"HOW LONG WILL STORMWATER PIPELINES REALLY LAST?"

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Abstract

The use of the straight-line depreciation based on age, for stormwater pipe networks, generally results in the reporting of excessive depreciation in the early phase of the portfolio's lifecycle. These assets, like many other pipeline systems, perform at or near as-new performance for most of their life with accelerated deterioration in the late stages. A more representative basis for determining deterioration is the use of structural condition analysis. However the development of condition based depreciation models for reinforced concrete pipe (RCP) stormwater pipelines is hampered by the lack of available data on current condition and deterioration mechanisms upon which to base the analysis.

Fully funding of depreciation is in place in New Zealand and may come into force in Australia within the next few years. This requirement makes it essential for asset managers to "get the figures right" when determining the depreciation allowance.

This paper describes the development of a methodology and model for Logan City Council's - RCP stormwater pipelines that can be implemented, in a cost effective manner, to calculate condition based deprecation to much better represent the actual deterioration and hence depreciation of the stormwater assets. Technical argument, supported by in field condition information, has been presented which is sufficient to satisfy the requirements of the Auditors and Regulators for the use of CBD.

Key Words:

Stormwater, reinforced concrete pipe, depreciation, condition, deterioration model, defects, RCP, asset life.

Introduction

Logan City Council currently manages a 610 km stormwater pipe network valued at $420M (2004 - replacement value). This network predominantly consists of reinforced concrete pipe (RCP) with an assumed asset life of 100 years. Much of this network was constructed in the 1980's and early 1990's following formation of Logan City in 1979.

Logan City currently depreciates this network under the straight-line accounting method which results in the reporting of excessive depreciation in the early phase of the network's life cycle. The current reported depreciation for Logan City's stormwater pipe network is $4.2M per annum (2004 valuation).

Utilising standard renewals annuity calculations, if a reserve was established for fully funding this depreciation, this reserve would grow to approximately $200M by the year 2070 before beginning to decline through asset renewals. This is obviously an untenable situation to Logan City and a more representative basis of determining depreciation for this network is required and the use of a condition analysis approach needed to be investigated, so that more realistic and reliable renewals figures could be reported to Council and funded in the future.

However, the development of condition based depreciation models for stormwater systems is hampered by the lack of available data on current condition and a lack of understanding of the deterioration

mechanisms upon which to base the analysis.

Probabilistic modelling has been used by others to predict changes in structural condition based on outputs from the SEWRAT computer program. The deficiency in this model of determining depreciation rates is that it is based solely on the internal condition of the pipe as determined by CCTV surveys and does not account for deterioration processes that affect the long term performance of the pipe. Additionally, the probabilistic model does not take account of the effect of maintenance or other forms of intervention on the progression of deterioration.

An alternative approach is to use knowledge of the performance of pipe line materials, under operational exposure conditions, to identify the major deterioration mechanisms that affect the structural performance of RCP's. These deterioration mechanisms can then be modelled to determine theoretical rates of loss of condition and subsequently the development of depreciation profiles.

This paper discusses the development of a theoretical condition based depreciation model for reinforced concrete stormwater pipes, based on sound engineering judgement that now requires adequate field data to support the theory.

Deterioration Mechanisms

- Background

Although little empirical data exists for exposure of this type of pipe to Australian conditions, the deterioration models have been developed using information available from other countries and theoretical evaluation based on GHD's extensive knowledge of materials performance. These models have been used here with some modifications to meet the needs of the Deterioration Model. The models for the various exposure cases are discussed in this section and summarised in Appendix 1 (Table 1) of this report. In order that a model of manageable size could be developed, certain assumptions had to be made as follows.

Installation Defects

The RCP are at risk of cracking and/or joint displacement due to:

- Poor handling during installation;
- Improper bedding and compaction of the surrounding soil;
- Movement of the soil or overloading due to heavy traffic.

