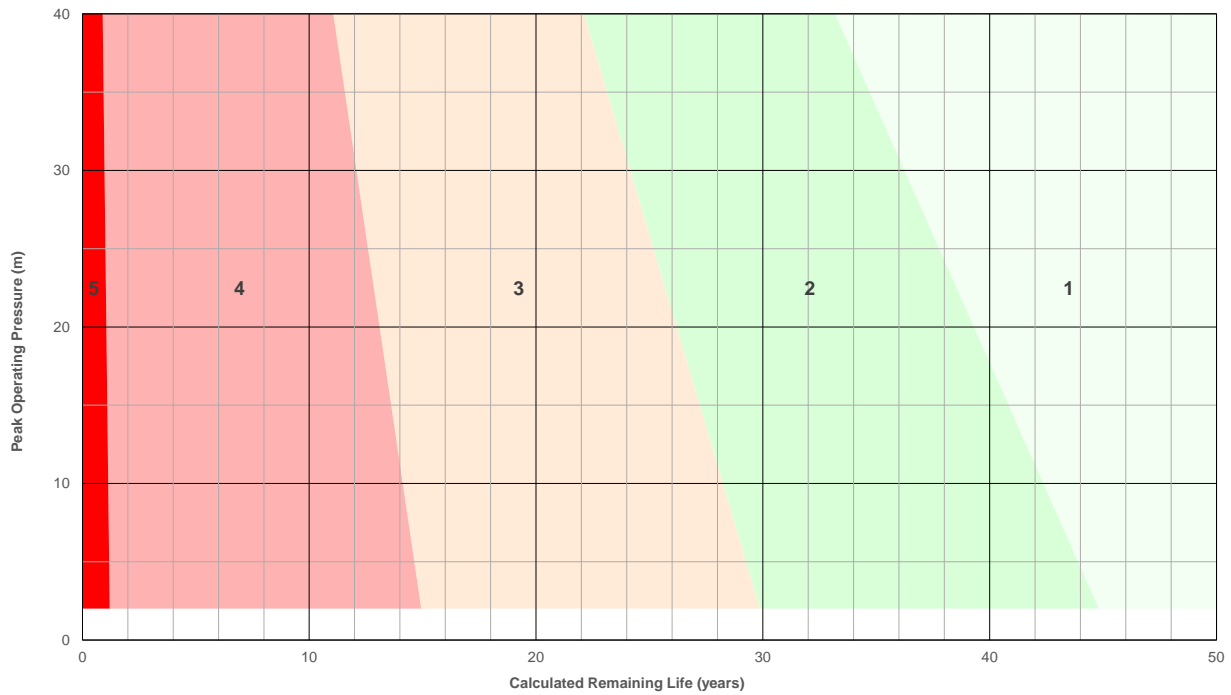
Condition Grading - DN 250 Class B (Water)
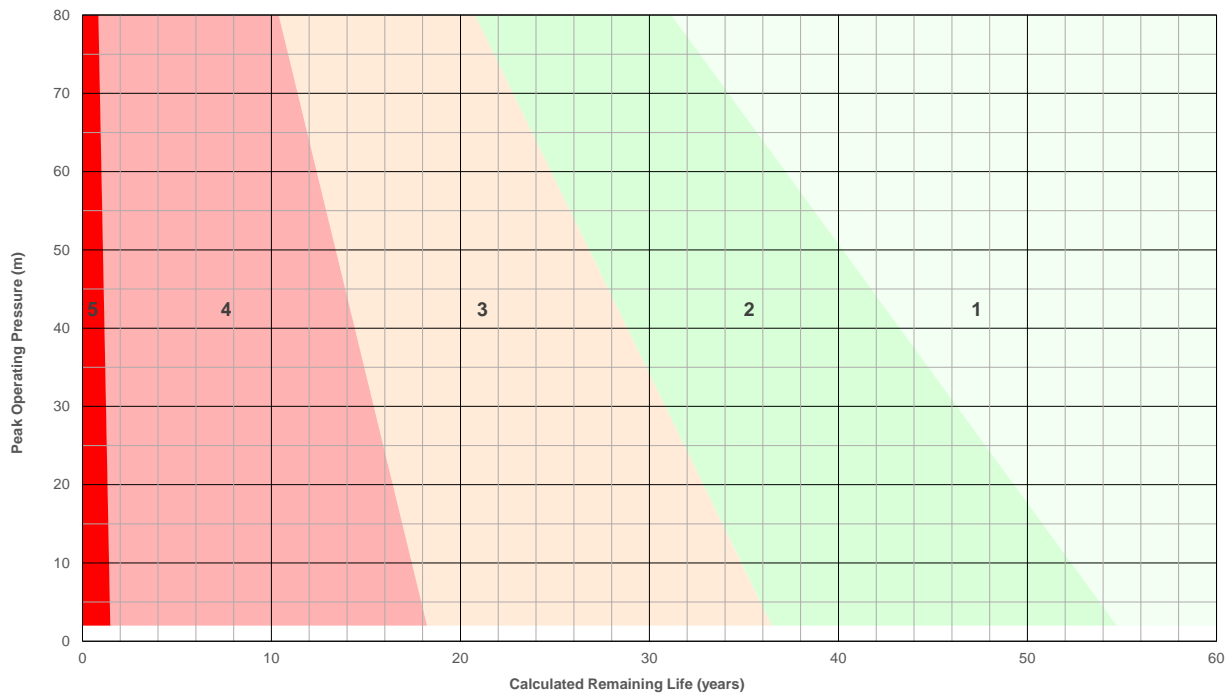
Condition Grading - DN 250 Class C (Water)
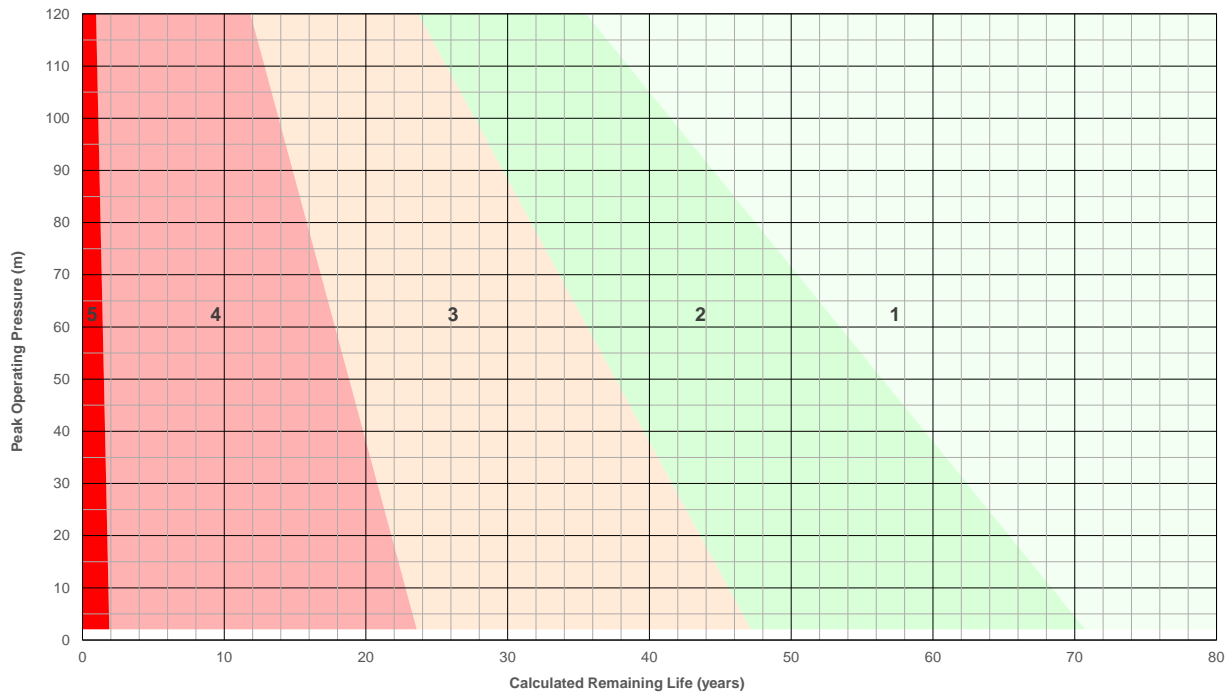
Condition Grading - DN 250 Class D (Water)
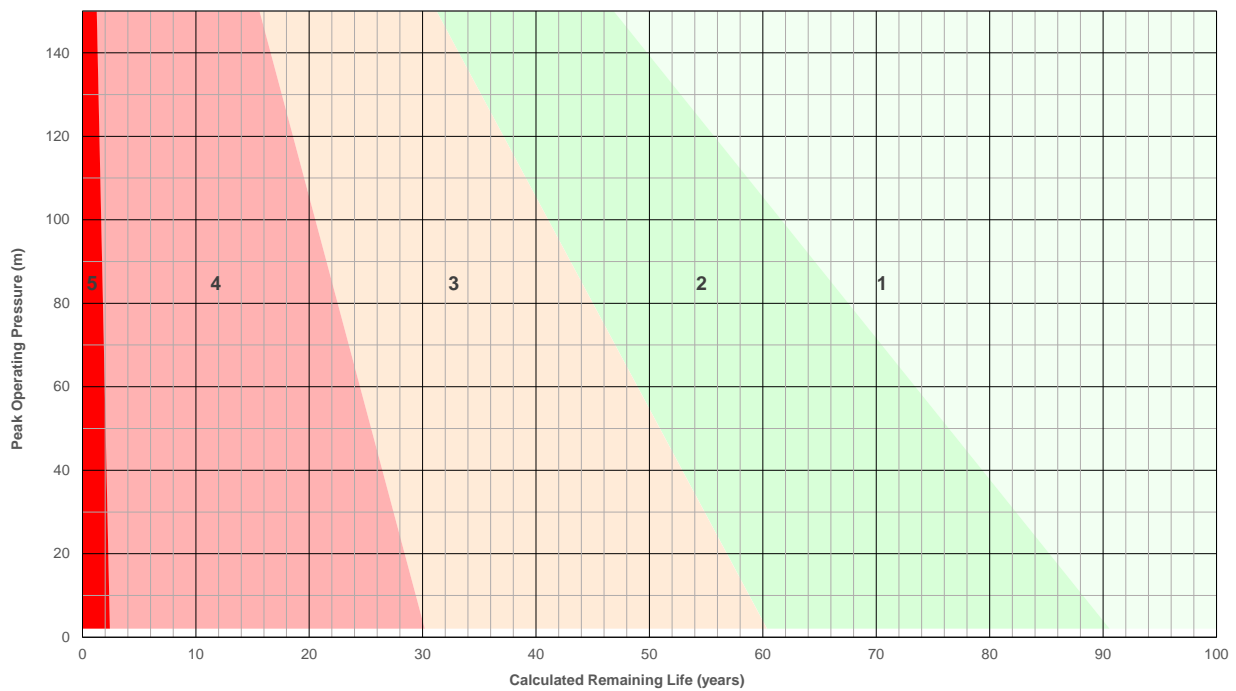
Condition Grading - DN 300 Class A (Water)
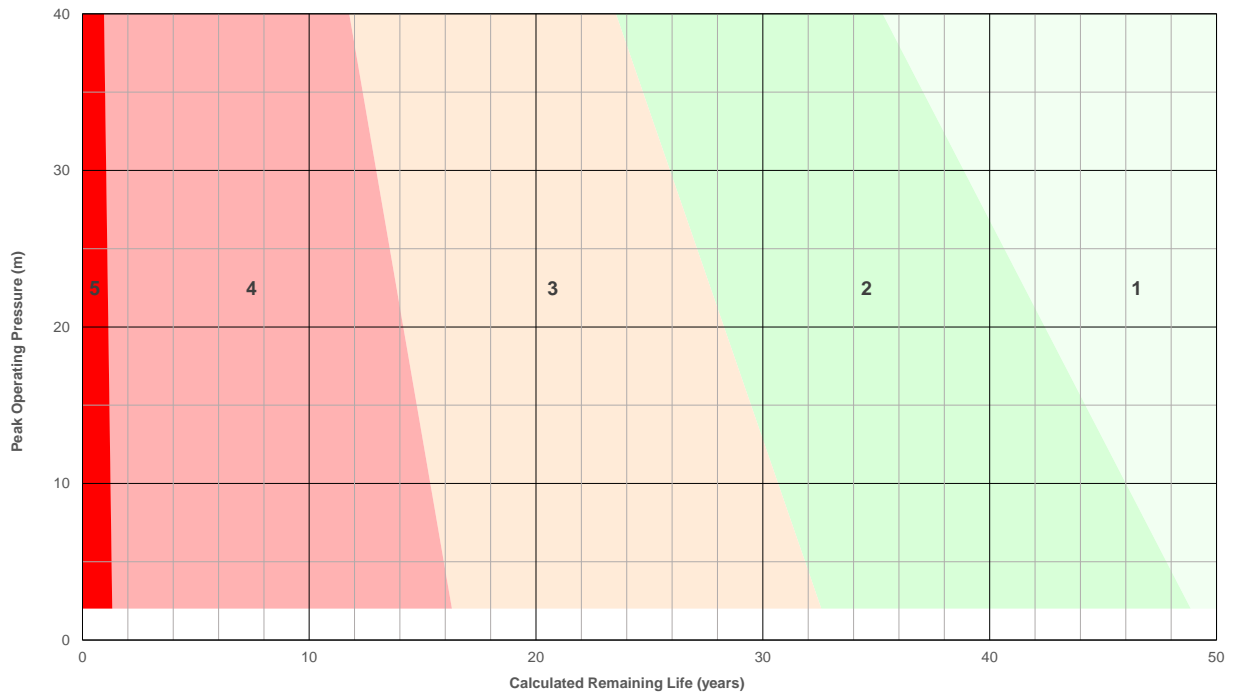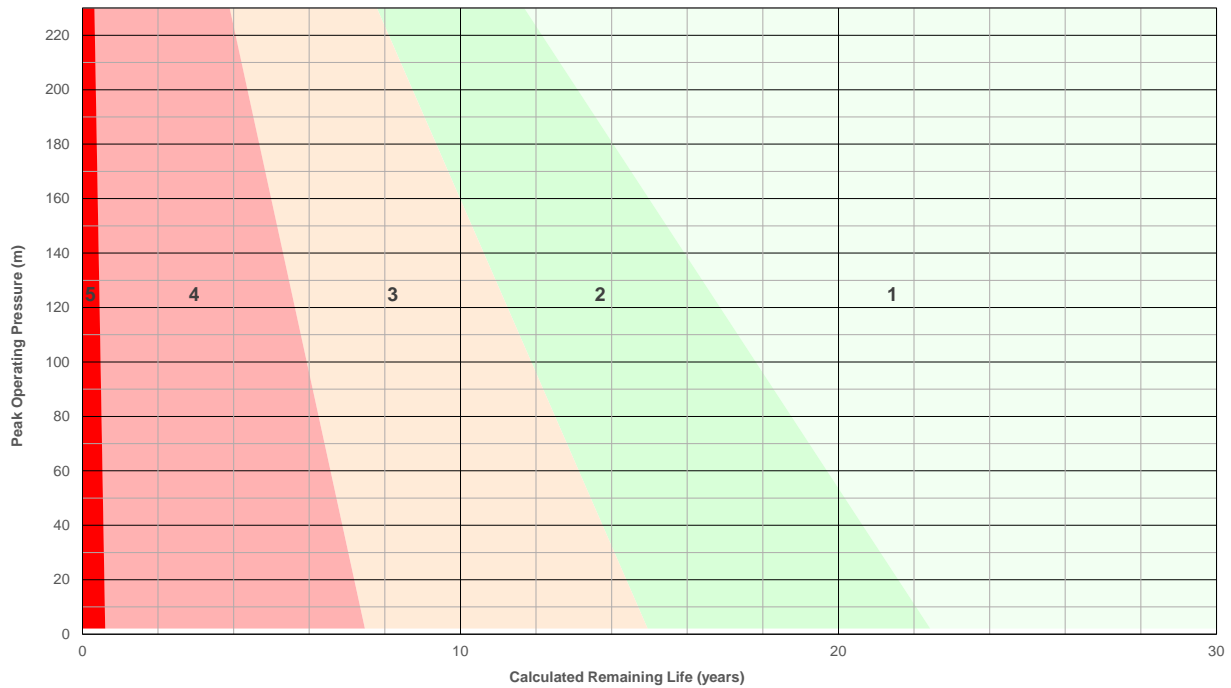

