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DETERIORATION, DEPRECIATION AND SERVICEABILITY OF STORMWATER PIPES

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Abstract: Stormwater pipe networks, as with other forms of buried infrastructure, are extremely expensive to develop and maintain. These high costs demand that an accurate evaluation of their current structural condition is essential for their effective management. This study presents a Markov model for the structural deterioration of stormwater pipes. The model is calibrated, using Bayesian techniques, to structural condition data from the stormwater asset database developed by Newcastle City Council (Australia). It is shown that the Markov model is consistent with the data. The pipe categories of diameter, construction material, soil type, and exposure classification were found to influence the deterioration process. The introduction of Australian Accounting Standard AAS27 compels Local Government to determine the depreciated value of their stormwater network. A rational approach to assessing depreciation is to base it on structural deterioration. It is shown that the depreciation methods required by AAS27 significantly overestimate the structural deterioration. However, the focus on structural condition is somewhat artificial and does not address the fundamental issues with regard to management of stormwater pipe assets. We suggest that the level of service provided by the pipe depends on its position in the network and on factors diminishing its original hydraulic capacity such as intrusions by tree roots, sedimentation and collection of debris. The defects identified in serviceability ratings from SEWRAT surveys can be assigned loss coefficients. Use of such coefficients in a hydraulic model of the pipe network will enable an assessment of surcharge frequency and hence the serviceability of the pipe. It is suggested that a combination of both structural and serviceability conditions should be considered when determining a stormwater pipe network management strategy.

Introduction

Stormwater pipes are provided to convey stormwater from streets and adjoining properties without nuisance for storm events of a given frequency as defined by average recurrence interval (ARI) (Institution of Engineers, 1987). The high costs associated with the installation and maintenance of stormwater pipe networks, as with other forms of buried infrastructure, demand that an accurate evaluation of their structural condition and the level of service provided by the pipes is essential for their effective management. This provides the motivation for this study, which models the deterioration of stormwater pipes as a Markov process and then discusses the serviceability provided by stormwater pipes. A detailed description of this study is provided by Micevski et al. (2002).

Furthermore, current Australian accounting standards (AASs), namely AAS27 (AARF, 1996), require that Local Government prepare annual financial statements. These statements must include, amongst other things, the depreciated amount for the stormwater pipes that are under their control. AAS27 calls upon AAS4 (AARF, 1997), which describes various depreciation methods. Both accounting standards rely on the Local Government Asset Accounting Manual (LGAAM; DLGC, 1995) to define the depreciation method. The LGAAM does not give a useful life for stormwater pipes; however, useful lives for sewerage and water supply pipes are provided. These useful lives are 80 years for water mains, while sewerage pipes range from 40–70 years.

The currently accepted industry practice is to use linear depreciation over a useful life of either 70 or 100 years for stormwater pipes. A more rational approach to assessing depreciation is to base it on structural deterioration.

The structural condition, and hence structural deterioration, of stormwater pipes is estimated through the use of condition ratings. The condition ratings take the form of five discrete states. These states are selected for consistency with the condition ratings specified within the LGAAM. State 1 represents a pipe in a near new condition, while state 5 represents a pipe in an unserviceable, i.e. failed, condition. These states are described in Table 1.

Table 1: Description of structural condition states (DLGC, 1995)

Structural Condition	Physical Description
1	Near perfect condition
2	Some superficial deterioration
3	Serious deterioration, requiring substantial maintenance
4	Level of deterioration affects the fabric of the asset, requiring major reconstruction or refurbishment
5	Level of deterioration is such to render the asset unserviceable

Review of the literature revealed that Markov models for infrastructure deterioration are quite common, with road bridges being a frequent candidate for analysis. For example, Cesare et al. (1992) estimated the Markov transition probabilities for various bridge types and bridge components using non-linear programming methods.

Some deterioration models for sewer pipe networks have been developed. Røstum et al. (1999) modelled the deterioration of Norwegian sewer pipes using a cohort survival model based on the Herz (1996) distribution. Mailhot et al. (2000) estimated the structural deterioration of a Canadian sewer network using a Weibull distribution model. Wirahadikusumah et al. (2001) modelled the deterioration of American combined sewer pipes using a Markov model calibrated to an exponential regression curve. However, the deterioration processes affecting sewer and stormwater pipes are considered to be different. Sewer pipes are subject to internal attack by acids associated with sewage, whereas stormwater is relatively clean, resulting in pipe damage being caused primarily by external factors.