The deterioration profiles assume minimal cracking has no effect on pipe deterioration, ie minor cracks <0.2mm wide. Cracks wider than this will allow the aggressive agents (chlorides, sulphates, etc) to reach the reinforcing steel sooner resulting in an accelerated deterioration process.

Installation defects as a failure mode are considered separately and have been built into the model.

Upper and Lower Bound

The pipes are factory made and the concrete is therefore of a consistent quality. However, there is likely to be some variability arising from pipes from different manufacturers. Of greater significance is variability within a given exposure condition. Exposure conditions have necessarily been grouped together to facilitate modelling, but significant variation still occurs due to the natural variability within the different soil classifications. To quantify this variability, Upper Bound and Lower Bound determination scenarios have been established for each of the exposure conditions. Condition information for assets in particular environments should place it somewhere between the Upper and Lower Bound. At present, data regarding the condition of the pipes is very limited. For the purpose of valuation the Lower Bound of these two lines is therefore used. As more data becomes available, the lines will adjust to reflect more accurately the actual rather than theoretical performance.

When considering the likely performance of pipes in the various environments, the

following time estimates were made for both the upper and lower bounds.

T1 Initiation - the point at which the pipes chemical or physical properties fail to provide adequate protection to the reinforcement and corrosion commences.

T2 First visible signs of damage such as spalling.

T3 Structurally significant damage

T4 Structural distress

T5 Collapse

Selection of Pipe

The RCP manufacturers produce a range of pipes for various conditions. Based on advice from LCC staff, it is possible in some areas that regular or standard classes of pipe have been used in onerous soil conditions rather than the correct grade of pipes. This is particularly crucial for

- Tidal Areas with >20,000 ppm of chlorides (pipes with cover of 15 or 20mm to be used).
- Groundwater or runoff water containing 1,000 to 10,000 ppm sulphates (pipes made with Sulphate Resisting Cement to be used).
- Groundwater or run off water with sulphates >10,000 ppm (no cement based pipe to be used).

Deterioration has been forecast on the basis of the correct grade of pipe for the regular cases. Additional assessments have been carried out to determine the reduction in life arising from the use of incorrect pipe.

Availability of Soil and Groundwater Data

Whilst the individual attack mechanisms that could apply have been considered, the information relating to the soil at individual locations is limited and broad approximations had to be made. For this reason, some of the categories of attack have been combined. The likelihood of groundwater was taken into consideration rather than varied with known ground water level.

Forms of Attack on RCP

The types of attach considered are:

- Carbonation
- Tidal Areas
- Chlorides in Groundwater
- Chlorides in Stormwater
- Sulphate Soils
- Abrasion
- Acid Attack Internal and External
- CO_2 Leaching Internal and External

Calibration

The models used are based on the information available. In order to confirm their accuracy they will require calibration. This will require that at all opportunities where pipes are exposed for repair due to accidental damage, maintenance, replacement to increase capacity or for whatever reason, samples are taken and tested in the manner appropriate to the exposure condition of the pipe. In addition, existing and new CCTV inspection results plus representative core samples will need to be incorporated into the analysis and related to the exposure conditions and deterioration models proposed in this report.

Maintenance

One of the most common problems relating to RCP stormwater pipes is the penetration of tree roots. It is assumed that this will be dealt with as part of a maintenance programme and if managed properly is not life limiting. Where damage has occurred due to tree roots this is taken into account in our assessment of cracking and its impact on life expectancy.

LIFE EXPECTANCIES

Appendix 1 (Table 1) describes the T1 to T5 estimates where the nominated form of attack is the only or most aggressive the pipeline is exposed to. These estimates are drawn from research and considered judgement of material technology experts. They consider the likely chemical or physical deterioration rate expected for the pipeline exposed to the condition described. As there are many variables involved such as varying soil type along the length of pipe, inconsistent construction, variable groundwater exposures etc, an upper and lower range has been provided.

Sulphate, Acid and CO_2 Leaching Exposure

Detailed testing of the soils to which the pipes are exposed was not available. A geological assessment was carried out based on available geological soil maps and limited testing from government agencies. From this a combined assessment of the risk of acidity/sulphate/CO_2 leaching was developed based on soil type, likely presence of water and topography.