Condition Grading - DN 300 Class B (Water)
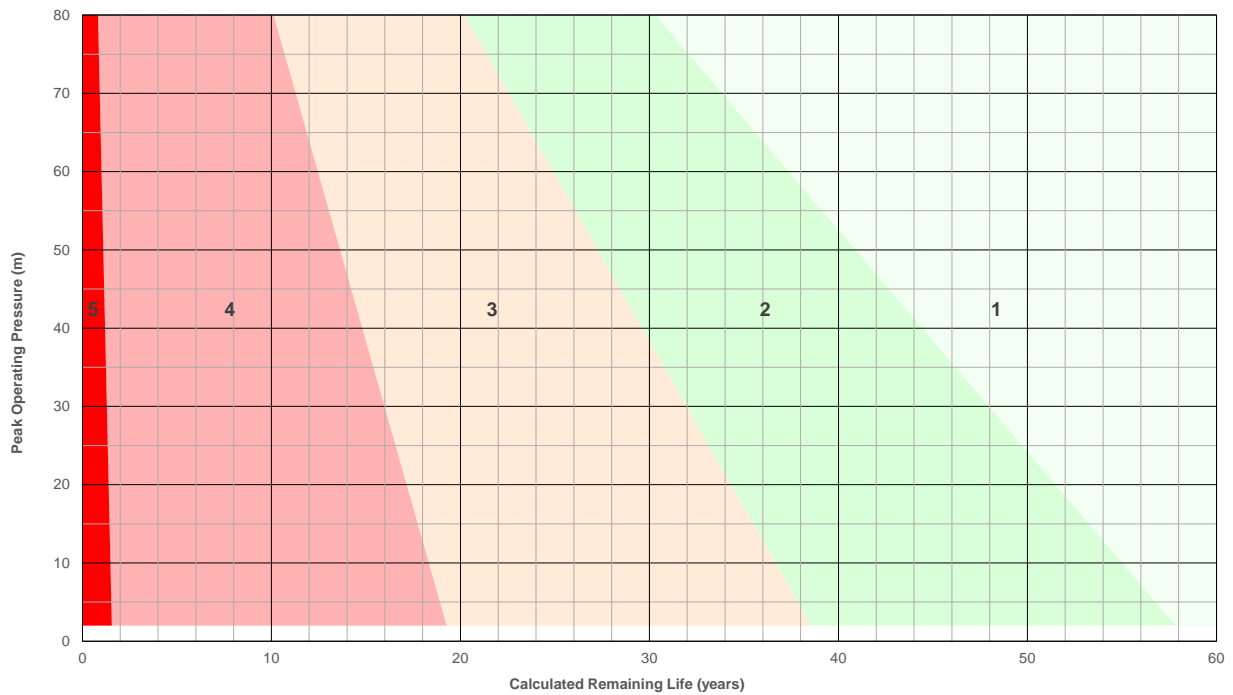
Condition Grading - DN 300 Class C (Water)
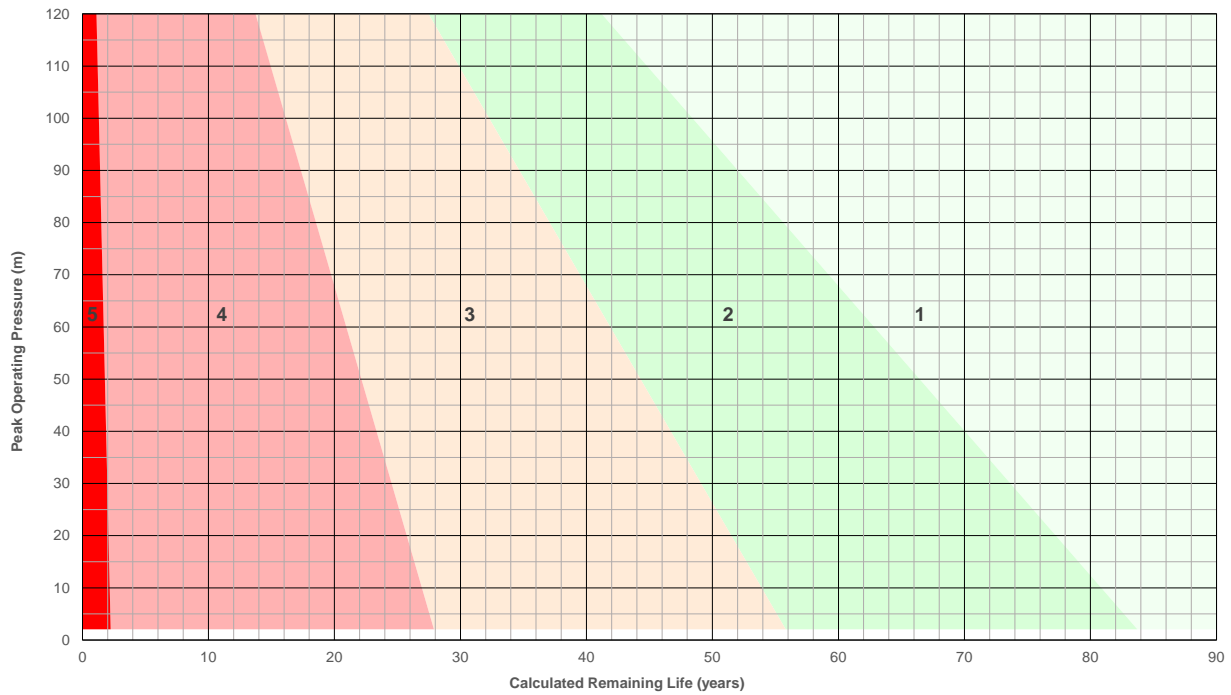
Condition Grading - DN 300 Class D (Water)
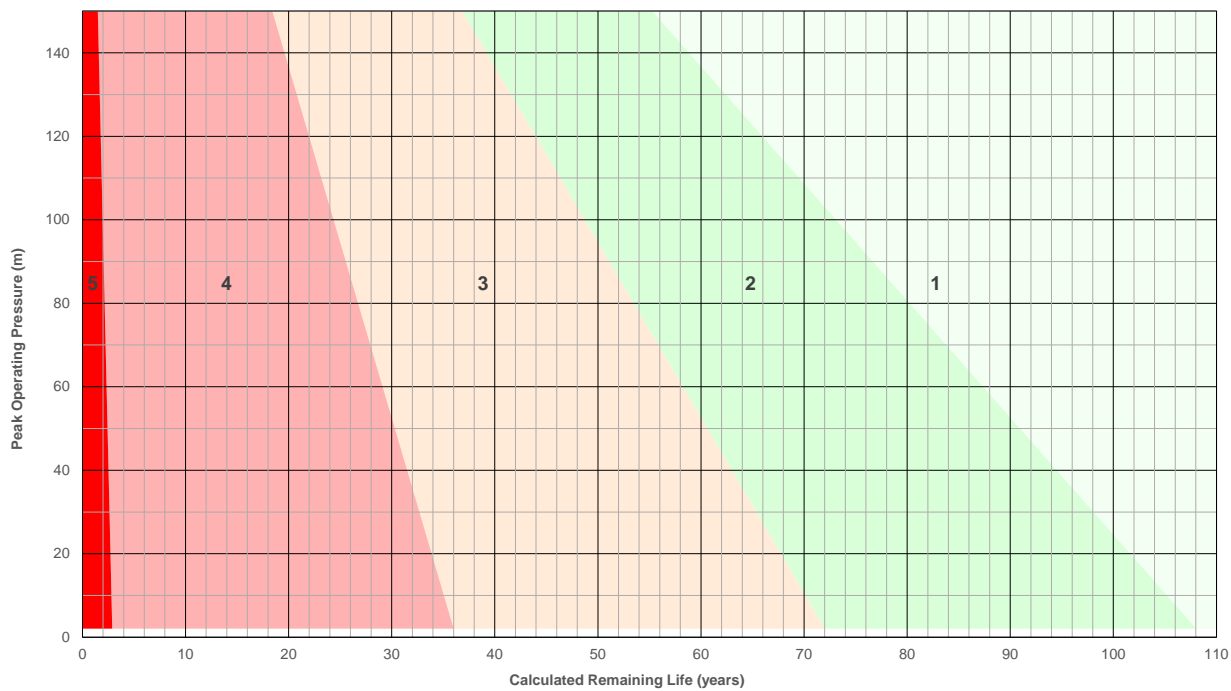
Condition Grading - DN 375 Class A (Water)
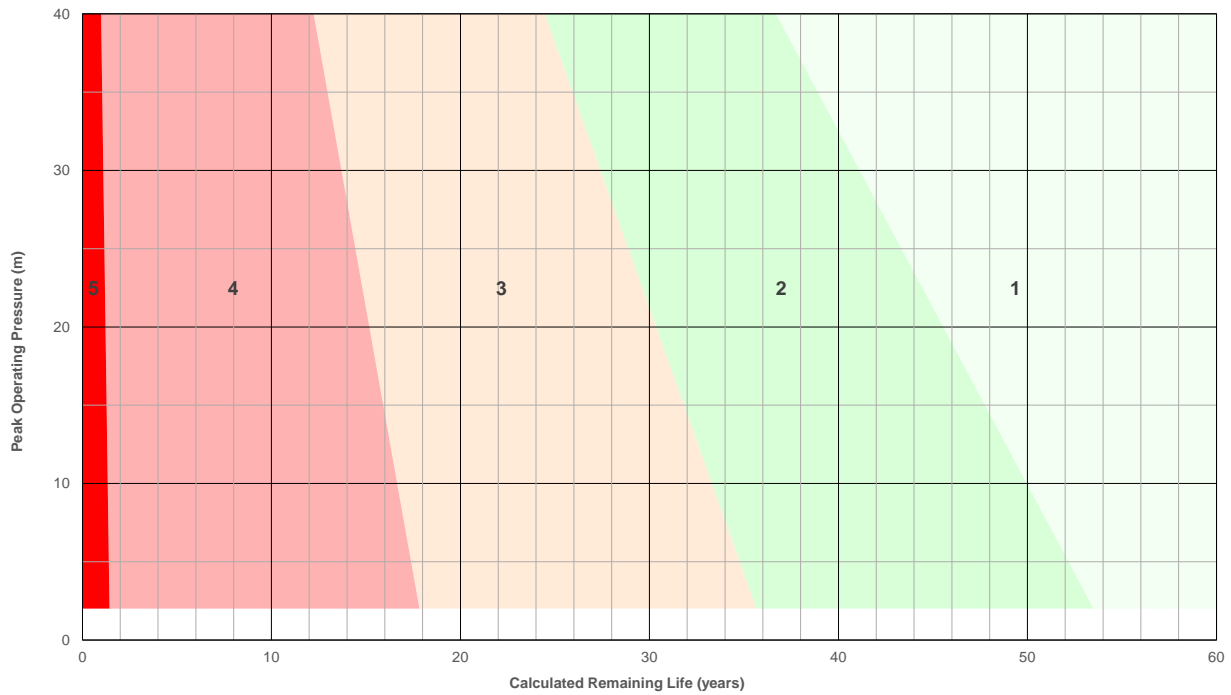
Condition Grading - DN 375 Class B (Water)
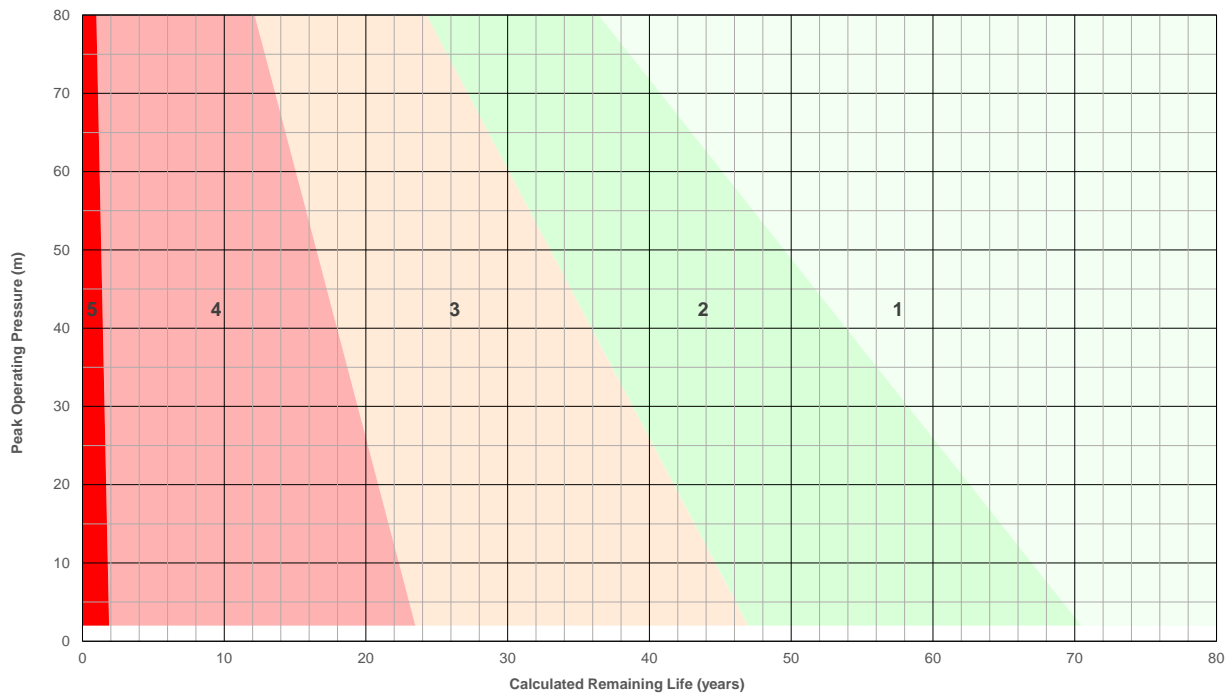
Condition Grading - DN 375 Class C (Water)
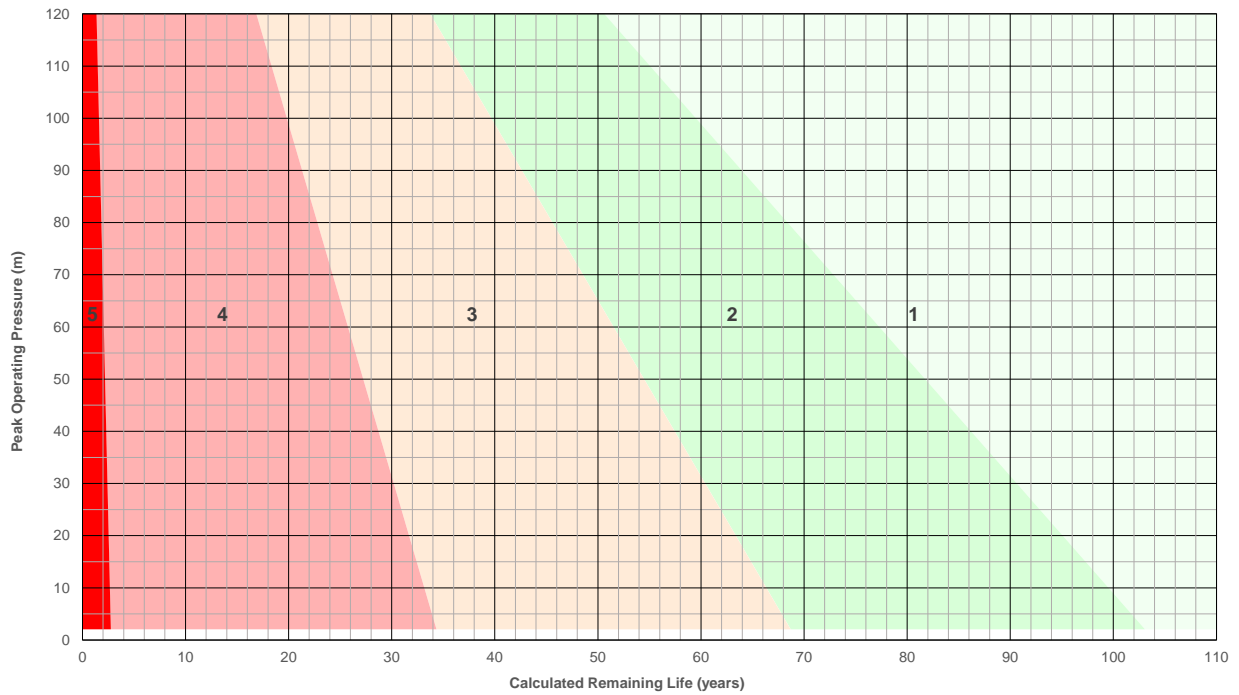
Condition Grading - DN 450 Class A (Water)
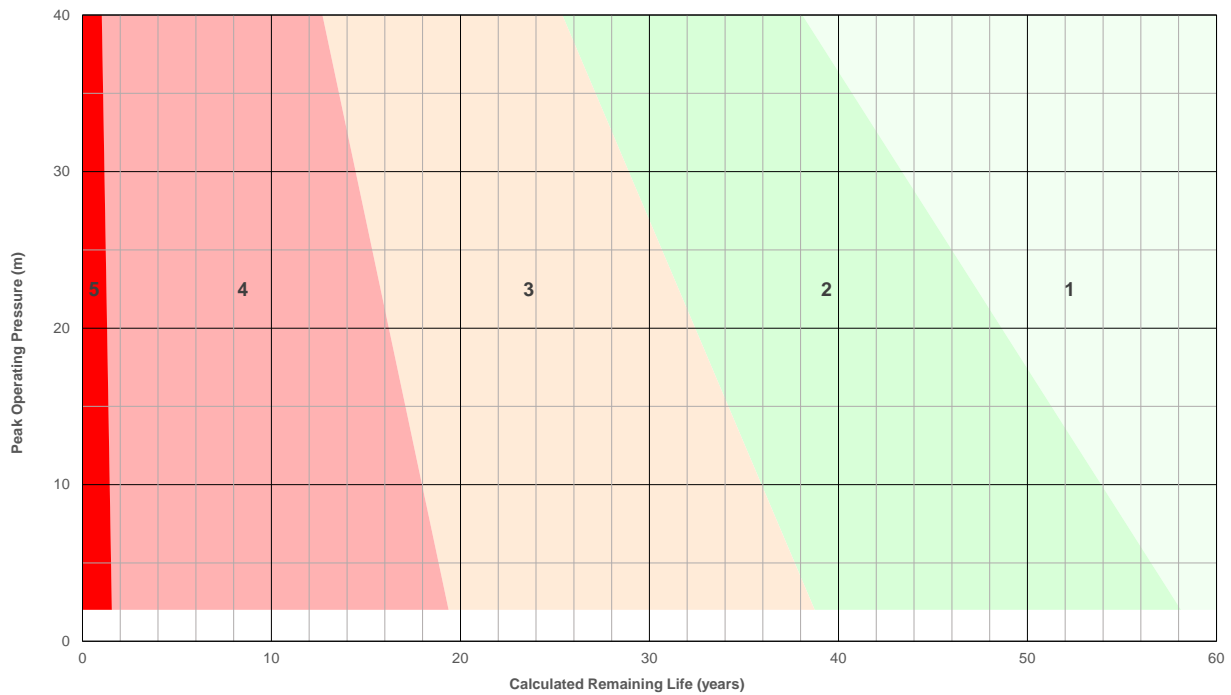
Condition Grading - DN 450 Class B (Water)
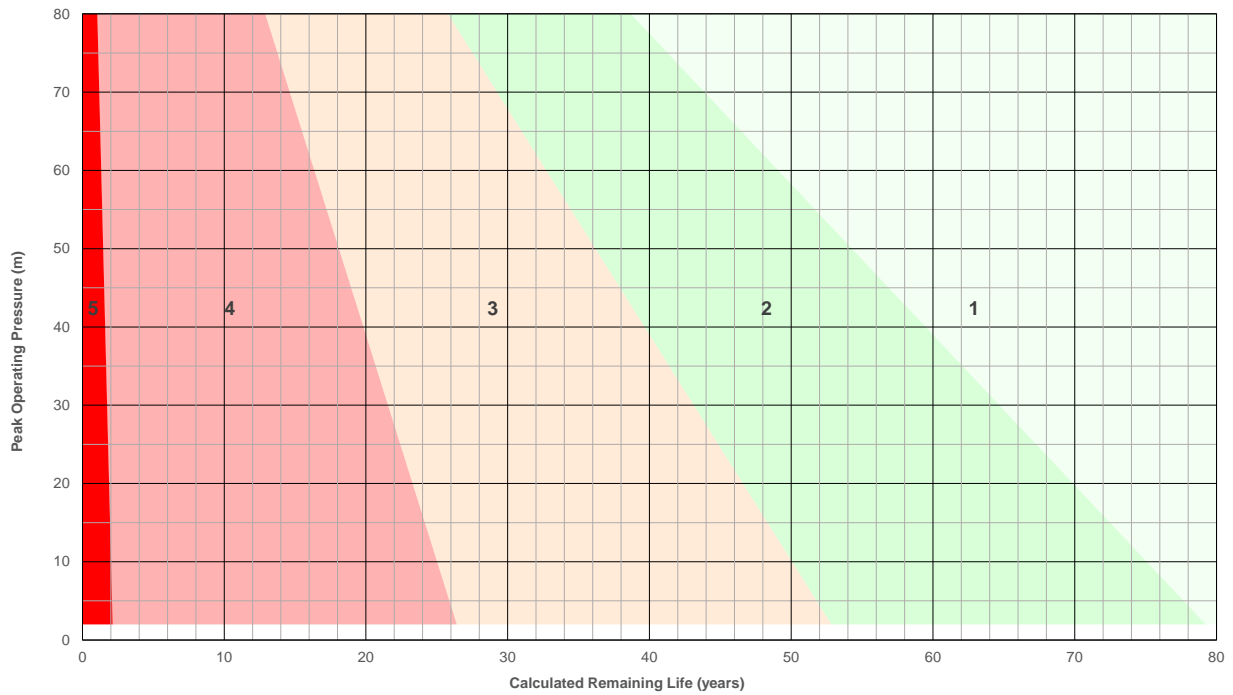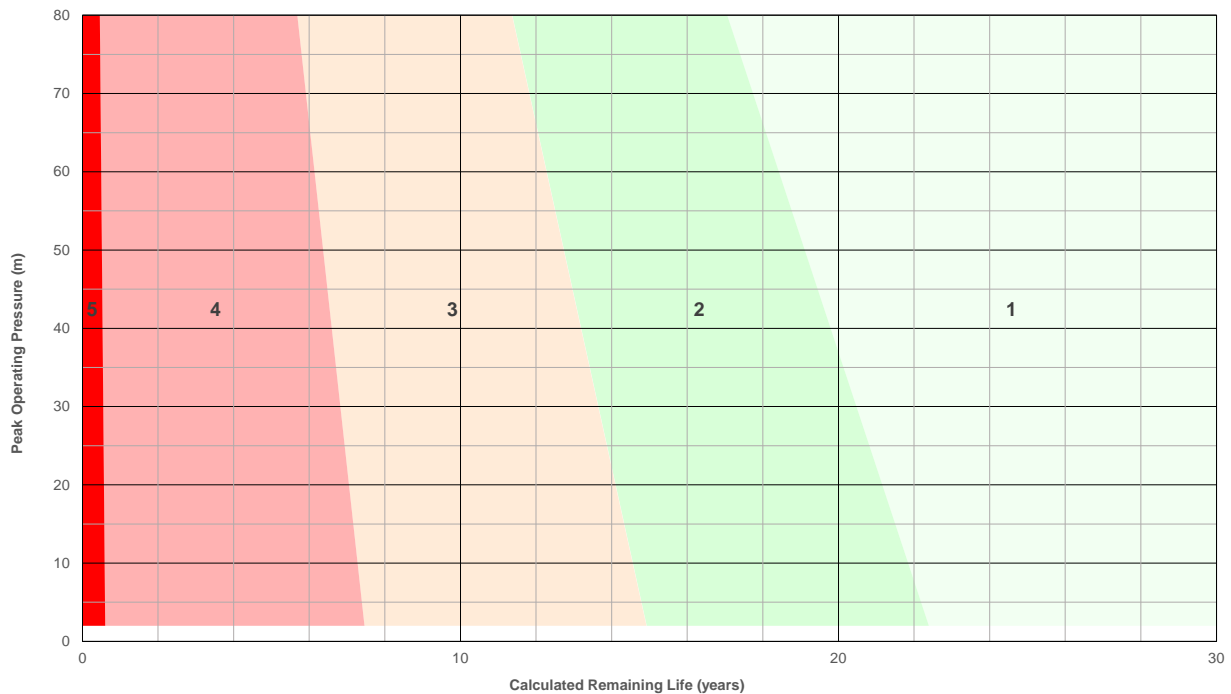

Condition Grading - DN 450 Class C (Water)

Condition Grading - DN 525 Class A (Water)

Condition Grading - DN 525 Class B (Water)

Condition Grading - DN 525 Class C (Water)

Condition Grading - DN 600 Class A (Water)

Condition Grading - DN 600 Class B (Water)

Condition Grading - DN 600 Class C (Water)

CONDITION GRADING CHARTS – WASTEWATER (DN 50 to DN 600)
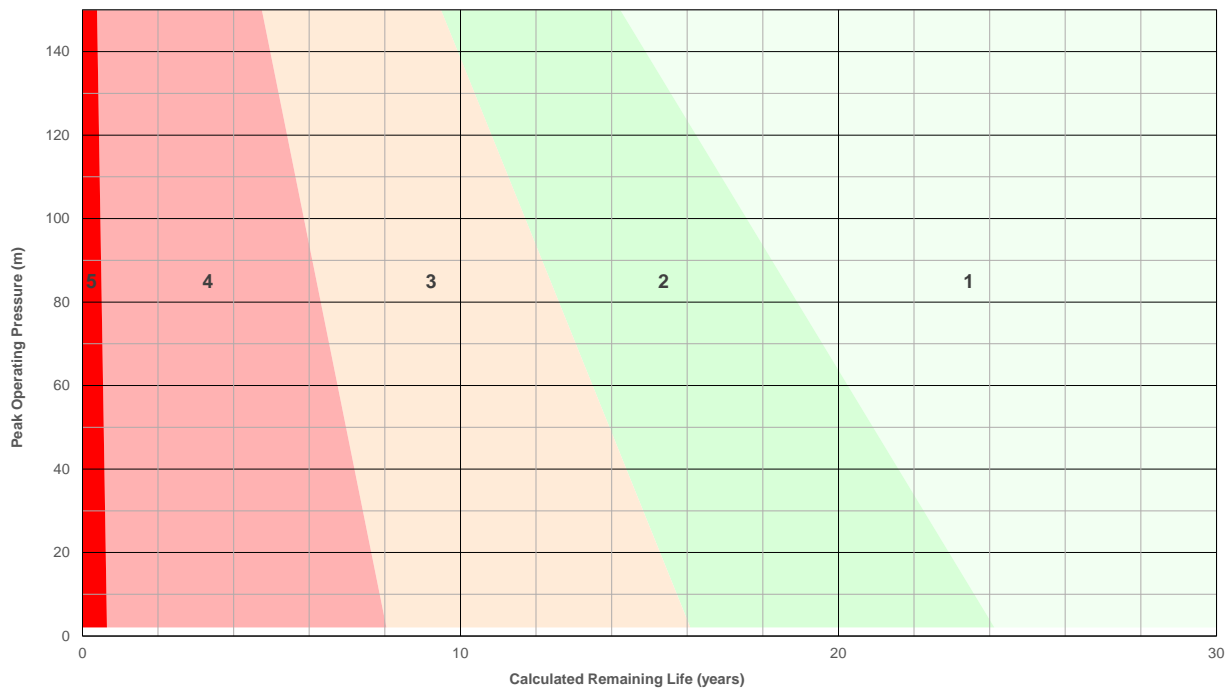
Condition Grading - DN 50 Class AF (Wastewater)
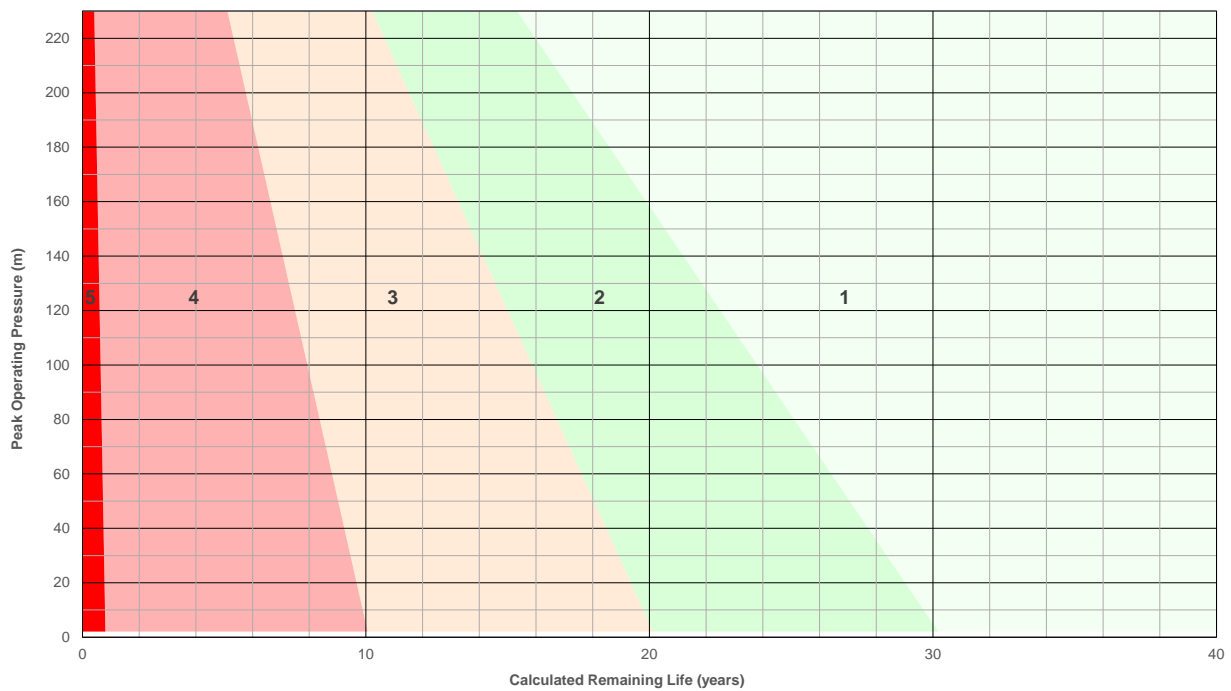

Note: Class E and F are based on NZS 3202:1977

Condition Grading - DN 75 Class AB (Wastewater)
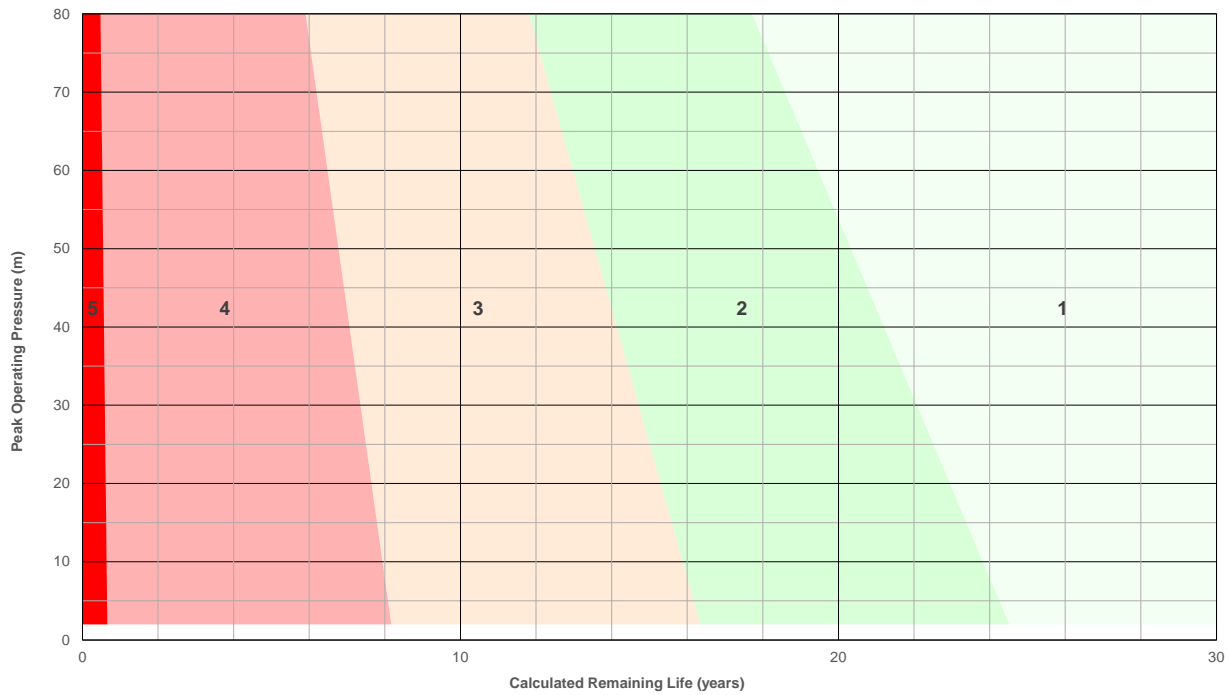
Condition Grading - DN 75 Class CD (Wastewater)

Condition Grading - DN 80 Class EF (Wastewater)
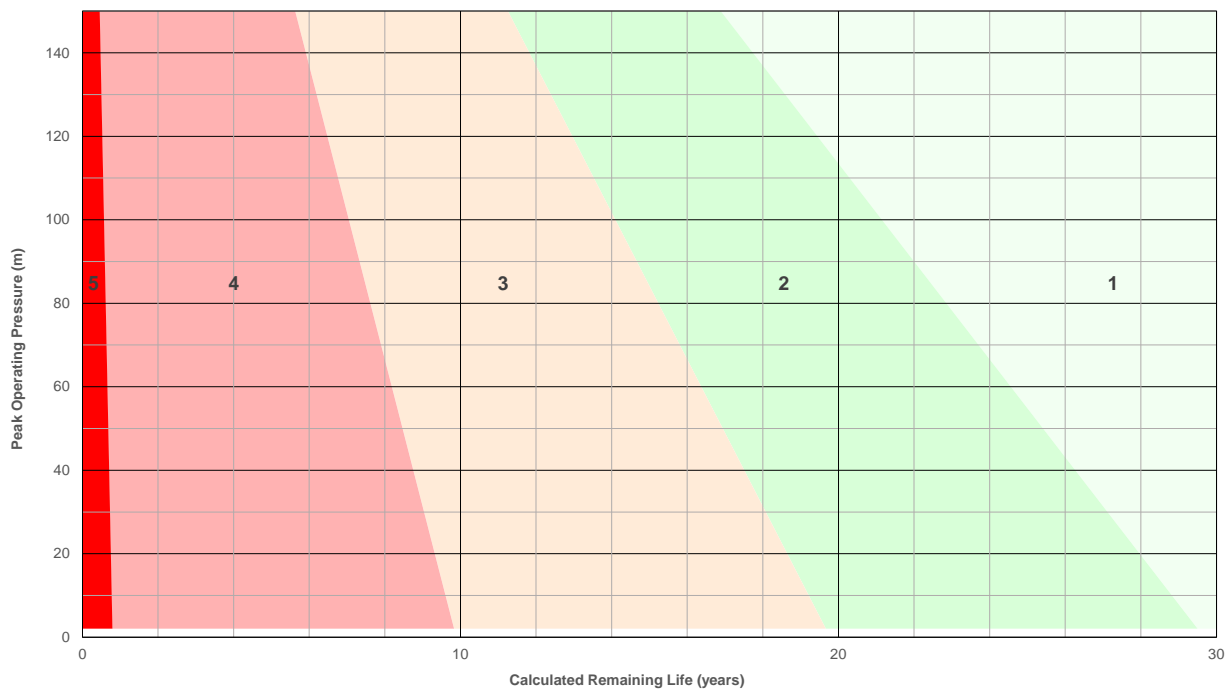

Note: Class E and F are based on NZS 3202:1977

Condition Grading - DN 100 Class AB (Wastewater)

Condition Grading - DN 100 Class CD (Wastewater)

Condition Grading - DN 100 Class EF (Wastewater)

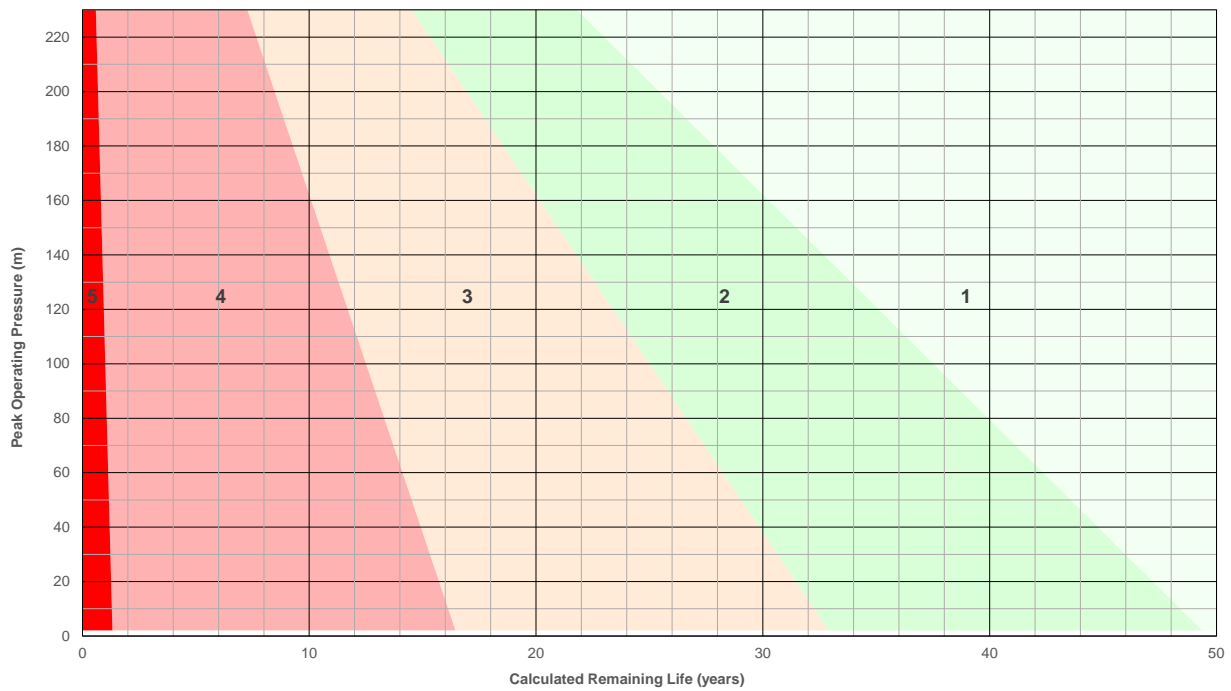Note: Class E and F are based on NZS 3202:1977

Condition Grading - DN 150 Class AB (Wastewater)

Condition Grading - DN 150 Class C (Wastewater)

Condition Grading - DN 150 Class D (Wastewater)
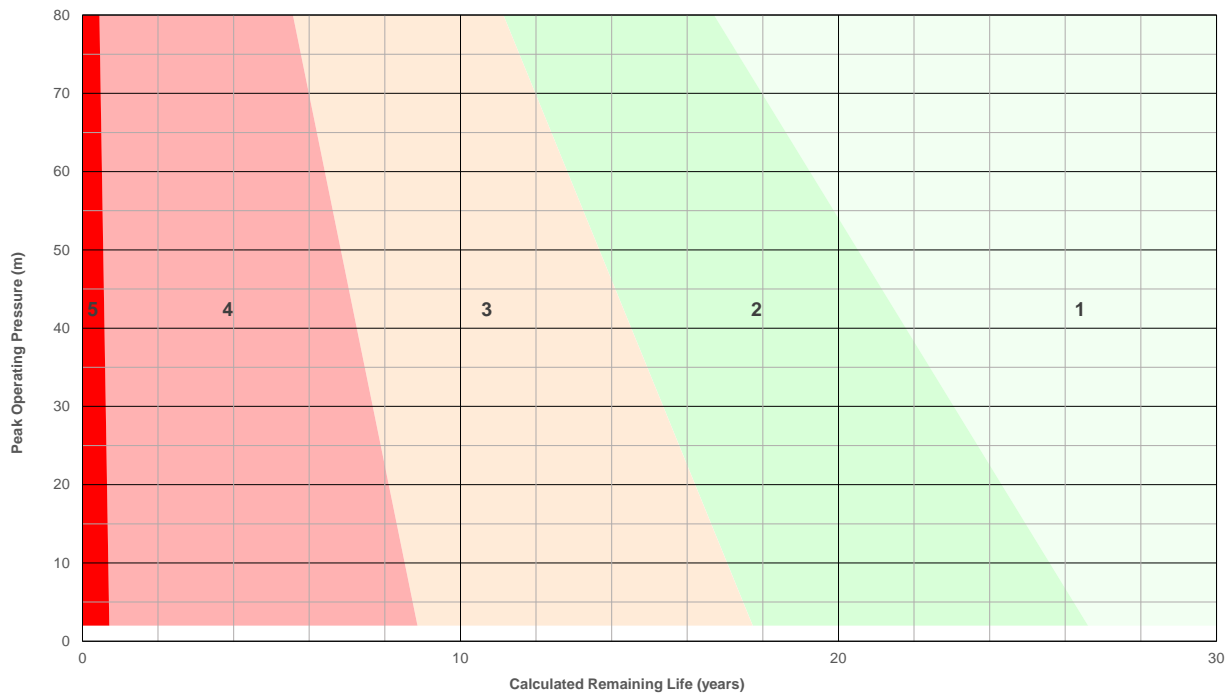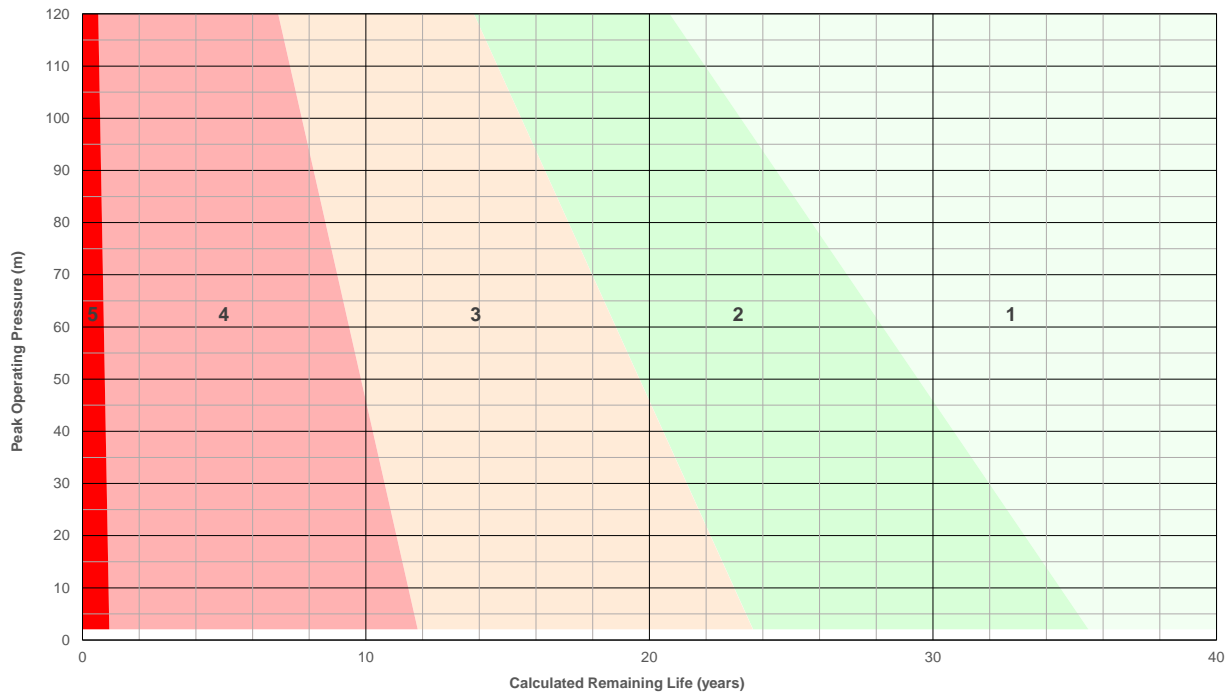
Condition Grading - DN 150 Class E (Wastewater)

Note: Class E and F are based on NZS 3202:1977
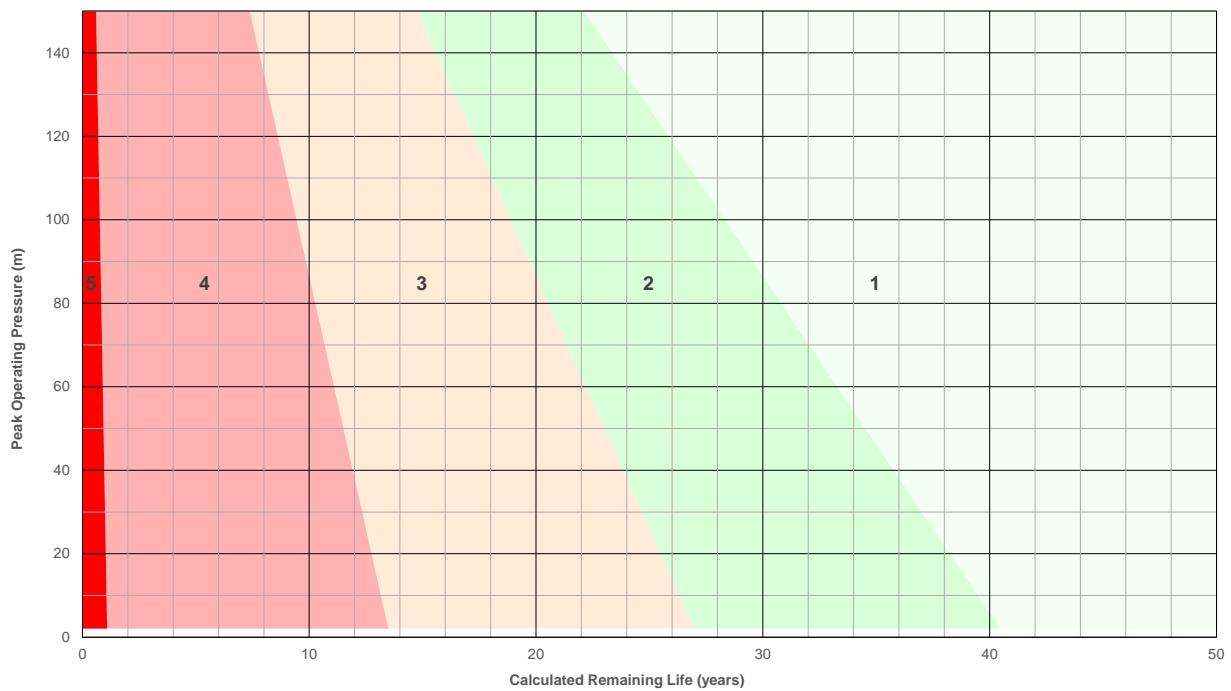
Condition Grading - DN 150 Class F (Wastewater)

Note: Class E and F are based on NZS 3202:1977
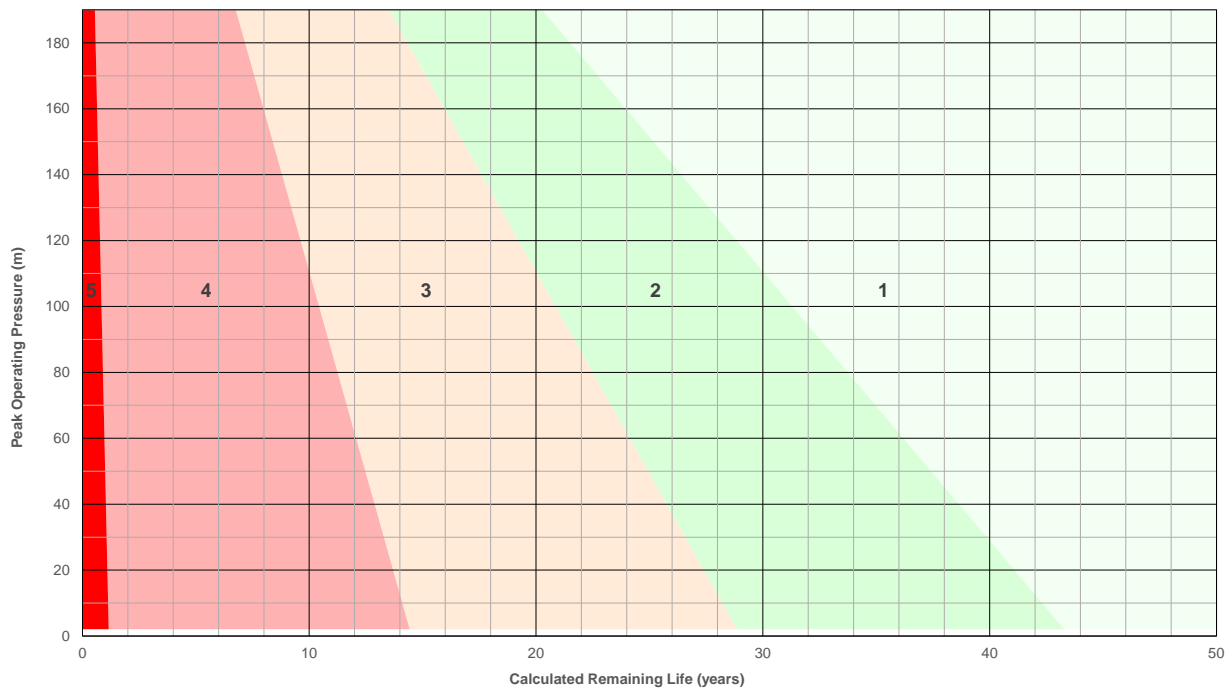
Condition Grading - DN 200 Class A (Wastewater)

Condition Grading - DN 200 Class B (Wastewater)
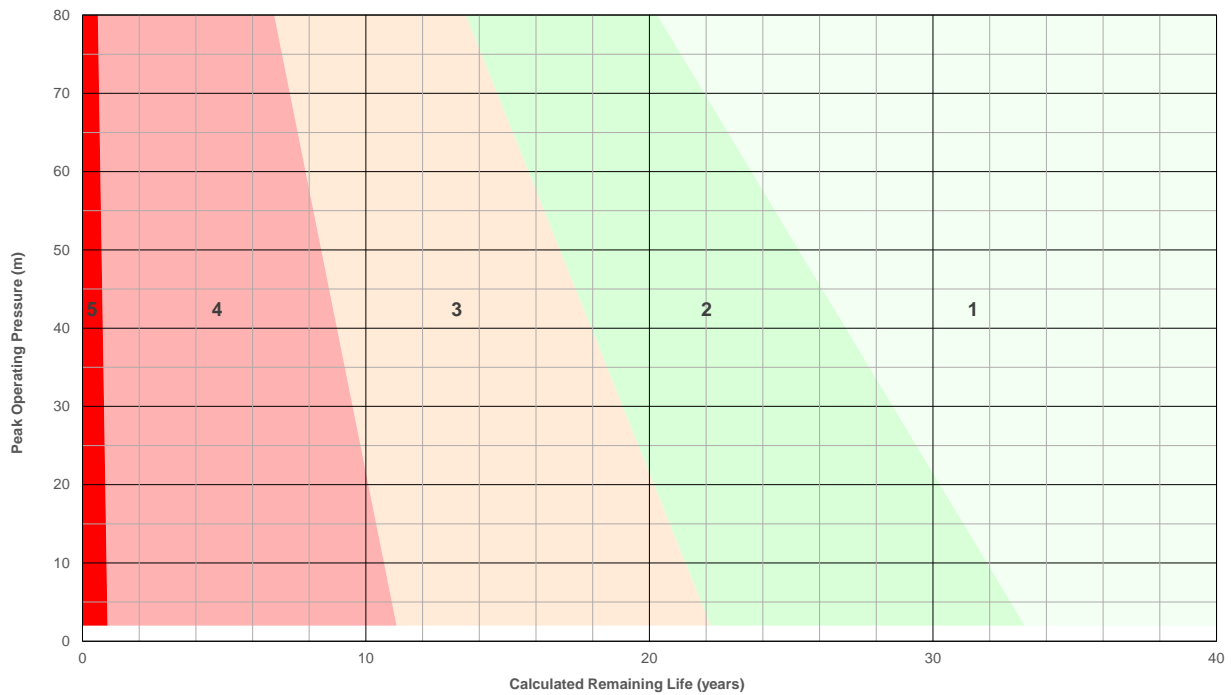
Condition Grading - DN 200 Class C (Wastewater)

Condition Grading - DN 200 Class D (Wastewater)

Condition Grading - DN 225 Class A (Wastewater)

Condition Grading - DN 225 Class B (Wastewater)

Condition Grading - DN 225 Class C (Wastewater)

Condition Grading - DN 225 Class D (Wastewater)

Condition Grading - DN 250 Class A (Wastewater)

Condition Grading - DN 250 Class B (Wastewater)

Condition Grading - DN 250 Class C (Wastewater)

Condition Grading - DN 250 Class D (Wastewater)

Condition Grading - DN 300 Class A (Wastewater)

Condition Grading - DN 300 Class B (Wastewater)