Times to T1-T5 upper and lower bound have been taken as follows:

Exposure risk 1 or less:	Carbonation
Exposure risk 2.5-3:	Most aggressive of the 3 exposures, External acid
Exposure categories in between:	Pro rata

Appendix 2 (Table 2) details the times to damage states for varying acid sulphate risk conditions.

The three diagrams shown in Appendix 3 show the approach followed using GIS mapping data to determine the risk exposure.

- The first diagram (Figure 1) describes the soil types across Logan City Council, each of which was given an aggressiveness rating.
- The second diagram (Figure 2) shows the topographical information. The closer to sea level the more likely the presence of groundwater and saline environments.
- The third diagram (Figure 3) shows the pipe network colour coded based on the risk exposure area each is located within.

Of interest is the likelihood that the vast majority of pipelines are located in a benign environment and would most likely have little more than carbonation attack as the principle form of attack.

Many readers will be able to recount examples of pipelines that have prematurely failed but in the context of the entire network how many pipelines would experience a similar fate. Of course all networks are unique and would vary between coastal and inland environments.

INTERVENTION POINTS

RCP can theoretically be patch repaired. However, this is costly per unit length and difficult to achieve, either by a remote control device or by human entry. In reality, once corrosion of the steel has commenced, the process will continue and the structural integrity of the pipe will be compromised in the relatively near future. Full repair of RCP requires a lining system.

Lining would need to be installed at Structurally Significant Damage, T3. After structurally significant damage has taken place, deformation could mean that the liner cannot be fitted.

Smaller pipes do not present a significant risk of ground collapse, or damage arising from leakage. Depending on LCC's view on risk, it may be possible to delay replacement of pipes until collapse, T5, for smaller diameter pipes, say up to 450mm diameter. Pipes greater in diameter than this should be replaced at T4, Structural Distress.

DETERIORATION MODEL

Based on the timing described above it is assumed that the pipe would be lined at T3 Structurally Significant Damage as this is, in all cases, cheaper than replacement. An exception to this would be where the future of the pipe in that area was in doubt due to future changes in use.

It is therefore proposed that deterioration be on a straight line basis to T3 (the X axis point being the age in years and the Y axis being full replacement less the cost for lining, ie residual value). Thereafter the value would reduce to end of life (T5, Collapse for pipes 450mm or less or T4, Structural Distress for pipes greater than 450mm diameter). Illustrations are shown in Appendix 4 as Figures 4 and 5 for typical cases.

The point at which the line changes gradient is T3, typically the point where the pipeline "could" be structurally relined. The gradient of the line from T0 to T3 is governed by the difference in cost between replacement and structural relining. This information can easily be translated into a depreciation rate. Should the structural relining not prove the most appropriate solution when time T3 is reached, the deterioration rate can be increased to reflect the likely residual life to T4 or T5 replacement. Obviously increased visual and physical condition assessments of the pipeline will be required as the pipeline approaches T3.

ADDITIONAL DEFECTS

Some additional defects have been taken into account in the model produced but have been excluded from detailed discussion in this paper. These defects include:

- Cracking of installed pipes.
  Circumferential and longitudinal cracking present differing impact on life.
- Joint Displacement
- Infiltration

Conclusion

Logan City Council in partnership with GHD have developed a theoretical conditional based depreciation model for reinforced concrete stormwater pipes. The major inputs to this model are soil conditions, groundwater environments, construction defects, longitudinal cracking, joint displacement and abrasion.

Utilising pipe relining technologies, gives us the opportunity to refurbish ageing stormwater pipelines at a far cheaper rate than full replacement. The model is based on relining pipelines when they begin to exhibit significant structural damage (ie: T3). An exception to this would be when the function of the pipeline was in doubt due to future changes eg: capacity upgrades. The model is therefore based on a straight line basis to T3, with the X axis being the age in years and the Y axis being the full replacement cost less the cost o relining, ie residual value. With the value of the asset reducing to zero at the assumed end of life (T5, collapse for pipes <600mm or T4, structural distress for pipes >= 600mm). Figures 4 and 5 illustrates typical deterioration profiles.