Condition Grading - DN 300 Class C (Wastewater)
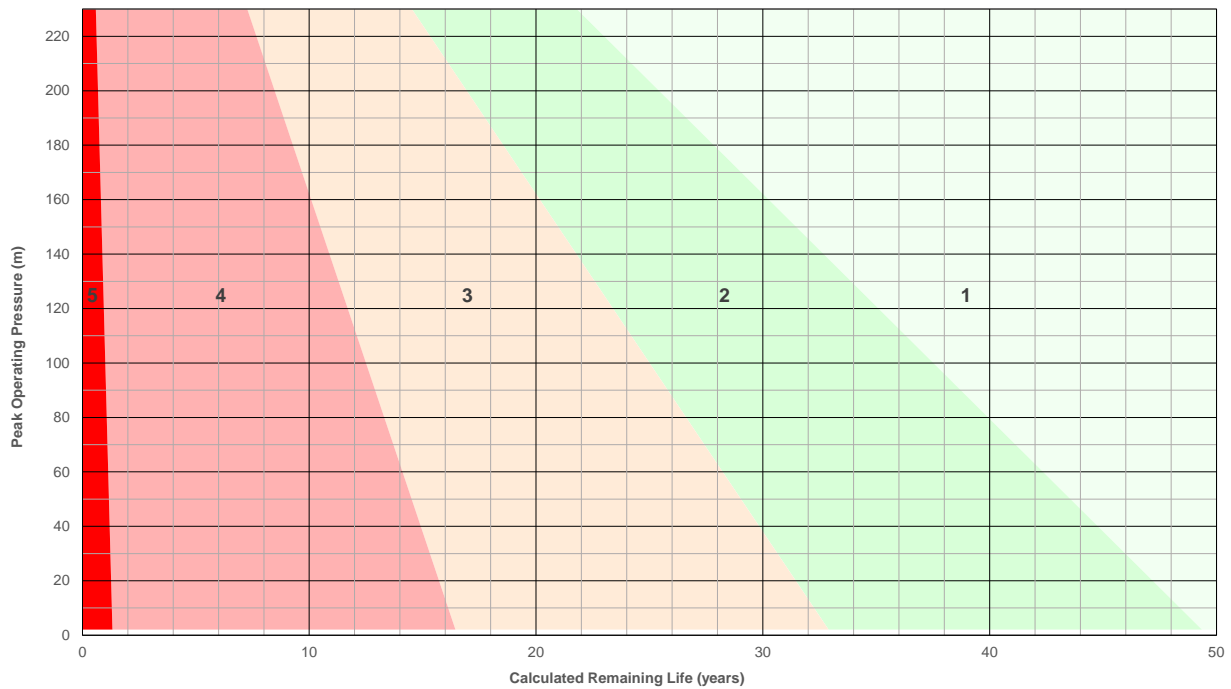

Condition Grading - DN 300 Class D (Wastewater)

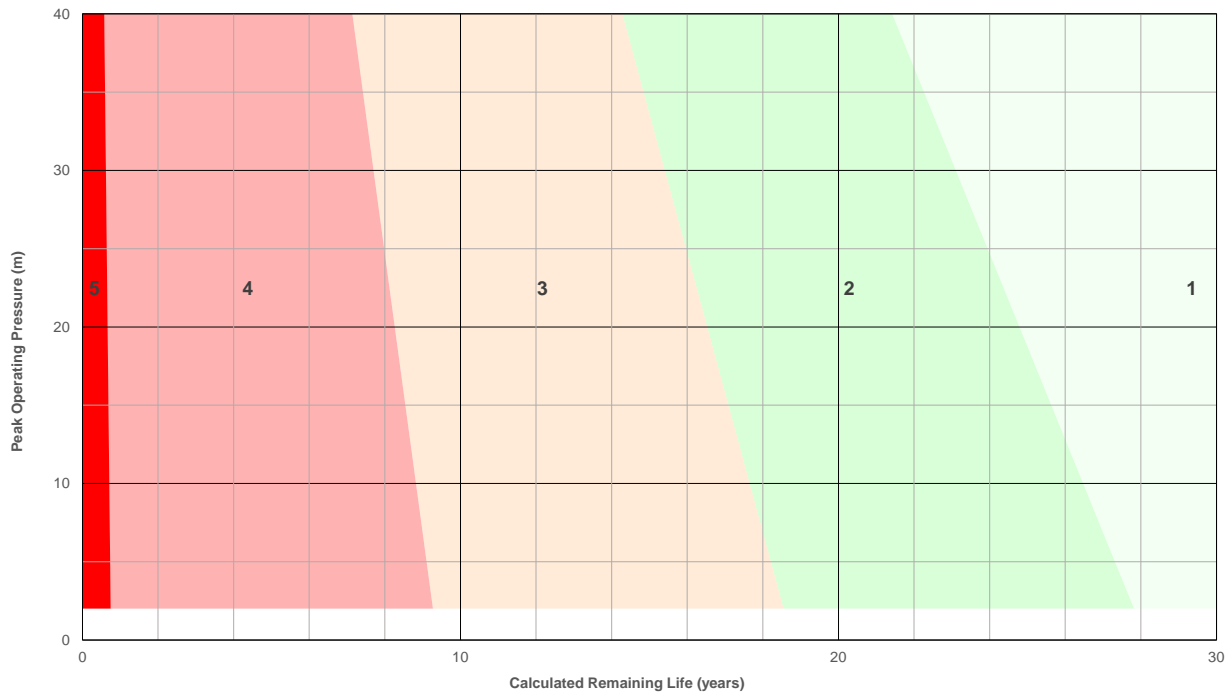## Condition Grading - DN 375 Class A (Wastewater)

Condition Grading - DN 375 Class B (Wastewater)

Condition Grading - DN 375 Class C (Wastewater)

Condition Grading - DN 450 Class A (Wastewater)
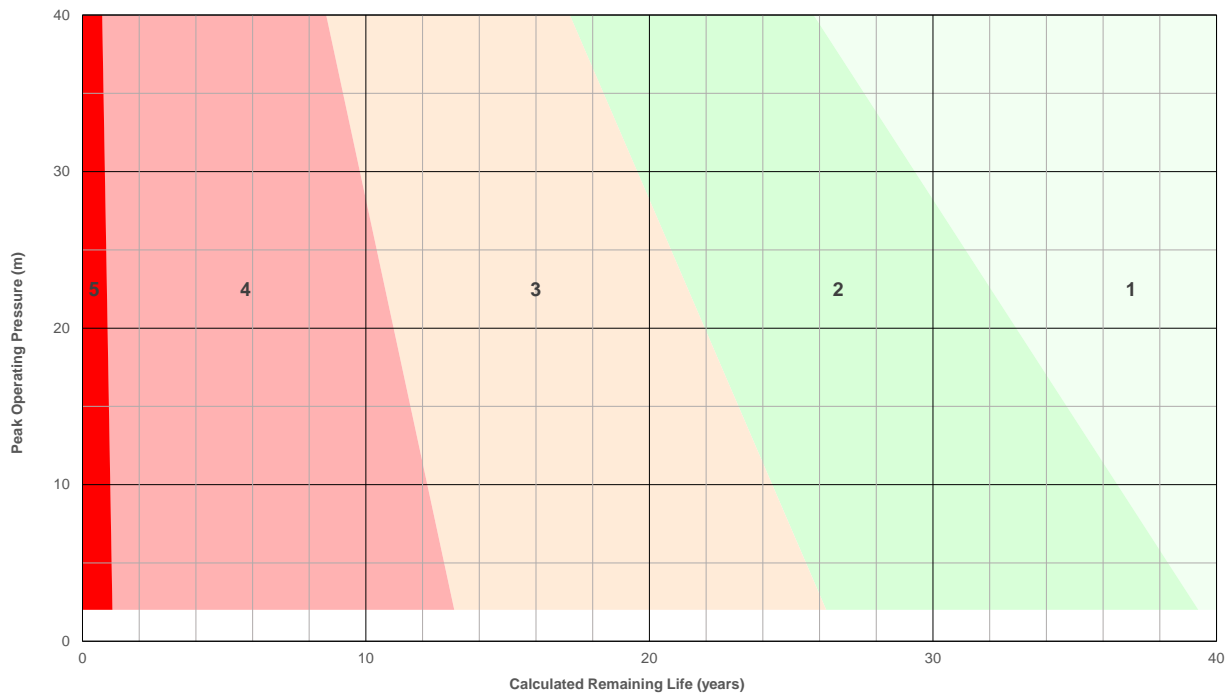
Condition Grading - DN 450 Class B (Wastewater)
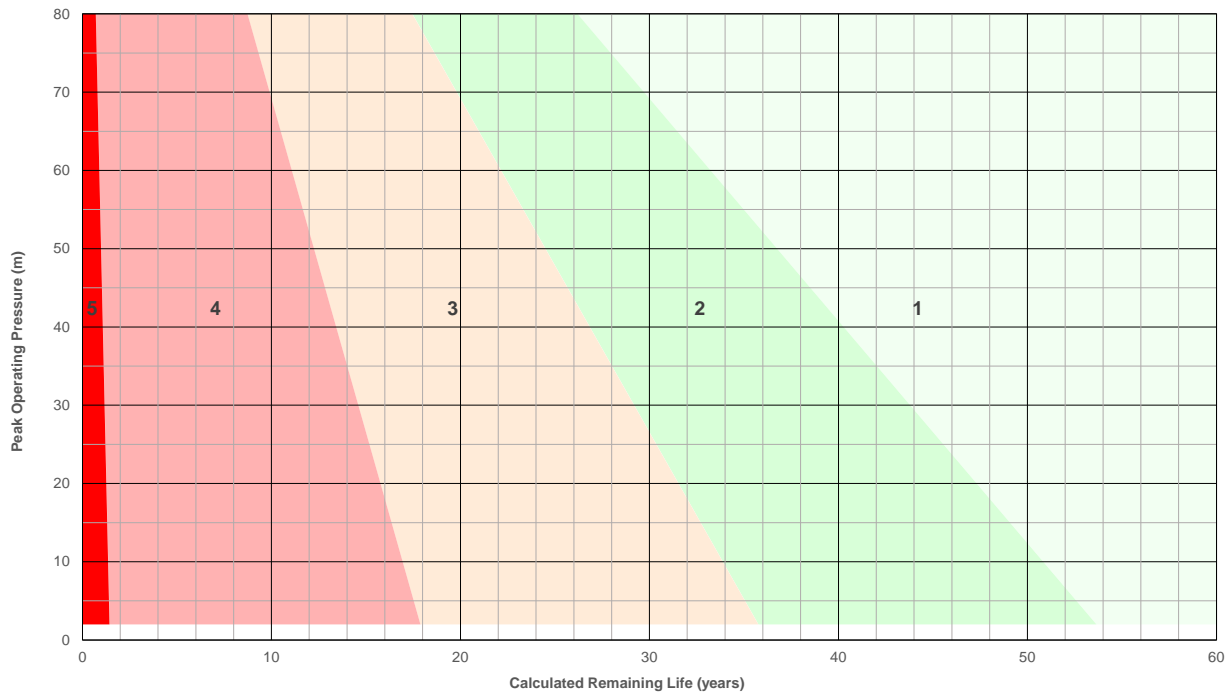
Condition Grading - DN 450 Class C (Wastewater)
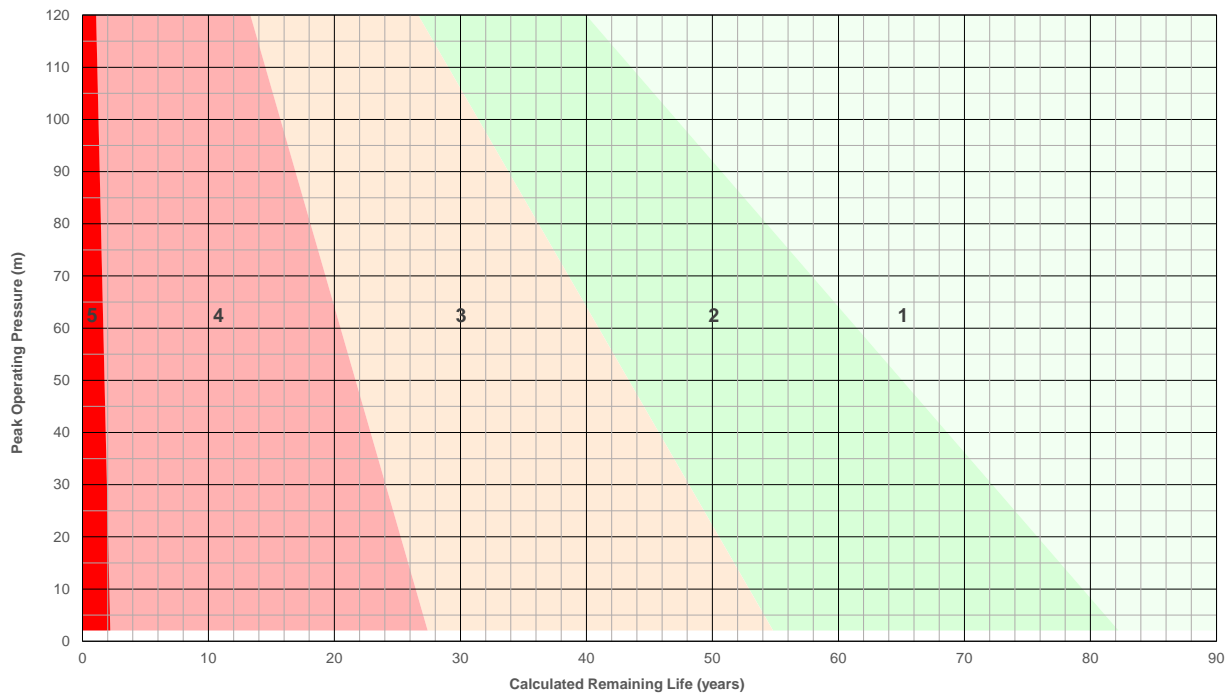
Condition Grading - DN 525 Class A (Wastewater)
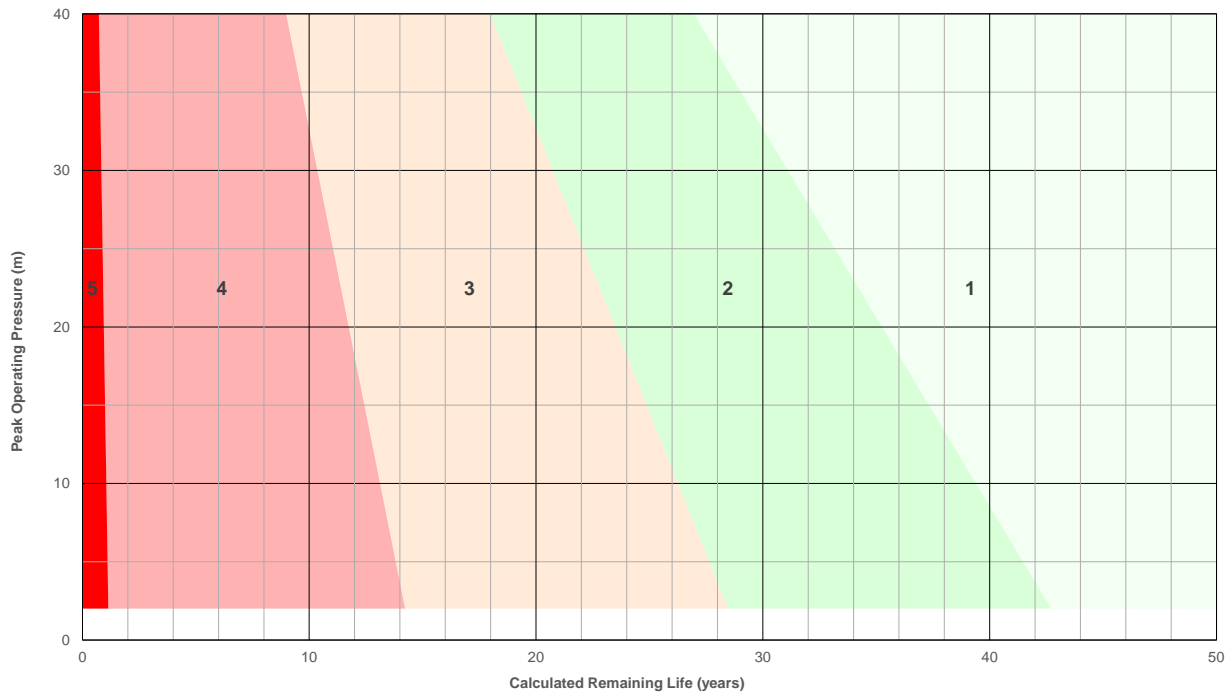
Condition Grading - DN 525 Class B (Wastewater)
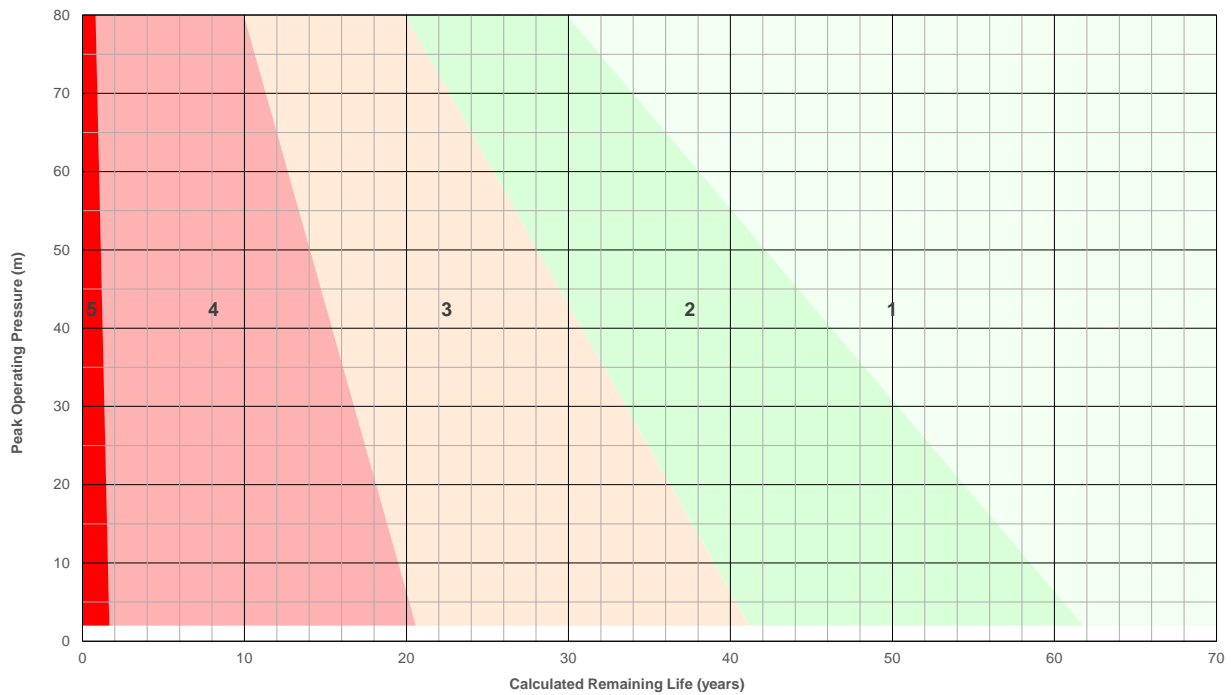
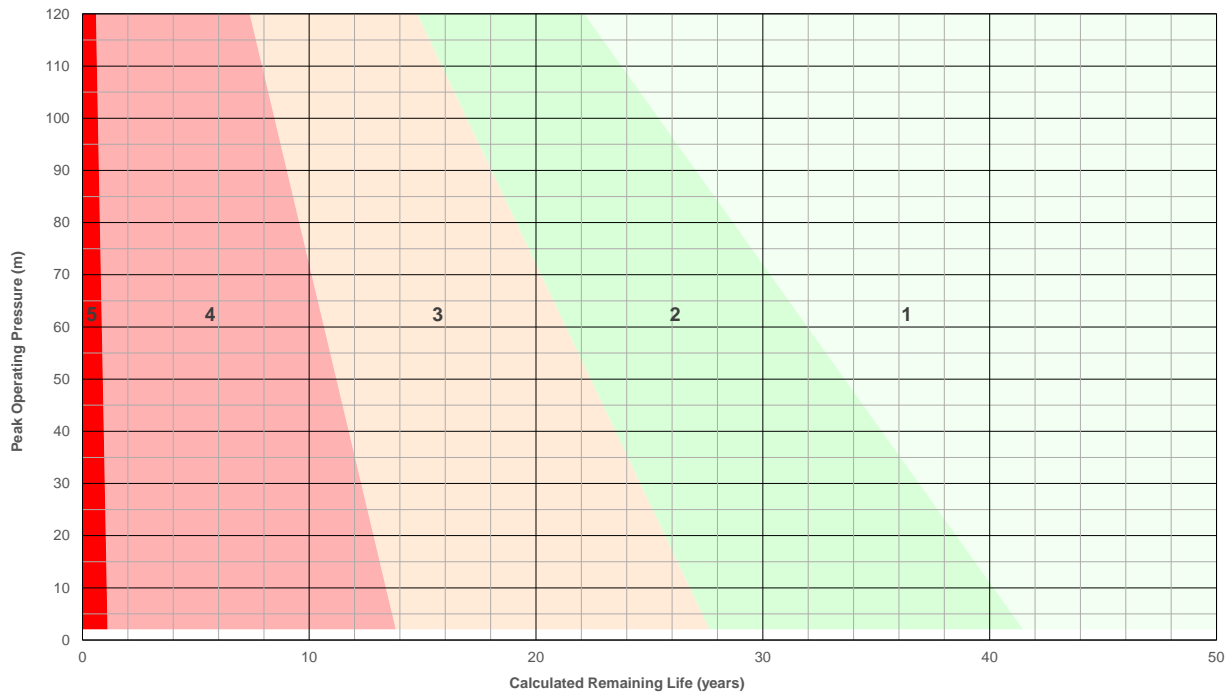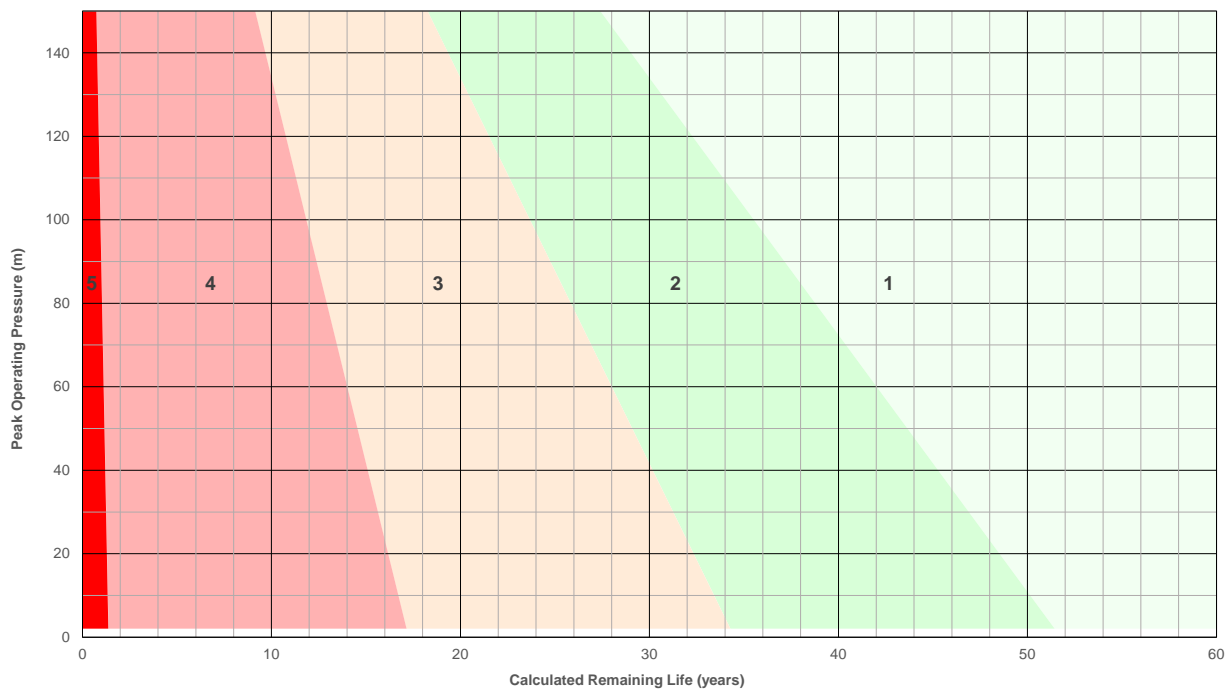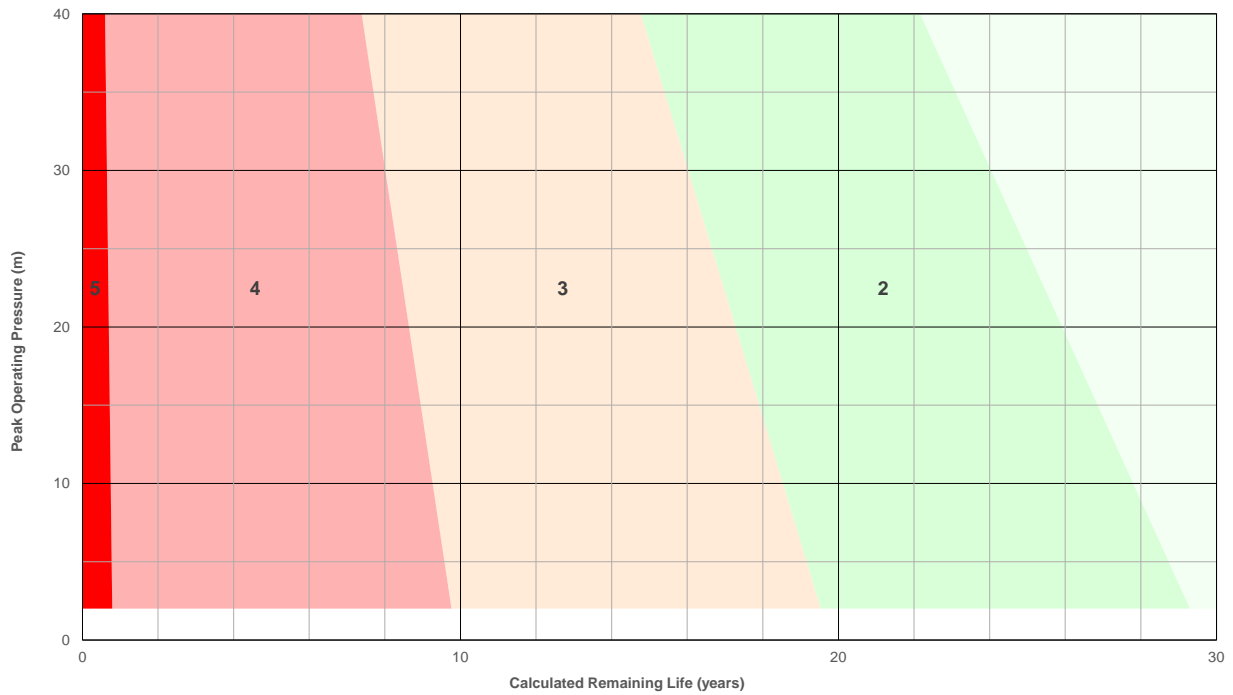## Condition Grading - DN 525 Class C (Wastewater)
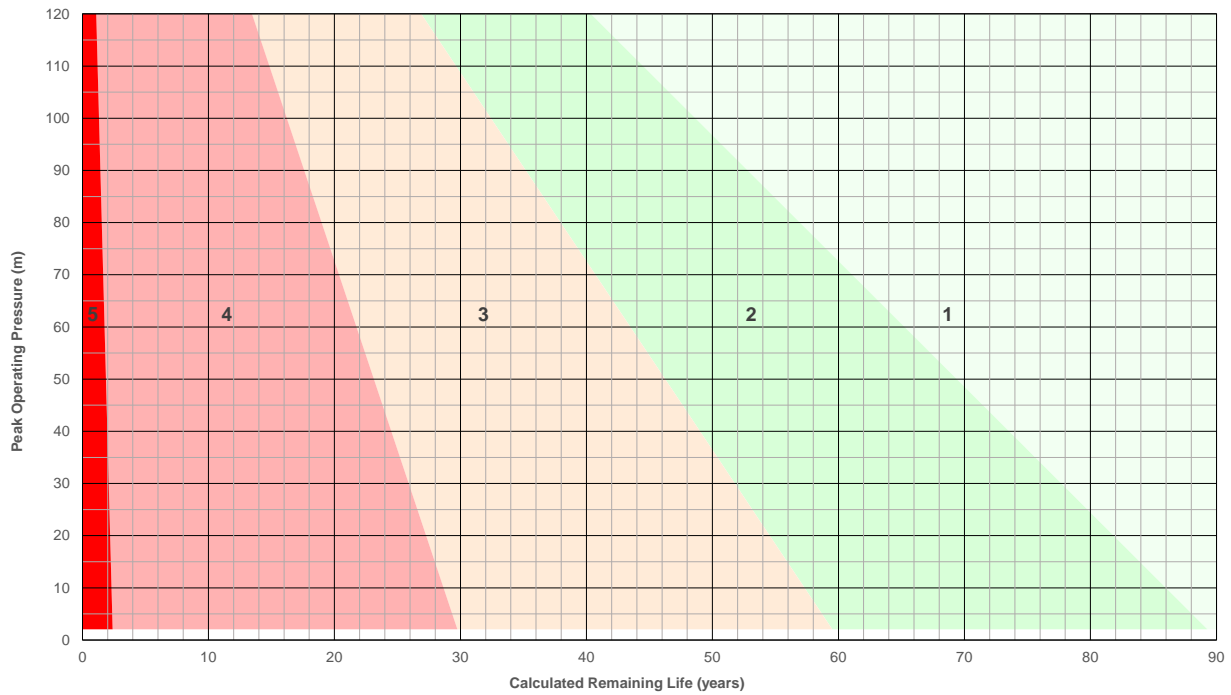
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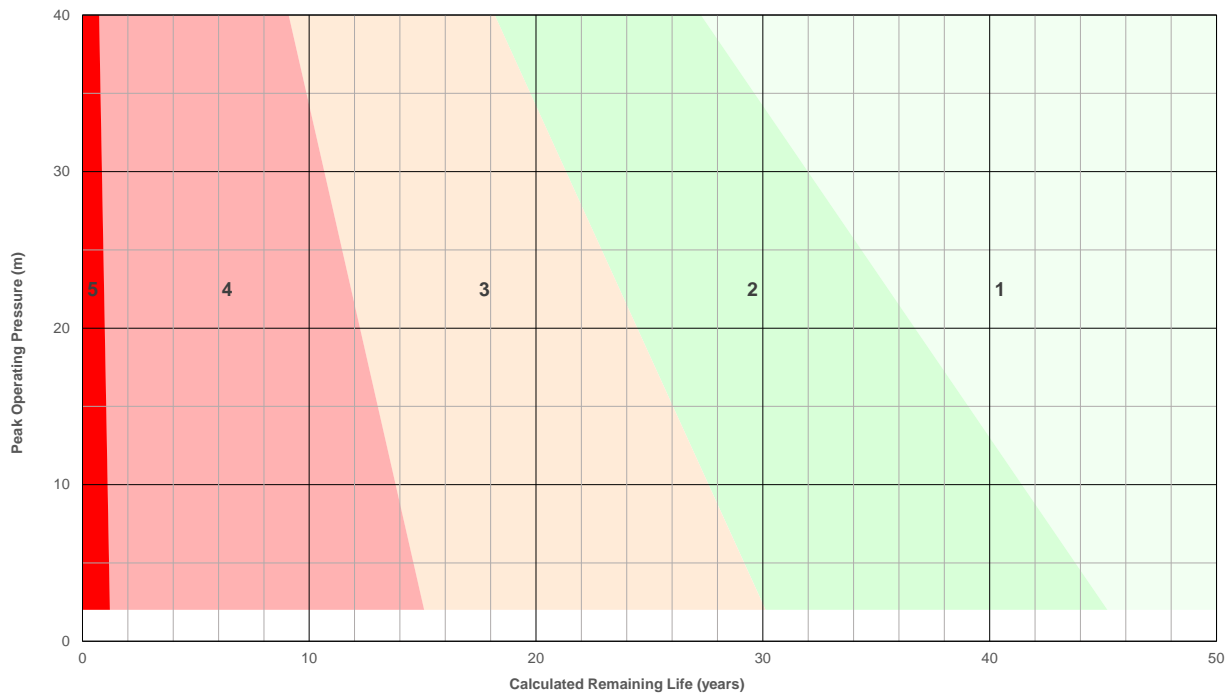
Condition Grading - DN 600 Class B (Wastewater)

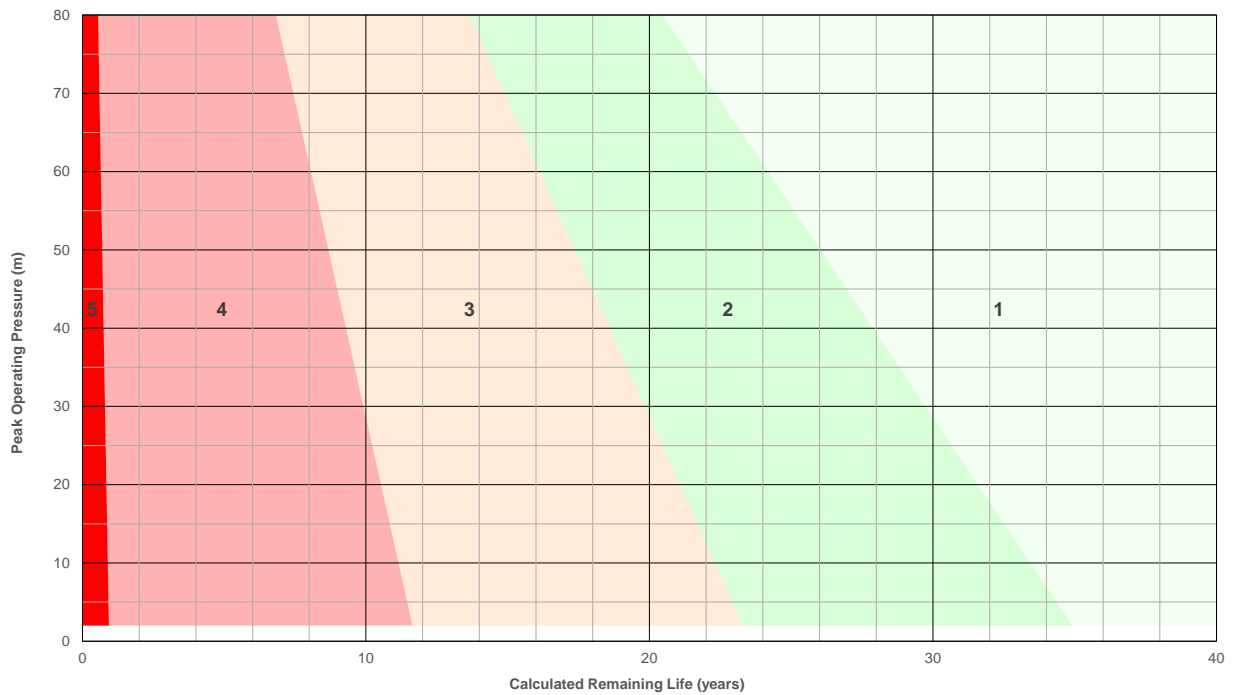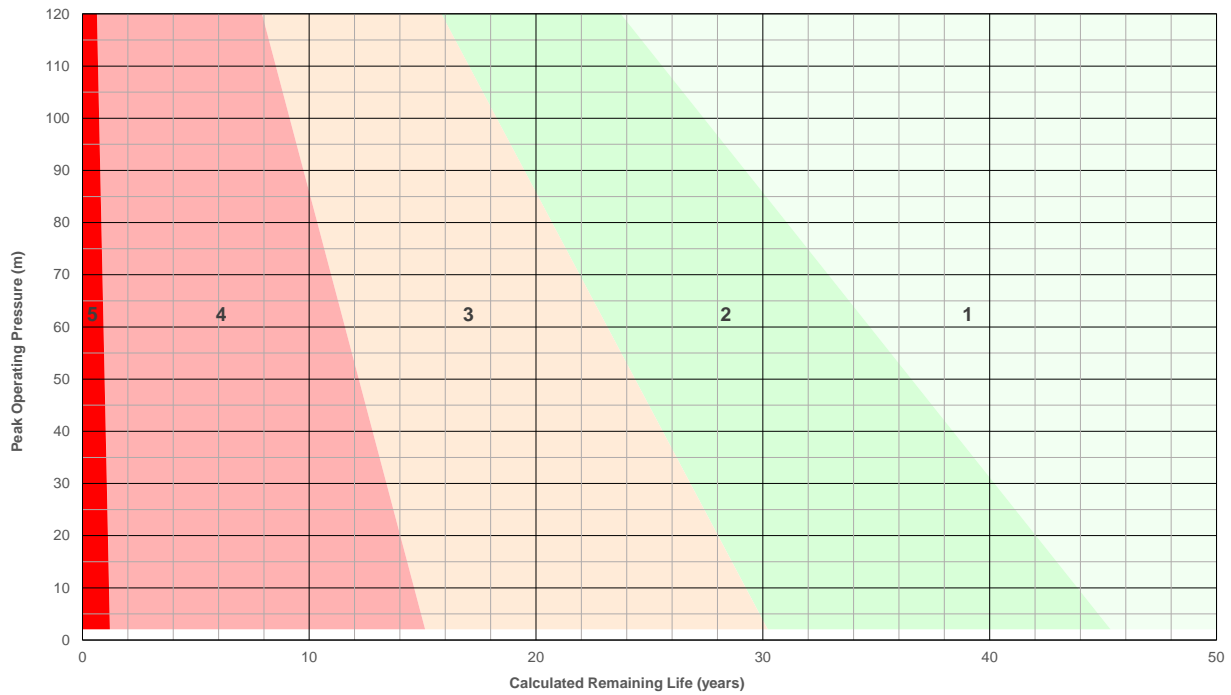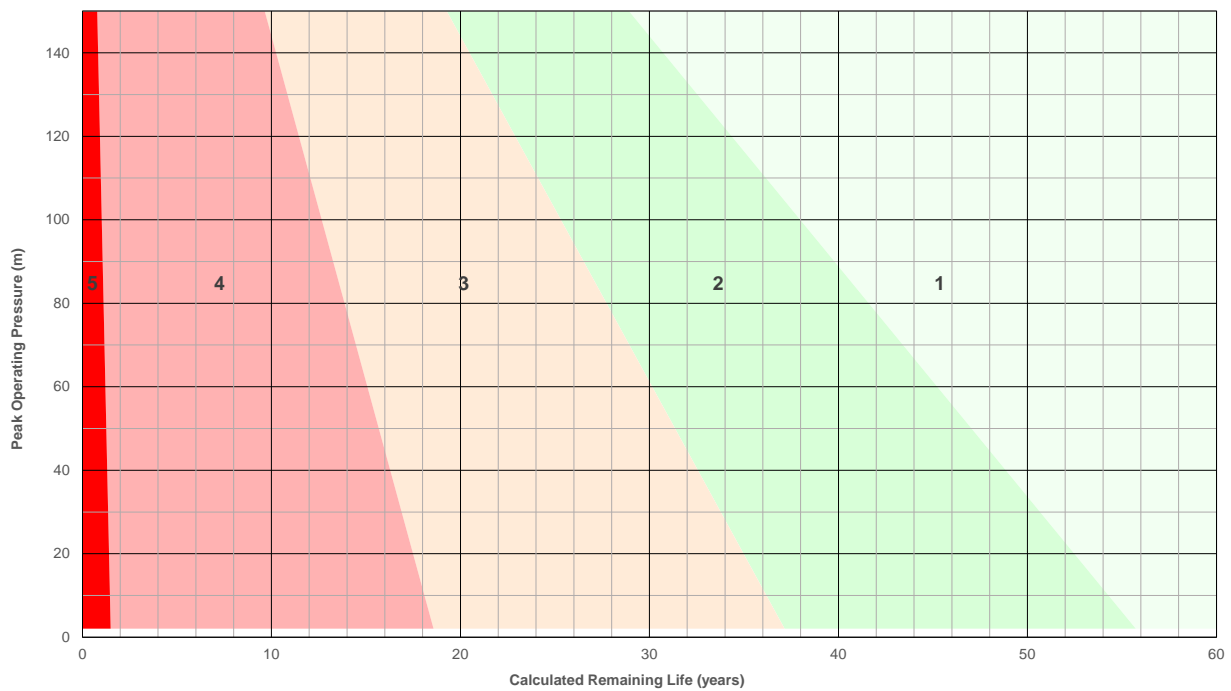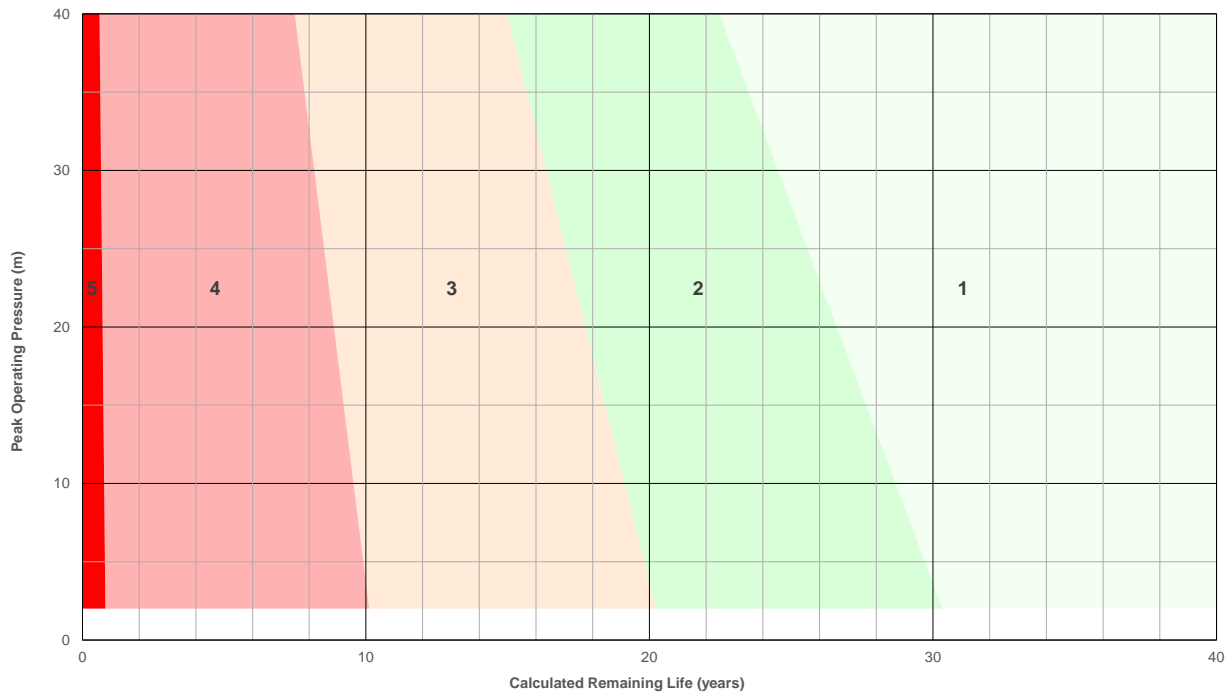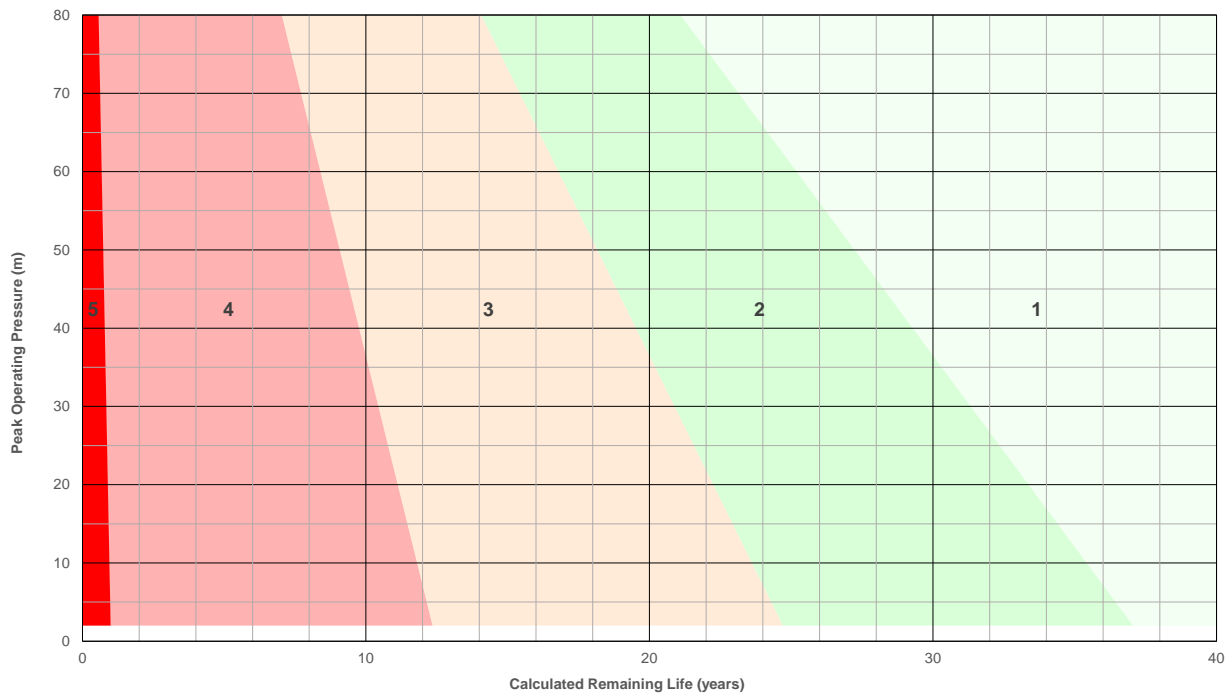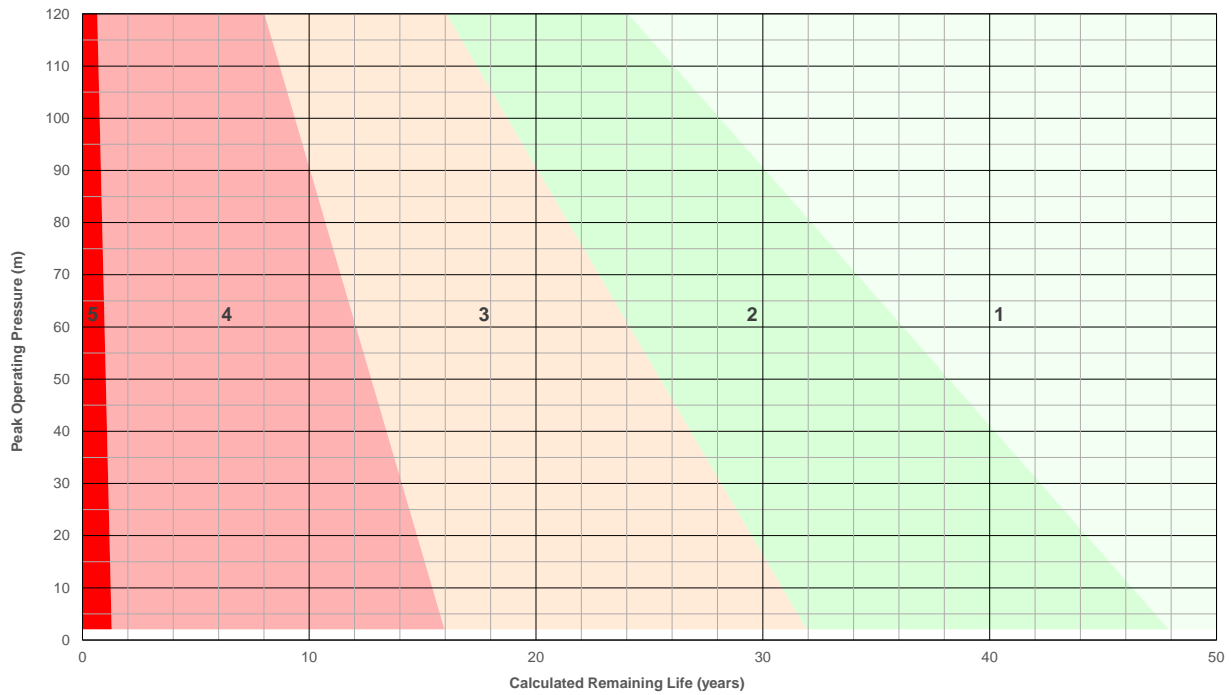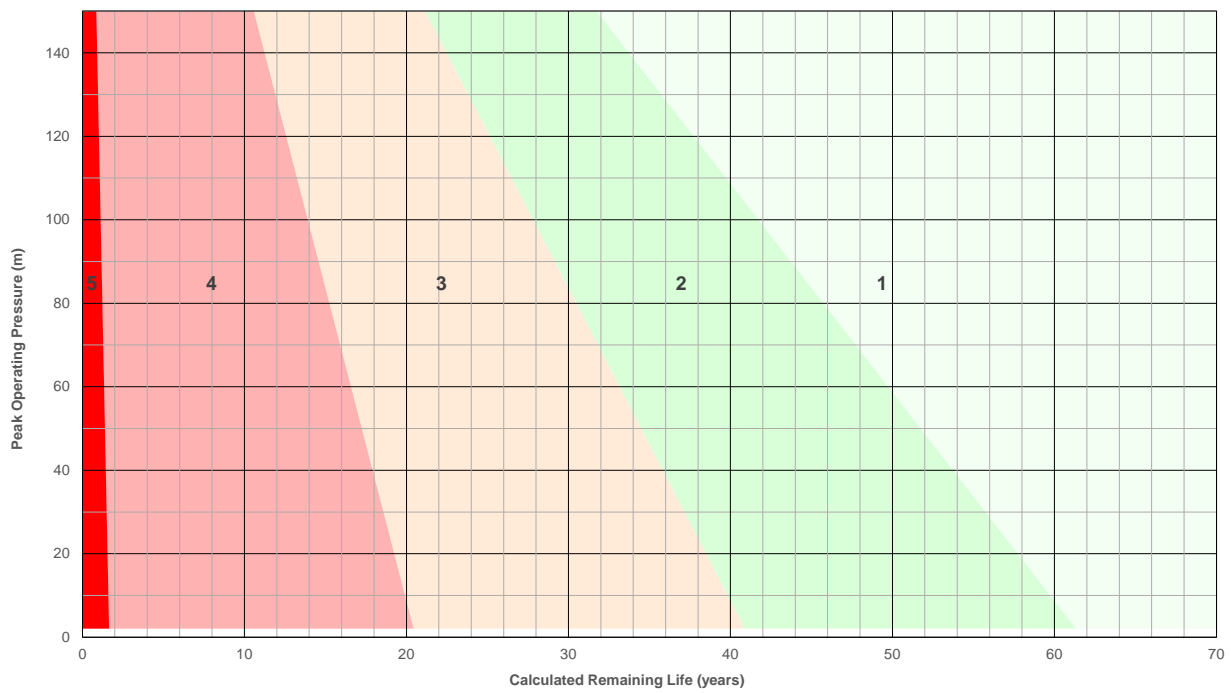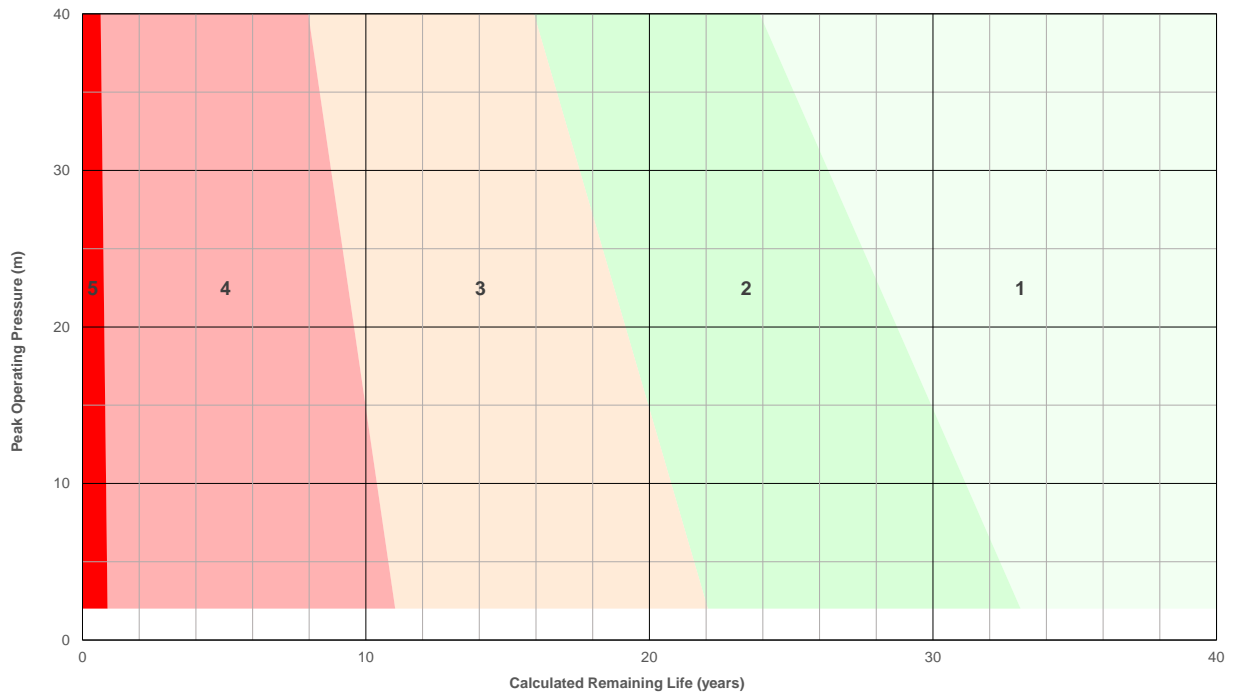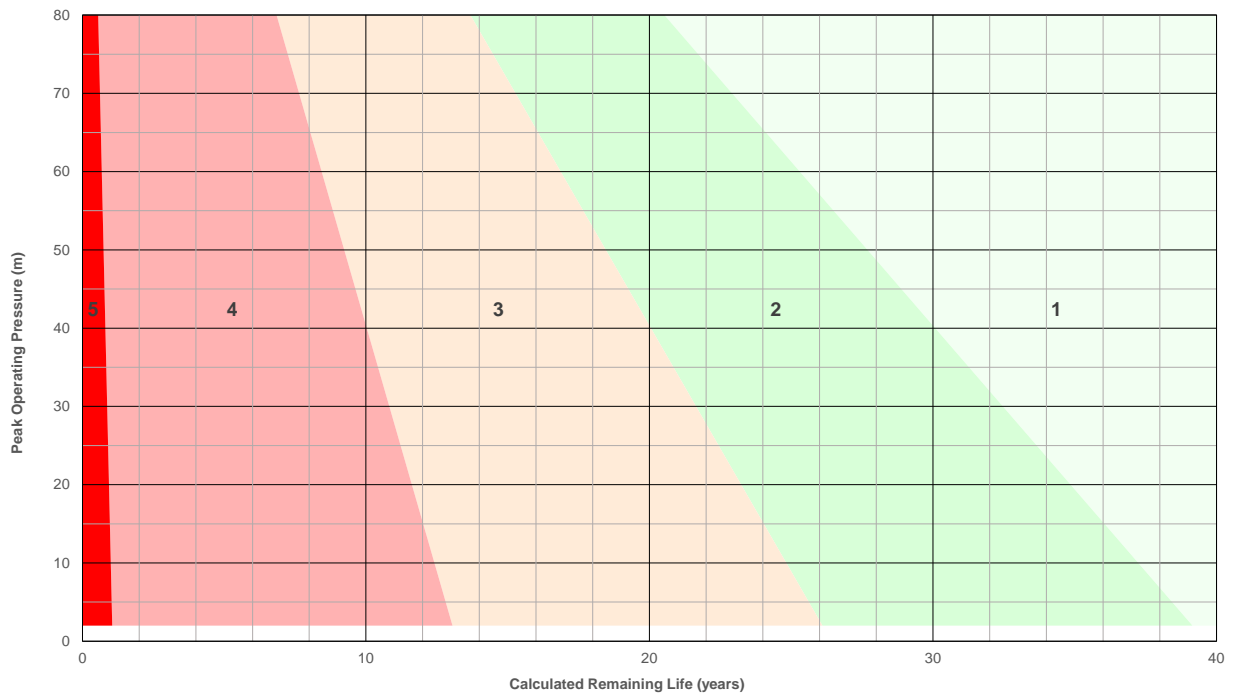