In view of the lack of insitu data and the need to have the model accepted, the lower bound times should be used initially, this can then be adjusted as data for exposure conditions become available. The model also includes the facility to adjust as a percentage between the upper and lower bound cases, this can also be adjusted as more data becomes available.

Based on applying the lower bound scenarios (ie greatest deterioration and depreciation rate) to the limited data available at Logan City, the annual "condition based depreciation" figure for Council's $420m stormwater pipe network is theoretically reduced to $2.6M (compared to the $4.2M pa straight line depreciation figure currently reported).

Data will now need to be gathered to calibrate the model to fulfil the criterion that it is "condition based depreciation".

APPENDIX 1

Table 1 - Times to Damage States for Varying Exposure Conditions

Exposure Condition	Initiation T1 Years	First Visible T2 Years	Structurally Significant T3 Years	Structural Distress T4 Years	System Collapse T5 Years
Carbonation - Internal	Atmospheric				
Best	**200**	**220**	**250**	**260**	**265**
Worst	**75**	**95**	**125**	**135**	**140**
Chlorides - Internal	<20,000ppm				
Best	130	145	175	185	190
Worst	70	80	110	120	125
Chlorides - External	<20,000ppm				
Best	**60**	**80**	**110**	**120**	**125**
Worst	**45**	**65**	**95**	**105**	**110**
Chlorides - Int & Ext	Tidal				
Best	**100**	**120**	**150**	**160**	**165**
Worst	**70**	**90**	**120**	**130**	**135**
Sulphates - External	1000-100000ppm SRC pipe				
Best	**140**	**160**	**200**	**210**	**215**
Worst	**40**	**60**	**100**	**110**	**115**
Abrasion	<5% Grade				
Best	**100**	**120**	**160**	**180**	**200**
Worst	**20**	**40**	**80**	**100**	**120**
Acid - External	pH<5				
Best	**40**	**60**	**100**	**110**	**115**
Worst	**10**	**30**	**70**	**80**	**85**
Acid - Internal	pH<5				
Best	**60**	**80**	**100**	**110**	**115**
Worst	**20**	**50**	**70**	**75**	**85**
CO2 leaching - Int & Ext					
Best	**45**	**70**	**100**	**110**	**115**
Worst	**15**	**40**	**70**	**80**	**85**

Table 2 - Times to Damage States for Varying Acid Sulphate Risk Conditions

Exposure Risk Condition	Initiation T1 Years	First Visible T2 Years	Structurally Significant T3 Years	Structural Distress T4 Years	System Collapse T5 Years
Very High					
Best	40	60	100	110	115
Worst	10	30	70	80	85
High					
Best	93	113	150	160	165
Worst	27	47	83	93	98
Moderate					
Best	147	167	200	210	215
Worst	43	63	97	107	112