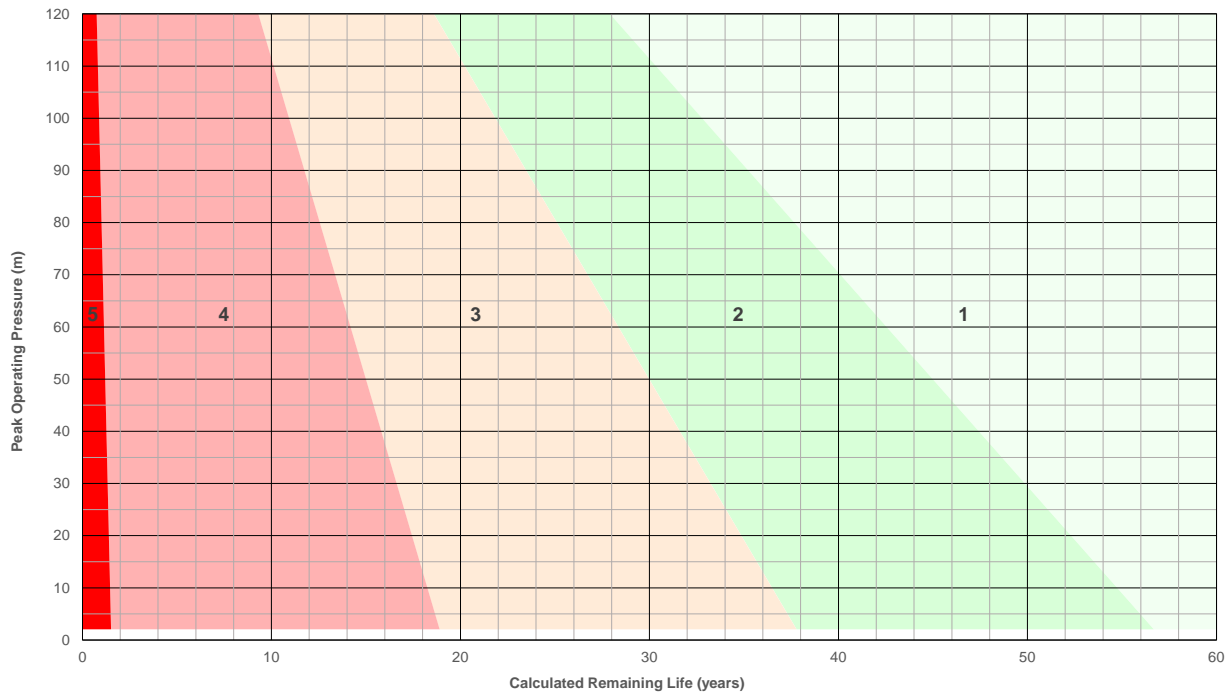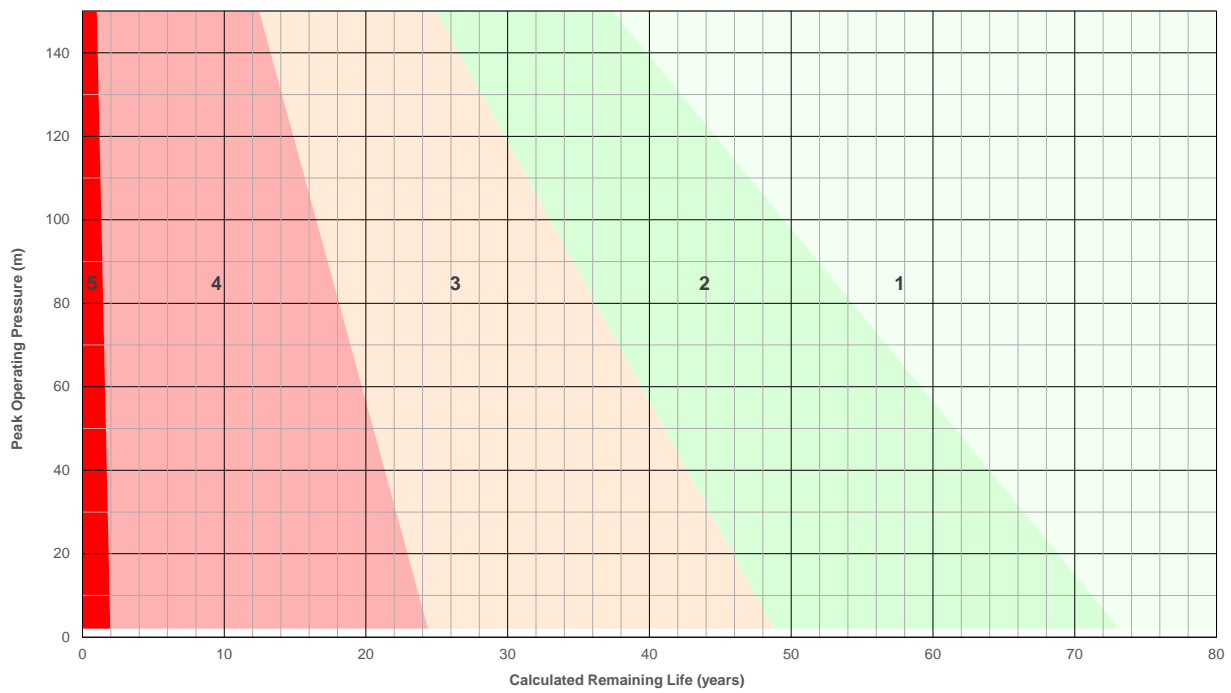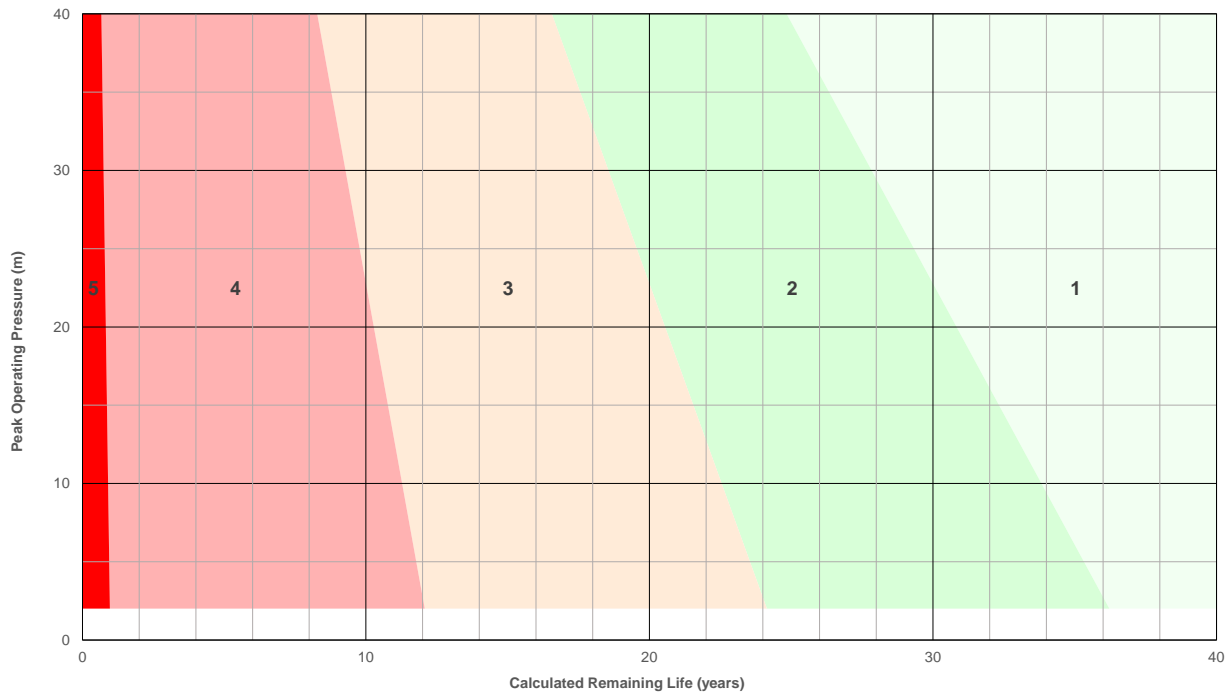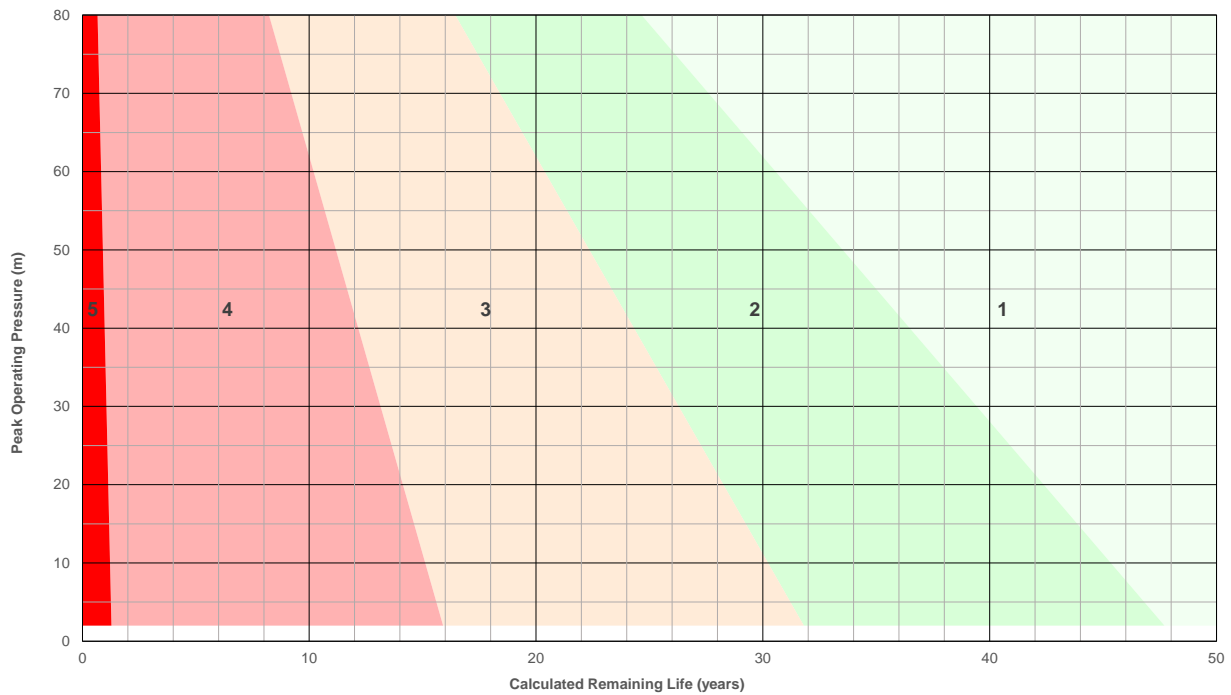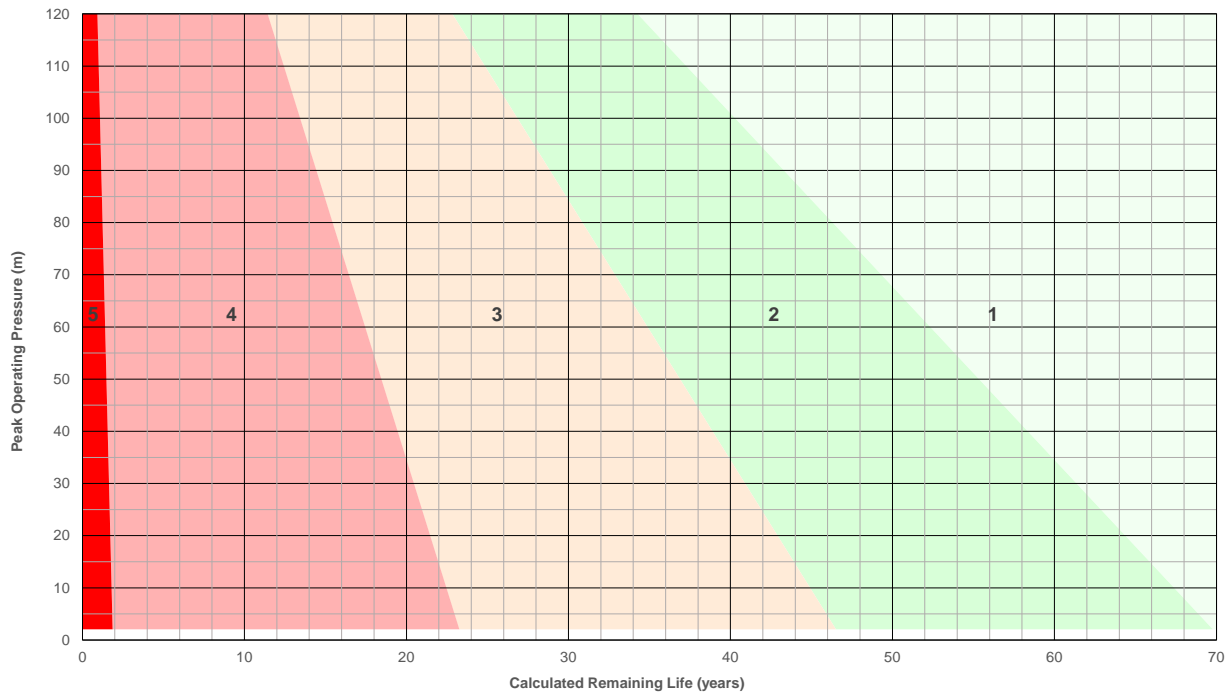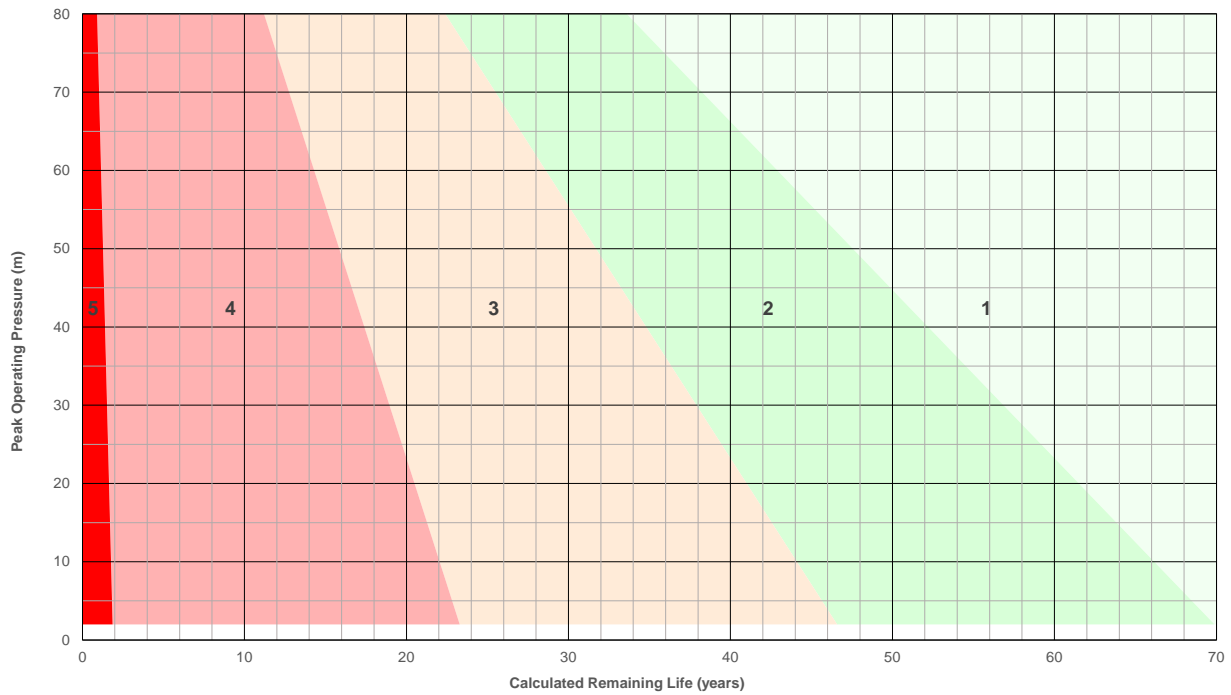**Condition Grading - DN 600 Class C (Wastewater)**
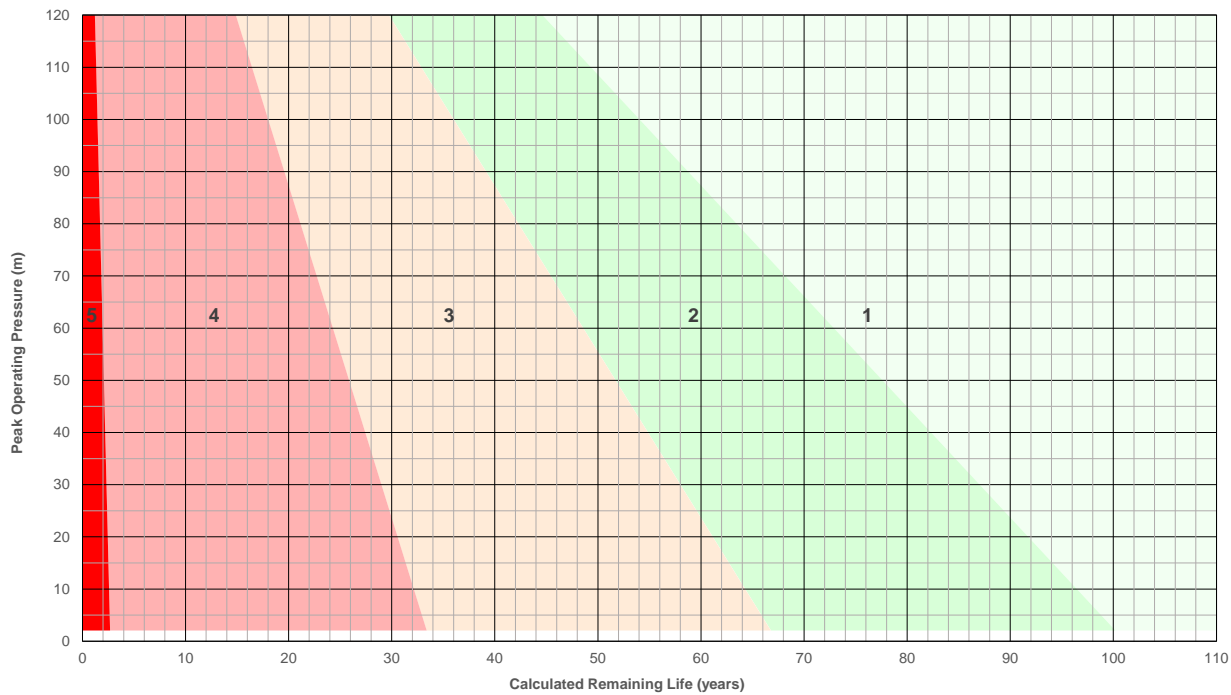
7   GLOSSARY OF TERMS AND ABBREVIATIONS

American Water Works Association (AWWA)

Established in 1881, the American Water Works Association is a non-profit organisation that publishes standards for treatment, transportation and storage of water was well as other related fields.

Amended Water

Amended water is used to adequately wet AC pipes during handling and cutting operations by repeated spraying. Amended water is made by adding a wetting agent to tap water to assist penetration and wetting of the pipe surface. Use approximately 10 ml of detergent per litre of water.

Asbestos Cement (AC)

AC as used for pipes is composed of approximately 10-15% asbestos fibres in a matrix of ordinary Portland cement or, since the mid 1950's, Portland cement and finely ground silica.

The process for making pipes was refined between 1906 and 1913 by Societa Anonia Eternit Pietra Artificiale of Genoa Italy and their Mazza process was almost universally adopted world-wide.

The AC pipe matrix is non-friable unless the cement has deteriorated to the extent that the surface (internal and external) asbestos fibres are no longer bound and can crumble when dry (quite rare).

ASTM International (formerly American Society for Testing and Materials)

ASTM International is a Standards Organisation that develops and publishes voluntary consensus technical standards for a wide range of materials, processes, systems, services and products, including AC pipes.

Average Combined Deterioration Rate (Det'n Rate)

The average combined deterioration rate in mm / year and is calculated by the following formula:

$$Ave.Det'n\ Rate\ (^{mm}/yr) = \frac{MIDD\ + MEDD\ (mm)}{Pipe\ Sample\ Age\ (years)}$$

Barlow's Formula

Barlow's formula relates the internal pressure that a pipe can withstand to its dimensions and the strength of its material.

$$P = \frac{2\,S\,t}{D}$$

Where:

P = Pressure
S = Allowable stress
t = Wall thickness
D = Outside Diameter

Building Research Association of New Zealand (BRANZ)
BRANZ is an independent and impartial research, testing and consulting organisation.

Controlled Equipment[21]

The use of equipment is controlled if the equipment is enclosed while being used, or the equipment is designed to capture or suppress airborne asbestos and is used in accordance with its design; or the equipment is used in a way that is designed to capture or suppress airborne asbestos safely; or any combination of the above paragraph applies.

Competent Personnel[22]

Means a person who has the knowledge, experience, skill, and qualifications to carry out a particular task (under the Health and Safety at Work (Asbestos) Regulations 2016), including any knowledge, experience, skills and qualification prescribe in a safe work instrument.

Computed Tomography Scanning (CT Scanning)

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[21] Extract from Health & Safety (Asbestos) Regulations 2016.
[22] Extract from Health & Safety (Asbestos) Regulations 2016

Computed tomography is an X-ray imaging procedure in which a narrow beam of X-rays is aimed at the pipe sample and quickly rotated around the pipe, producing signals that are processed by a computer to generate cross-sectional images (or "tomographs" of the pipe sample) typically at 2 mm intervals for AC pipe scanning.

The tomographic images are enhanced by computer to show changes in density within the pipe wall and the scanner software can be used to measure the depth of deterioration.

Coupon Sample (Core)

A core is a disc of pipe cut from the pipe wall using a hole saw and is generally carried out while the main is under pressure. Typically the cores recovered from AC pipes are in the range of 30 – 48 mm in diameter although both larger and smaller cores are possible.

Deterioration (of AC Pipes)

AC pipe deteriorates as a result of chemical reactions between the cement / silica binder and its environment.

Two deterioration processes typically occur – lime leaching and sulphate attack. These processes, in the medium to long-term, result in softening of the interior and / or exterior surfaces of the pipe accompanied with loss of strength of the wall.

This deterioration appears to continue at a relatively constant rate from the time of installation of the pipe. The depth of deterioration of AC pipes can be determined from direct measurement of the colour change in phenolphthalein (pH indicator) on a freshly prepared surface or, typically, from CT scanning.

Estimated Year of First Pressure Failure due to Deterioration (EYF)

The lifetime prediction charts provided, enable the user to estimate the number of years to first pressure failure due to deterioration of the AC pipe wall.

International Organisation for Standardisation (ISO)

ISO is an independent, non-governmental international organisation with a membership of 162 national standards bodies. Through its members it develops voluntary, consensus-based, International Standards.

Lifetime Prediction Charts

The Lifetime Prediction Charts have been developed to allow the user to estimate remaining life of an AC pipeline that has not been sampled or a condition assessment carried out.

Maximum External Deterioration Depth (MEDD)

The maximum external deterioration depth on a pipe sample as measured, in mm along a pipe sample.

Maximum Internal Deterioration Depth (MIDD)

The maximum internal deterioration depth on a pipe sample as measured, in mm along a pipe sample.

National Specification for Sampling and Testing of Asbestos Cement Watermains 2001 (the Manual – 2001)

The Manual – 2001 gives details of pipe sampling and testing procedures that are relevant to the assessment of the condition of AC watermain pipes.

New Zealand Water and Waste Association (NZWWA)

Refer to Water New Zealand (Water NZ).

Nominal Diameter (DN)

A numerical value of the size of pipe which is a convenient round number roughly equal to the manufactured internal diameter, in mm.

Note that as the OD for each pipe DN remains relatively constant (to allow for fittings compatibility), the ID decreases as the Pressure Class increases.

Outside Diameter (OD)

A numerical value of the mean outside diameter, in mm as determined by measuring a clean pipe specimen at an un-machined section of the pipe using a diameter (π) tape.

If the OD is measured at a factory machined section of the pipe or the outside of a joint collar, this shall be clearly noted.

Pipe Data

The relevant physical measurements of OD, ID, Wt and depth of deterioration recorded as accurately as possible to assist with the pipe condition assessment.

Pipe data also includes items such as pipeline location, pipe purpose, operating pressure, bedding material, depth of cover, surface condition (e.g. street, highway, berm, etc.), depth to water-table (if applicable), photograph(s) observations e.g. surface hardness, coating, lining, sleeving, manufacturer's markings, etc.

Pressure Class and Design (Maximum) Working Pressure (WP)

The pressure class can be either an alphabetic character or a numerical value (IS0 standards) that is given to the nominal maximum working pressure of the pipe.

The pressure classes for AC pipes used in New Zealand between 1937 and 1986 and their nominal maximum working pressure ratings (based on BS & NZS) are shown in table below.

Classification of Asbestos Cement Pressure Pipes

Pressure Class	Design WP (m head)	Std. TP (m head)	ISO Class (Eternit / Italit)	Design WP (m head)	Std. TP (m head)
Class A	30	60	5	25	50
Class B	60	120	10	50	100
Class C	90	180	15	75	150
Class D	120	240	20	100	200
Class E	150	300	25	125	250
Class F	180	360			

Note also that pipe imported from the UK (Eternit) were only Classes A, B, C and D. Classes E and F were only available in New Zealand and Australia ≤ DN 150.

Phenolphthalein Indicator

A chemical pH indicator that is dissolved in alcohol and water. It remains colourless at pH <8.2 and becomes more strongly magenta as the pH increases.

When applied to a freshly cut / prepared pipe end, the thickness of the wall from the surface to the colour change can be measured. This distance is the depth of deterioration, either internal or external.

Seriously deteriorated pipes can be completely deteriorated through the wall with no pH greater than 8.3. However, a false (full wall deterioration) result can be due to the pipe end being carbonated due to reaction of the cementitious surface with CO_2 in the atmosphere.

Test Pressure (TP)

The TP is the value of the hydraulic pressure that each pipe was subjected to by the manufacturer in the factory. Every pipe and matching coupling was tested to the TP before being released for delivery. The minimum TP specified in NZS 3202:1977[23] is shown in Table 8-4. James Hardies' Fibrolite pipes were subjected to a test pressure of 3 times the WP from approximately 1972[24].

Wall Thickness (Wt)

The Wt is the numerical value of the wall thickness of the pipe. It is found by measuring the wall thickness typically at 6 equally spaced intervals around the pipe circumference. The Wt may vary significantly.

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[23] NZS 3202:1977 Specification for ASBESTOS CEMENT PRESSURE PIPES.
[24] James Hardies' Fibrolite pipes were tested to 3 times the nominal WP from approximately 1972 - ref Fibrolite Pressure Pipes Technical Manual June 1972.

Working Pressure (WP)

Peak operating pressure, typically in meter's head of water (m head).

Water Research centre United Kingdom (WRc – UK)

WRc is an Independent Centre of Excellence for Innovation and Growth, who operate across different sectors including Water, Environment, Gas and Resource Management.

Water Research Foundation United States of America (WRF-USA)

The Water Research Foundation is an internationally recognized leader in water research that is dedicated to advancing the science of water by sponsoring cutting-edge research and promoting collaboration.

Their research provides industry insights and practical solutions to the most complex challenges facing the water community today and into the future.

Water New Zealand (Water NZ)

Water New Zealand is a national not-for-profit sector comprising approximately 1500 corporate and individual members.

Water New Zealand is the principal voice for the water sector, focusing on the sustainable management and promotion of the water environment and encompassing the three waters: drinking water, waste and storm waters.

WorkSafe New Zealand (Work Safe)

WorkSafe is the work health and safety regulator in New Zealand. WorkSafe's function includes monitoring and enforcing compliance with work health and safety legislation as well as providing guidance, advice and information on work health and safety.

8   REFERENCES

National and International Standard

Standard	Title	County of Origin
BS 486:1933	Asbestos Cement Pressure Pipes	United Kingdom
BS 486:1956	Asbestos Cement Pressure Pipes	United Kingdom
NZSS 285:1959	Asbestos Cement Pressure Pipes (BS 486:1956 Adopted)	New Zealand
BS EN 512:1995	Fibre-Cement Products – Pressure Pipes and Joints	United Kingdom
NZS 3202:1977	Asbestos Cement Pressure Pipes	New Zealand
AS A 41:1959	Asbestos Cement Pressure Pipes and Joints	Australia
AS 1711:1975	Asbestos Cement Pressure Pipes	Australia
AWWA C 400:1980	Asbestos Cement Distribution Pipe, 4in through 16in for Water and Other Liquids	United States of America
ISO 2785:86	Directions for selection of asbestos-cement pipes subject to external loads with or without internal pressure	Switzerland
ISO TC 77 (proposal)	Products in fibre reinforced cement, referenced in Eternit AC pipe catalogue circa 1957	Switzerland
ASTM C 500:1995	Standard Test Methods for Asbestos-Cement Pipe	USA
ASTM C 296:2015	Standard Specification for Asbestos-Cement Pressure Pipe	USA

Reference Documents, Publisher, Author and Year Issued

Reference / Title	Publisher / Author	Year Issued
A New Development in Asbestos Cement Pipe Condition Assessment	John Black, John De Ruyter and Jonathan Morris	2007
Field Description of Soil and Rock	New Zealand Geotechnical Society Inc.	December 2005
New Zealand Asbestos Cement Watermain Manual	NZWWA / Opus	2001
Guidelines for the Management & Removal of Asbestos	OSH (Department of Labour)	1995
Material durability in aggressive ground	D L Barry	CIRIA report 98 - 1983
Watermains: Guidance on assessment and inspection techniques	CIRIA (Construction Industry research & Information Association)	Report R162 – 1996
Planning the Rehabilitation of Water Distribution Systems	WRc (Water Research centre)	1989
Deterioration of Asbestos Cement Watermains, report DW10131	WRc (Water Research centre) J Mordak et al	1988
Pipe materials selection manual – Water Supply, 2nd edition	WRc (Water Research centre)	1989
Internal Corrosion of Water Distribution Systems	AWWA Research Foundation	1977
Report No. DWI0131, Deterioration of Asbestos Cement Water Mains	Dept. of the Environment, UK	December 1988
Pipeline condition assessment – Summary report, City Design	Waitakere City	June 1998
Pipeline condition assessment – Summary report – City Design	North Shore City	July 1998
Health and Safety at Work (Asbestos) Regulations 2016	WorkSafe	2016
Health and Safety at Work Act	WorkSafe	2015
Development of an Effective Management Strategy for Asbestos Cement Pipe	Water Research Foundation (WRF, PDF Report #4480)	2015
Environmental impact of Asbestos Cement Pipe Renewal Technologies	Water Research Foundation (WRF) & US EPA (Web report #4465)	2015
Long Term Performance of Asbestos Cement Pipe	Water Research Foundation (WRF, Web Report #4093)	2013
Guidance Manual for Managing Long Term performance of Asbestos Cement pipe	Water Research Foundation (WRF), Yafei Hu et al	2013

Appendix A: Standard Record Sheets

<table>
<tr><td colspan="6" align="center">**APPENDIX A1 – PIPE SAMPLE RECOVERY REPORT**
.... COUNCIL</td></tr>
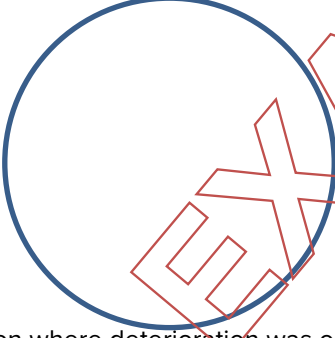<tr><td colspan="6" align="center">*Please complete form (in as much detail as possible). Seal in a plastic bag & enclose with each pipe sample.*</td></tr>
</table>

Work Order Number:	Date:		Time:		Asset ID:

Location (Take site photo):

Location address:

GPS Co-ordinates: E   N

Location Sketch (*use back of sheet if necessary***)**

Surface	Soil Type	Bedding	Pipe Material	Pipe Diameter	Exterior Condition
☐ Carriageway	☐ Topsoil	☐ Photo	☐ AC	☐ 100	☐ Good
☐ Footpath	☐ Clay	(of pipe in-situ)	☐ RC	☐ 150	☐ Fair
☐ Shoulder/Berm	☐ Sand/Gravel	☐ Natural	☐ DI	☐ 200	☐ Poor
☐ Private Property	☐ Fill	☐ Sand	☐ CI	☐ 250	
☐ Other	☐ Hard Rock	☐ Grit	☐ PVC	☐ 300	Comments:
	☐ Rotten Rock	☐ Scoria	☐ PE	☐ 375	
	☐ Other	☐ Other	☐ Other	☐ Other	
Cover - top of pipe to surface m	Groundwater depth from surface m				

Supply Cut off for hrs	No of Customers Effected: (est.)	Traffic Disruption: ☐ Very High ☐ Moderate ☐ Very Low

Pipe Sample Details and Notes

- Top of Pipe "As Laid" should be marked with spray paint or wax crayon before cutting pipe sample from pipeline.
- Sample should be 250 mm to 310 mm long (or as requested) and include an undamaged section of pipe.
- If a joint collar is uncovered in the excavation cut out the complete joint and send for assessment. Cut 100 mm to 200 mm each side of the coupler. For AC gravity sewer pipe samples and pressure pipes of DN 375 and larger, ensure that there is a section of pipe at least 300mm long for crush testing.
- Each pipe sample should be sealed in plastic promptly after extracting. Clearly label each pipe sample. Use two plastic bags (both independently sealed) for each pipe sample.
- Enclose all pipe samples in cardboard box(es) for courier to John Black / Adam Wheeldon, Opus International Consultants, 12 Moorhouse Avenue, Christchurch, New Zealand.

Sample length: mm	Pipe OD mm	Photo/s taken of pipe sample recovery & sample?

Operating pressure:

Preferably use a pressure data logger for 12 hr to 24 hr at 1 second intervals. Alternatively, a pressure gauge reading may be sufficient. *(It is also possible to take a video clip of a pressure gauge to record pressure surges on a pumping main).*

Pressure: m head.

Manufacturer's Markings on the pipe (if there are any – take photographs):	Year installed:

Remarks & Comments:

Contractors Name:		Signature:
Job completed:	Date	Time:

APPENDIX A2 – PIPE SAMPLE RECOVERY FORM – CORE SAMPLE
.... COUNCIL

Please complete form (in as much detail as possible) seal in a plastic bag & enclose with each core sample.

Work Order Number:	Date:	Time:	Asset ID:

Location (Take site photo):

Location address:

GPS Co-ordinates: E   N

Location Sketch (*use back of sheet if necessary*)

Surface	Soil Type	Bedding	Pipe Material	Pipe Diameter	Exterior Condition
☐ Carriageway	☐ Topsoil	☐ Photo	☐ AC	☐ 100	☐ Good
☐ Footpath	☐ Clay	(of pipe in-situ)	☐ RC	☐ 150	☐ Fair
☐ Shoulder/Berm	☐ Sand/Gravel	☐ Natural	☐ DI	☐ 200	☐ Poor
☐ Private Property	☐ Fill	☐ Sand	☐ CI	☐ 250	
☐ Other	☐ Hard Rock	☐ Grit	☐ PVC	☐ 300	Comments:
	☐ Rotten Rock	☐ Scoria	☐ PE	☐ 375	
	☐ Other	☐ Other	☐ Other	☐ Other	
Cover - top of pipe to surface m	Groundwater depth from surface m				

Core Sample Data and Exterior Deterioration

Exterior Deterioration (Depths in mm)

Mark Location where deterioration was observed

Core Location(O'clock, facing in flow direction):

Core Thickness:

Remarks & Comments:

Core Diameter: mm	Pipe OD mm	☐ Photo/s taken of pipe sample recovery & sample?

Operating pressure: Preferably use a pressure data logger for 12 hr to 24 hr at 1 second intervals. Alternatively, a pressure gauge reading may be sufficient. *(It is also possible to take a video clip of a pressure gauge to record pressure surges on a pumping main).* Pressure: m head.

Manufacturer's Markings on the pipe (photograph of any markings)	Year installed:

Each core sample should be sealed in plastic promptly after extracting. Clearly label each pipe sample. Use two plastic bags (both independently sealed) for each core sample. Core samples shall be couriered to John Black/Adam Wheeldon, Opus International Consultants, 12 Moorhouse Avenue, Christchurch, New Zealand.