APPENDIX 3

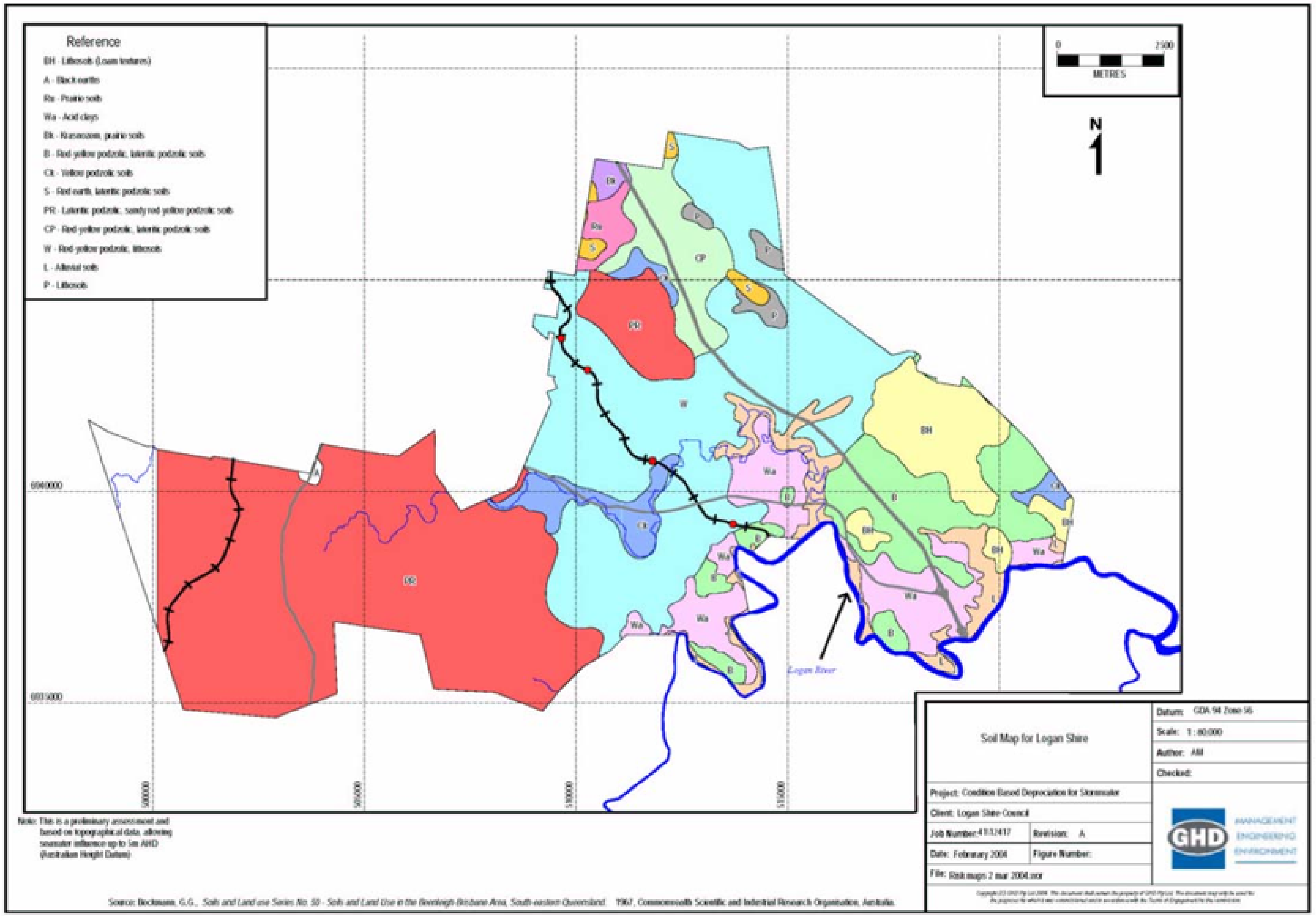

Figure 1 - Logan City Council Soil Mapping

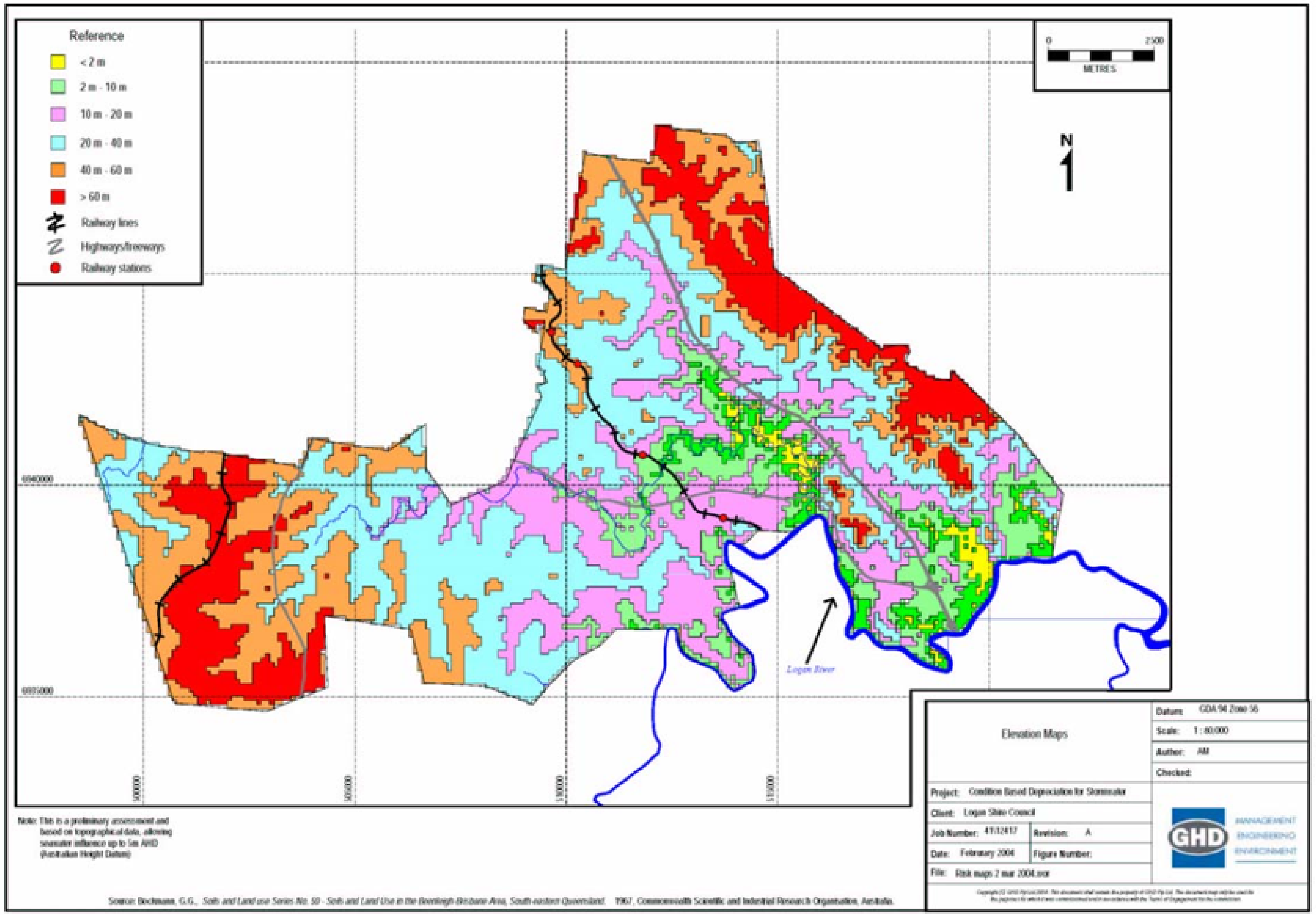

Figure 2 - Logan City Council Contour Mapping

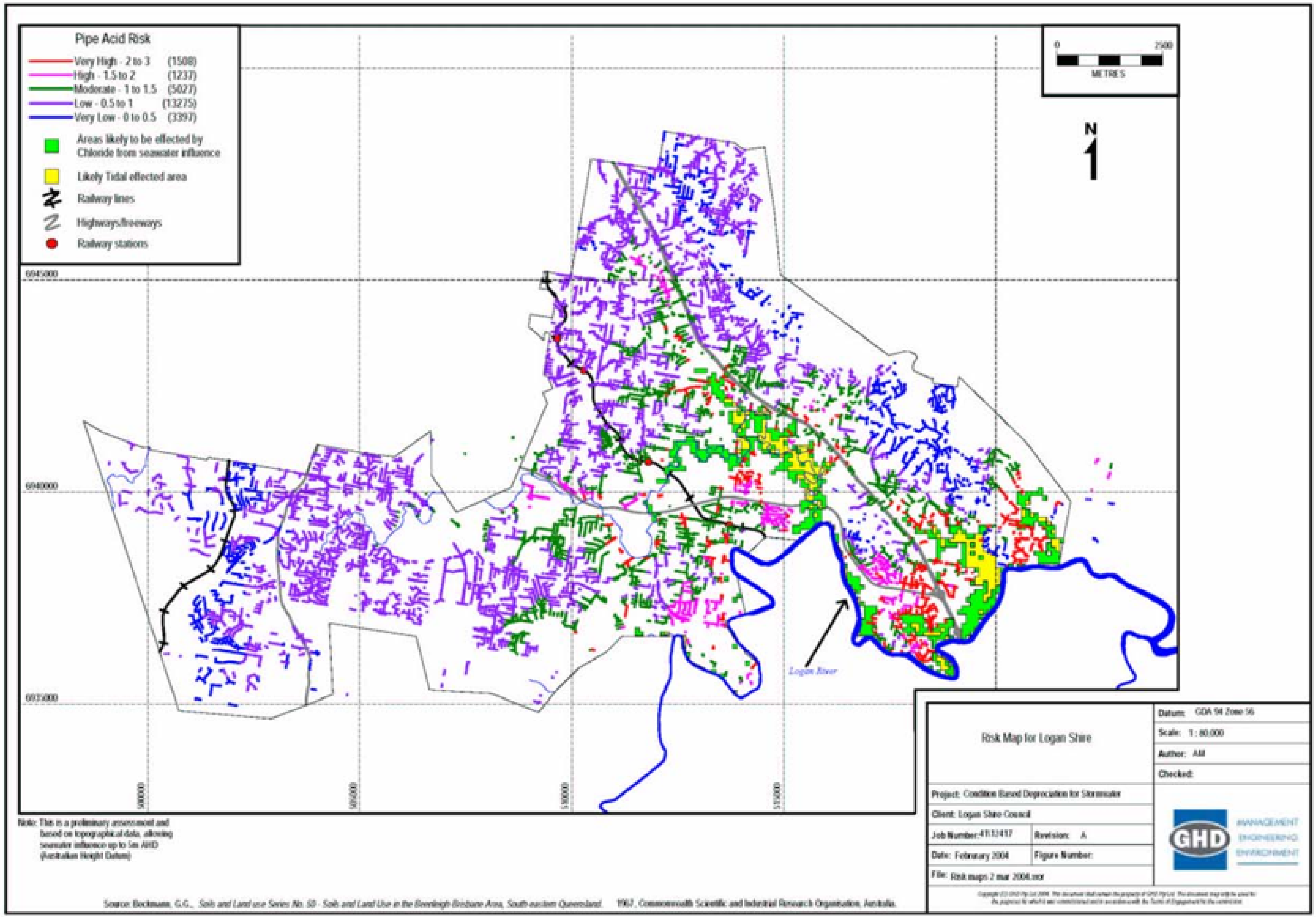

Figure 3 - Logan City Council RCP Risk Exposure Mapping

APPENDIX 4

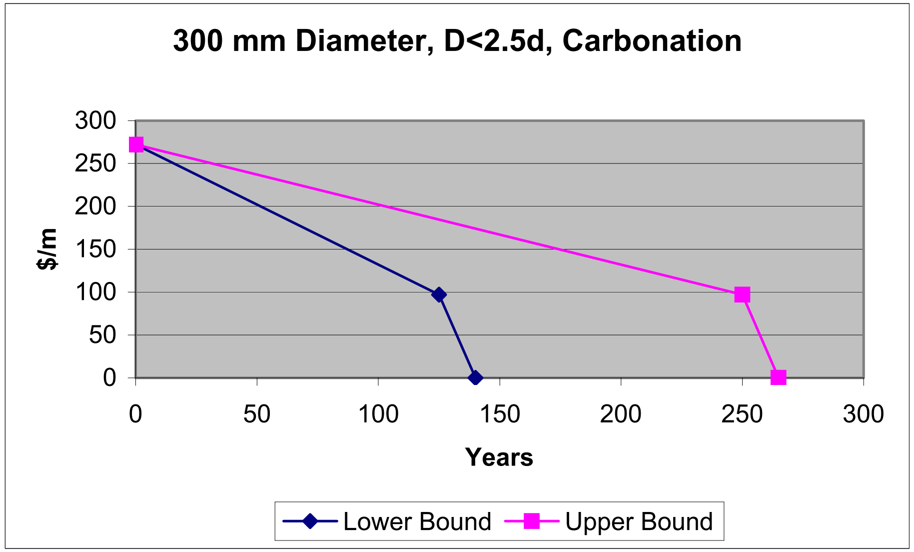

Figure 4

Example of Proposed Deterioration Profiles - 300mm Diameter

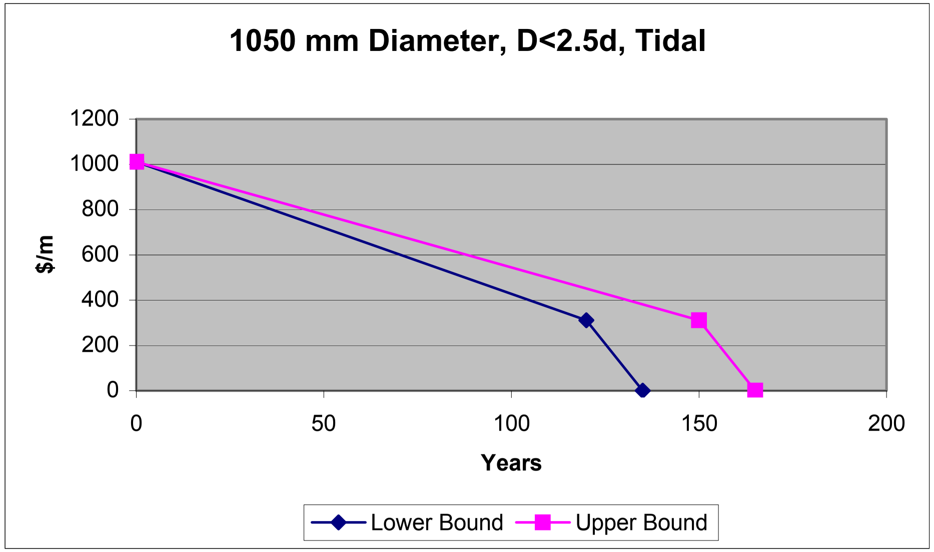

Figure 5

Example of Proposed Deterioration Lines - 1050mm Diameter

Biography:

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Ross is GHD's Manager Asset Management in their Brisbane office and is responsible for providing asset management services to the Queensland Market. Ross has travelled extensively throughout Australasia consulting on asset management issues and has a good appreciation of the various industry directions being pursued. Ross has consulted to a multitude of municipalities, state government bodies and private industry clients covering the management of both passive and dynamic assets. These services have often involved moving the client to a more commercially focused approach to the management of their assets. Consulting services provided cover all aspects of life cycle asset management and include process definition and improvement, technical audits and benchmarking, information systems selection and implementation, data management, valuations, depreciation and estimating, design management services, asset costing, works and maintenance management and risk management.

Rod Kennedy - Logan City Council, Queensland

BE(Hons), RPEQ, IPWEA(Q) South East Branch Committee Member

Rod is Logan City Council's Infrastructure Manager within the Department of City Works and is responsible for Capital Works Programming, Utilities Management, Counter Disaster Management, Contract Management, Floodplain Management and Asset Management. Rod has held this position since October 2000, prior to this Rod held Senior Engineering and Management positions at large metropolitan/rural fringe Councils in Sydney for 6 years, with a further 6 years in the private contracting sector.

Rod is currently a South East Branch Committee Member for the Institute of Public Works Engineering Australia, Queensland Division.