Contractors Name:		Signature:
Job completed:	Date	Time:

APPENDIX A3 – PIPE AND CORE SAMPLE INSPECTION RECORD								
Location:					Pipe use	Wtr	WW	SW
Asset Owner					Date			
Asset ID					Assessor			
Sample ID					Class (if known)			

Pipe Sample Type	**Pipe**	*Barrel*	*Machined End*	**Pipe & Joint**	*Spigot & Socket*	*Collar*	*Mechanical joint*	**Core**

Measurements (mm)	OD		ID		Length	

Wall Thickness (mm)							
Ext. Det'n Depth (mm)							
Int. Det'n Depth (mm)							

External Observations				Bitumen Dipped	Y/N	Top "As Laid" Marked?		Y/N
Manufacturers Markings			Y/N	Markings:				
Hardness	Very Hard	Hard	Moderate	Soft	Very Soft	Comments:		
Surface Condition (Multiple)	Scoring		Scouring		Gouges	Dents	Holes	Cracks
	Other / Comments:							

Pipe Observations		Interior Stained?		Y/N	Colour of stain:		
Erosion	Y/N	Comments:					
Hardness Int / Ext	Interior			Exterior		Comments:	

Sample as Received	Dry	Moist	Wet	Saturated	Comments:	
Bedding Sample Received?		Y/N	Pea gravel	Rice gravel	Medium Gravel	
Fine Gravel		Coarse Sand	Medium Sand	Fine Sand	Scoria	
Silt		Clay	Peat	Other:		

Organic Matter	Y/N	Small	Medium	Large
Comments:				
Moisture Content	Dry	Moist	Wet	Saturated

Photos	Y/N	**Crush Test**	Y/N	**CT Scan**	Y/N

General Comments:

Appendix B: Identification of Different Types of Asbestos Cement Pipes

Asbestos Cement Pipe Historical Background

The use of AC pressure pipes for water supply commenced in New Zealand (NZ) in approximately 1935[25] although the earliest confirmed use is 1937, where Everite pipes sourced from the UK were used in a Waikato township.

The first NZ AC pipes were made by James Hardie & Coy Pty Ltd at Penrose, Auckland in ≈1940[26], using the low capital cost "Sutton" process, where pipes were formed from flat sheets of asbestos cement wrapped around a mandrel and cured under water. The Sutton Process was superseded after WWII by the "Magnani" process which operated until the change to the "Mazza" process (steam cured in an autoclave) in approximately 1959[27].

Mazza process pipes were still being sourced from the Eternit or Italit companies in Belgium and Italy in the late 1950's and early 1960's.

AC was the pipe material of choice for reticulation and trunk watermains from the 1950's to the mid 1980's and thousands of kilometres of pipes from 2″ diameter (DN 50) to 2′ diameter (DN 600) were installed.

AC pipes up to DN 750 were available in Australia in the 1980's but as far as can be determined, no pipes of this size have been used in NZ.

AC pipes were used almost exclusively for water supply until the mid-1960's, but after that, there was increasing use for wastewater pressure mains, gravity sewers and to a lesser extent, stormwater pipelines.

Overview & Summary

AC pipes installed in NZ were sourced from four companies:

- Turners Asbestos Cement Co, UK, (Everite Pipes)
- Eternit Ltd Co from Italy & Belgium (Eternit and Italit)
- James Hardie & Co Ltd, NZ (Fibrolite)
- James Hardie & Co Pty Ltd, Australia (Fibrolite)

Pipes sourced from these manufacturers had easily distinguished jointing systems. This allows the pipe manufacturer to be identified and can help identify the installation year (or period) / age of the pipeline and the contemporary manufacturing standard.

Key manufacturing standards for AC pressure pipes are summarised below:

- ISO T 78 ≈1956, (an interim standard referred to in Eternit / Italit literature).
- 1937 – 1959, BS 486:1933.
- 1959 – 1977, NZS 285:1959 (BS 486:1956 adopted without change).
- 1977 – 1986, NZS 3202:1977.
- 1959 – 1975, AS A.41:1959.

Key dates for AC pipes are summarised in the table below.

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[25] *NZ Engineering Feb 15 1960 – P G Ellery, Asbestos Cement Pipes.*
[26] *A Very Good Business – One Hundred Years of James Hardie Industries 1888 - 1988, Brian Carroll.*
[27] *Technology in Australia 1788 – 1988 Chapter 12 – Manufacturing Industry.*

Table B1-1 Key Dates for AC Pipes in New Zealand

Date	Comments
1933	BS 486:1933 Asbestos Cement Pressure Pipes manufacturing standard issued.
1937	Oldest confirmed installation date for AC pipes in NZ. Some also installed during WWII in army training camps.
~ 1937 to ~ 1955	Everite AC pipe imported from the UK. The pipe was bitumen coated & lined. • Screw joints for DN 50 – DN 150 (see Appendix B1, Photo B1-3). • Cast Iron Detachable (Gibault) joints for DN 200 – DN 450.
1953 to 1986	Fibrolite pipes made in NZ. Maximum of DN 225 in 1954, increased to DN 375 by 1960.
1954 to ~ 1965	Fibrolite pipes with a fixed socket joint glued to a machined taper on one end of the pipe and a rolling rubber ring joint. Refer to Appendix B2, Photo B2-3.
1958 to 1960	Eternit and Italit pipes from Italy and Belgium. These pipes used Simplex Collars. Refer to Appendix B3, Photo B3-3.
1959	NZSS 285:1959 Asbestos Cement Pressure Pipes issued. There were a reasonable number of significant changes between the 1933 and 1959 standards.
1959	Largest pipes made in NZ were 15" Class C.
1965 to 1986	Fibrolite Supertite collars (replaced the fixed socket joint in ~ 1965).
1972	DN 450, DN 525 and DN 600 introduced by James Hardie & Coy Pty Ltd under the FIBROLITE trademark.
1973	Manufacture of DN 50 and DN 80 pipes ceased.
1977	NZS 3202:1977 Asbestos Cement Pressure Pipes issued. Only relatively minor changes between the 1959 and 1977 standards, (minimum tensile strength increased).
1986	Manufacturing of AC pipe ceased in NZ, Australia, UK, Europe and the USA.

Appendix B1 – Everite AC Pipe Identification			
Manufacturer **County of Origin**		Turner & Newall United Kingdom	
New Zealand Installation Period		~ 1937 – ~ 1957	
DN Range	DN 50 – DN 450	**Standard**	BS 486 : 1933
Joint Types	DN 50 – DN 150 Screw Joints DN 200 – DN 450 Cast Iron Detachable (Gibault) Joint	**Key Features**	• Bitumen dipped pipes • Wall thickness typically greater than the standard

B1-1: Typical external view of an Everite pipe. Approx 50% of the bitumen coating is remaining, however, the CT scan confirmed that it was providing little to no protection against deterioration.

B1-2: Internal view of an Everite pipe, the bitumen lining is still visible. The longitudinal seam from the mandrel joint is clearly visible.

Appendix B1 – Everite AC Pipe Identification – Cont'd

B1-3: Photograph of Everite screw joint disassembled.

B1-4: Photograph of a Cast iron detachable (gibault) joint.

Used in NZ from 1937 to approx. 1957 for nominal bore pipes ≥ 6" (150 mm), consists of the following components:

- One centre collar
- Two cast iron flanges
- Two rubber rings
- Wrought iron bolts (usually not galvanised)

Bitumen Coating (Black) still present

Wide tool markings

Rubber Ring Location
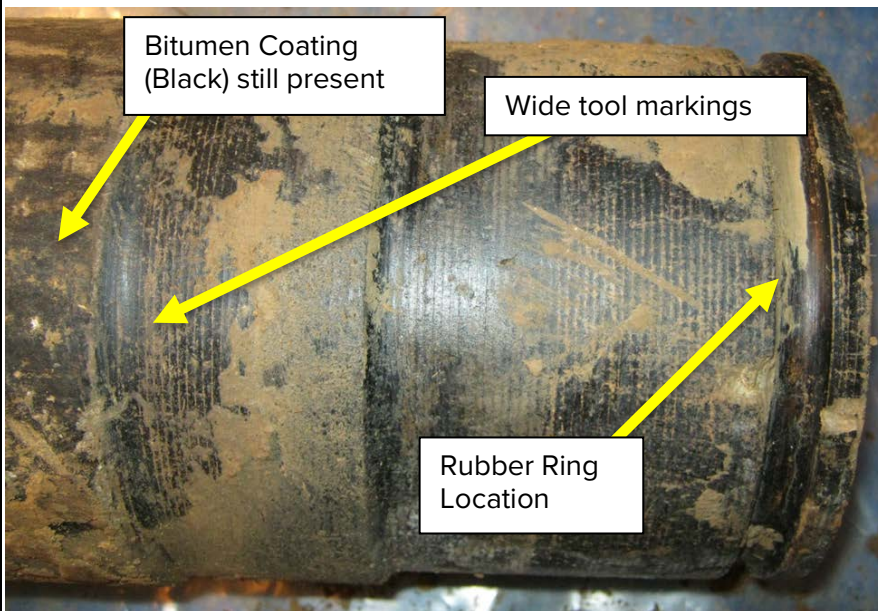
B1-5: Everite (factory machined) spigot.

The bitumen coating, wide tool marks (from machining) and the rubber ring location are highlighted.

| Appendix B2 – Fibrolite AC Pipe Identification			
Manufacturer **County of Origin**		James Hardie & Co Ltd Australia and New Zealand (Auckland)	
New Zealand Installation Period		~ 1953 – ~ 1986	
DN Range 1954 **1960** **1972**	DN 50 – DN 225 ≤ DN 375 ≤ DN 600	**Standards**	BS 486:1933 NZSS 285 : 1959 NZS 3202 : 1977
Joint Types	Pre 1965 Fixed Socket Post 1965 Supertite Collar Cast Iron Detachable (Gibault)	**Key Features**	• Some early pipes were bitumen dipped • Distinctive roller pattern

B2-1: Early Fibrolite pipe (circa 1954), bitumen dipped: - White stencilling reads "*Fibro**OLITE** press*ure pipe".

B2-2: Fibrolite pipe, circa 1961, - Red stencilling reads "***FibrOLITE PRES****sure pipe*".

Appendix B2 – Fibrolite AC Pipe Identification – Cont'd

"FIBROLITE" SOCKET

RUBBER RING COMPRESSED IN SOCKET
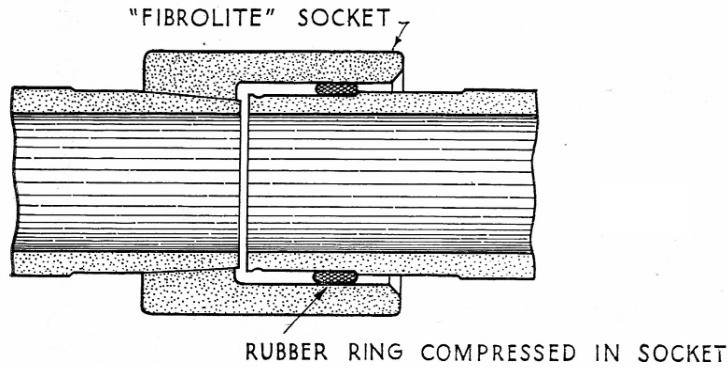
B2-3: Fibrolite Socket, copied from 1953 Fibrolite catalogue.
In use in NZ from ~ 1953 to approx. 1965, three components to the joint
- Fibrolite socket (glued to factory machined tapered end)
- Rubber ring
- Machined spigot with ring grove

Class C/D

DN 4" (100 mm)

Fibrolite

Supertite

Manufacture Date 22 / 11 / 68
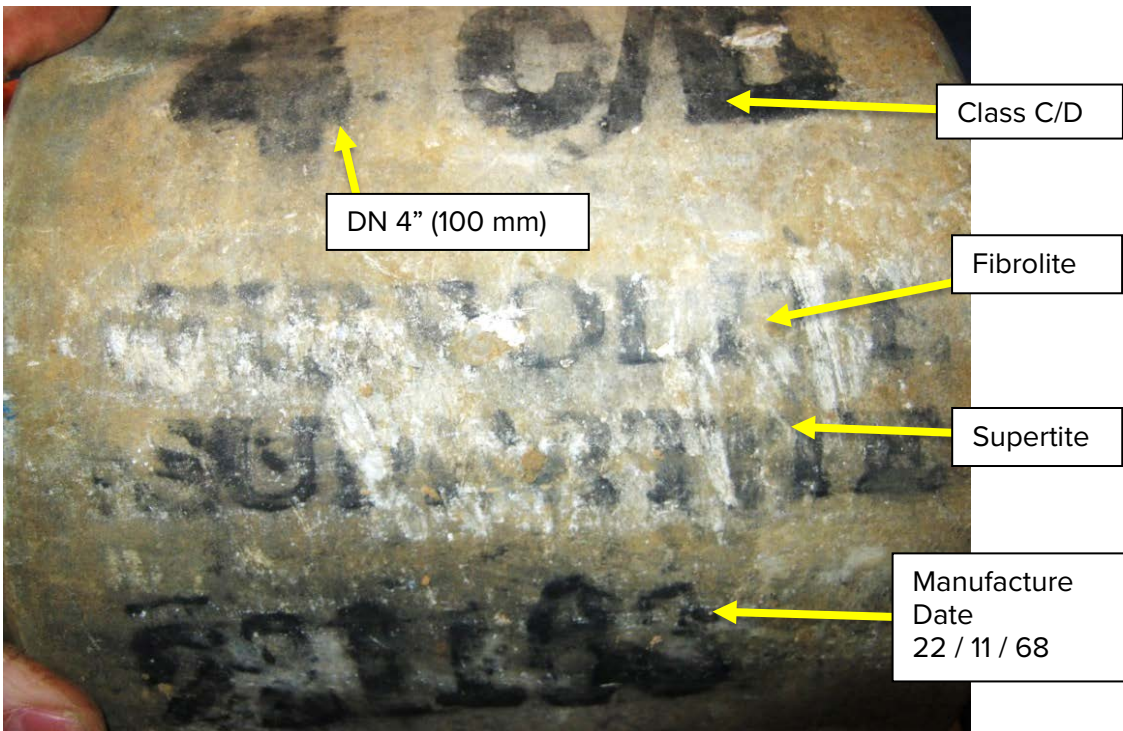
B2-4: Supertite collar (post 1965), with manufacturers marking.

General Comment: Pipes were sometimes supplied in "short" lengths down to 3.4 m. Not more than 10% of the pipe order could be shorts. Typical short lengths were 3.85 m, 3.7 m and 3.4 m.

Appendix B3 – Italit / Eternit AC Pipe Identification		
Manufacturer **County of Origin**	Eternit Ltd Co Italy & Belgium	Eternit pipes made for export were usually marked "ITALIT"
New Zealand Installation Period	~ 1958 – ~ 1960	
DN Range	DN 50 – DN 450	**Standards**	ISO T 78 (Interim Standard) BS 486 : 1933 NZSS 285 : 1959
Joint Types	All DN's Simplex Joint	**Key Features**	Typically the highest material strength of all the AC pipes (25 MPa). Tightly controlled dimensional compliance.
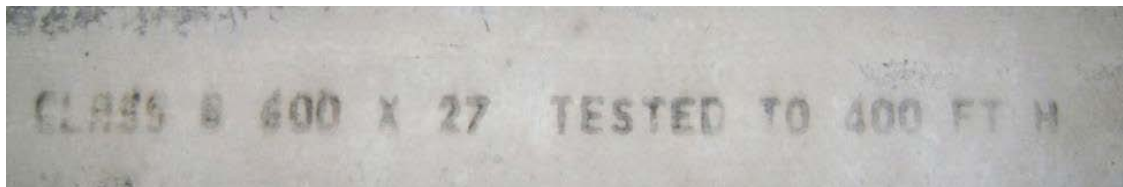
B3-1: Italit pressure pipe, the black stencilling reads "ISO Class B 600 X 27 Tested to 400 Ft H". Confirming this is a DN 600, Class B pressure pipe factory tested to 400 feet head (~ 120 m) of water i.e. twice its designed maximum operating pressure.

B3-2: Eternit wastewater pipe, installed in an above ground application.

Appendix B3 – Italit / Eternit AC Pipe Identification – Cont'd
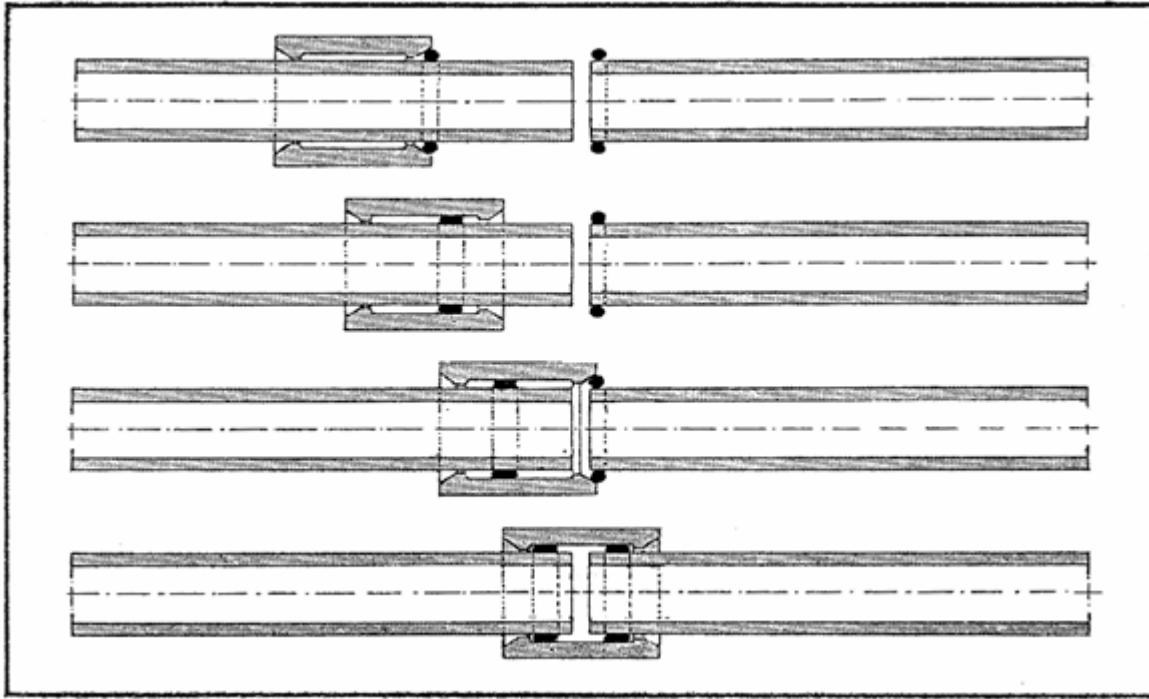
B3-3: Illustration of the assembly of a simplex joint, taken from a 1950's Eternit catalogue.

B3-4: DN 600 Simplex joint, with the partially visible black stencilling "MAZZA" referring to the manufacturing process.

B3-5: DN 500 Simplex joint from a trunk watermain.

Appendix C: Deterioration Depth Measurements – Straight Edge Callipers
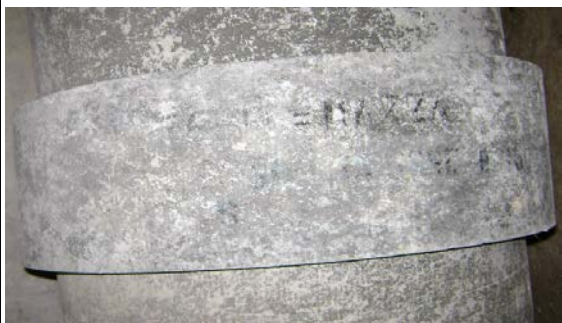
Refer to Volume 1 regarding appropriate Health and Safety procedures.

The depth of deterioration can be measured directly from a cut and prepared surface, using callipers. This may not be possible in a field situation.

The pipe can be filed with a flat mill file until the sound AC matrix is located. By painting the cut surface with phenolphthalein indicator, the undeteriorated material will be obvious. The width of the "cut" at that point (c), can be used to calculate the depth of the deteriorated AC, using the diagram and formulae below
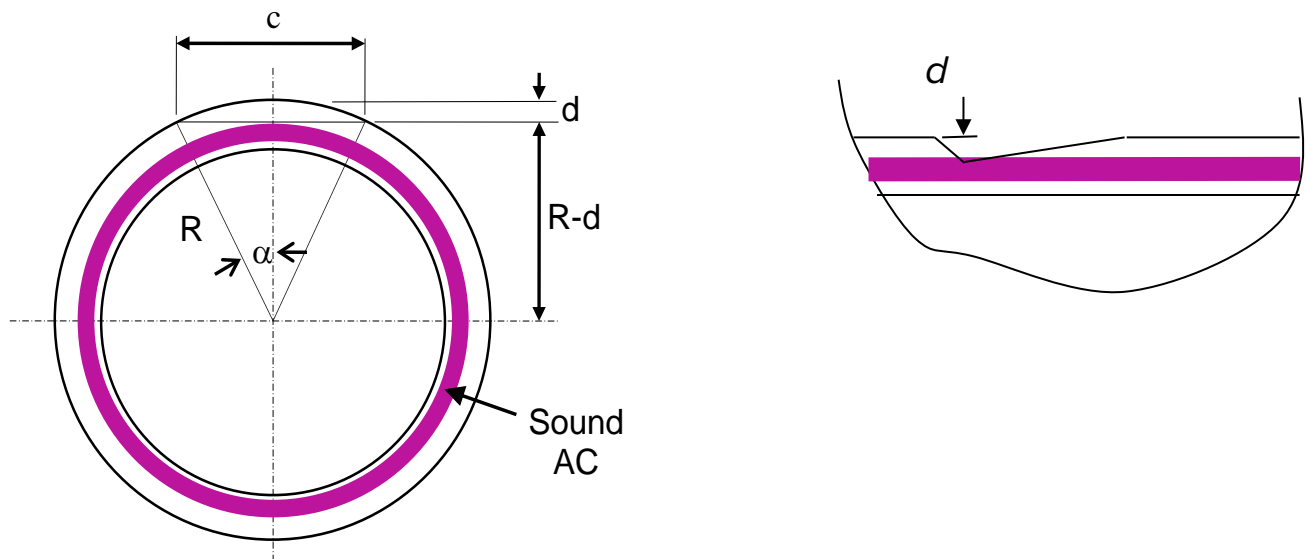
The depth of deterioration can be calculated from the following formula. [It is necessary to measure the pipe OD and the width of the "cut" (c)].

$$\alpha = Sin^{-1} \frac{c}{2R}$$

$$d = R - (RCos\alpha)$$

Where:

    c = Width of cut

    d = Depth of deteriorated layer

    R = Pipe OD/2

    α = Half of angle at centre

The depth d can also be measured directly using callipers and a straight edge. A set of plastic callipers can be glued to a suitable straight edge and the depth of the deteriorated layer measured using the depth gauge.

Precautions

The file must be held flat as there is a danger of "rocking" the file and thus over-estimating the width C.

The filing must be carried out with extreme care to avoid removing a significant amount of the undeteriorated AC material with the possibility of causing pipe failure. This operation should only be carried out by someone who has experience in pipe sample evaluation

Appendix D: Asbestos Warning Labels

DANGER

**LUNG DISEASE &
CANCER HAZARD**

**CONTAINS
ASBESTOS
CEMENT PIPES
FOR TESTING**

**DO NOT OPEN
WITHOUT PROPER
TRAINING & PPE**

a

WARNING!
**CONTAINS ASBESTOS
CEMENT WATER PIPES
FOR TESTING**

**Breathing asbestos dust
can cause fatal diseases**

**Do NOT open this sealed
package without wearing:**

1. **Approved respiratory
   protection and**
2. **Disposable overalls &
   appropriate PPE**

h =
40% H

a

white 'a'
on a black
background

H

h =
60% H

WARNING!
CONTAINS ASBESTOS

**Breathing
asbestos dust
causes fatal diseases**

Do NOT sand, drill, shape, cut
or otherwise disturb without
either:
1. Adequate and serviceable
   dust collection equipment
   or
2. Wearing approved respira-
   tory protection.

standard wording
in white and/or
black on a red
background