No deterioration models for stormwater pipe networks were found within the literature. However, it is noted that Jacobs et al. (1993) used chance constrained multi-objective programming to optimally schedule the rehabilitation of a stormwater drainage network. Their model assumes that pipes deteriorate linearly with time and aims to minimise the total expected costs from rehabilitation and expected losses from wear out and flooding.

The principal contribution of this study is the application of a multi-state Markov model to simulate the structural deterioration of stormwater pipes. Bayesian methods are used to calibrate the model and statistical hypothesis tests are used to validate the suitability of the model.

The organisation of the paper is as follows. The next section provides a brief overview of the case study involving data from the stormwater network located in Newcastle, NSW. The Markov model is introduced and the procedures used to calibrate and validate the Markov model, as well as the theory associated with these procedures are discussed. The results of the case study then follow. Finally, the results from laboratory studies of serviceability of stormwater pipes are presented along with a discussion of results.

Case Study Description

Data Source

The data set used in the case study was obtained from the Newcastle City Council (NCC) stormwater asset database. The data set consisted of a total of 497 pipes. Information recorded for each pipe included asset identification, condition rating, survey, and other general pipe information. All pipes were situated within road reservations, and so were subject to traffic loadings.

The total length of pipes within the database is 17 km, whilst the length of the entire NCC stormwater network is 380 km – providing a sample size of approx. 4.5%.

The pipes ranged in age from 3 to 110 years, with approximately 60% of pipes being contained within the 51 and 56 year age groups. In accordance with industry practice and accounting standards, NCC uses linear depreciation over a useful life of 70 years. The replacement value of the network was estimated, in 1997, to be approx. $145 million.

Condition Evaluation Procedure

The structural and serviceability condition ratings of the stormwater pipes were assessed using the SEWRAT computer program, which is a component of the evaluation system contained within the Australian Conduit Condition Evaluation Manual (Water Board, 1991). SEWRAT provides a condition rating based on the number and severity of defects affecting a pipe. Defects are assessed using closed circuit television (CCTV) surveys of a pipe. When a defect is encountered, a score is allocated based on the type and severity of the defect. On completion of the survey, SEWRAT then calculates three scores. These being the peak (maximum total score for a single metre length), mean (total score divided by the total length), and average (total score divided by the number of defects) scores.

The pipe is then graded according to threshold values of the peak, mean, and average scores, with the worst grading of the three being used. SEWRAT uses a three state grading system. This is unsuitable for Local Government requirements, which requires a five state system in accordance with Table 1. Coombes (1997) found state 5 to be redundant for stormwater pipes. State 5 represents a pipe that cannot convey water. This is not observed in the field, where even extremely structurally damaged stormwater pipes can still convey stormwater effectively (see Figure 1). Thus, a four state grading system was adopted using the first four structural condition states described in Table 1. The data was classified using this four state system.

Figure 1: Extremely damaged pipe that still conveys stormwater effectively

Pipe Categories

The data set was classified according to the pipe categories present within the data set. These pipe categories were then sub-classified into their constituent values. Table 2 summarises the categories used within this study.

Table 2: Categorisation of stormwater pipe data

Analysis / Category	Data Set / Category Value (Number of Samples)
Entire Data Set	Entire Data Set (497)
Split Sample	split1 (249), split2 (248)
Diameter	d<600 (376), d≥600 (121)
Material	conc (342), VC (135)
Soil Type	all (296), pod (201)
Exposure	A2 (216), B2 (238), C (43)
Serviceability	s1 (191), s2 (88), s3 (101)

The entire data set was randomly split into two separate data sets, labelled as split1 and split2, for use within the split sample analyses.

Pipe diameter was separated into two categories values representing small and large pipes. Small pipes (d<600) have diameters of less than 600 mm while large pipes (d≥600) have diameters of 600 mm or greater. The distinction at 600 mm ensured that a sufficient number of pipes were available to permit a reliable investigation into the effects of pipe size.

The two major pipe construction materials, concrete (conc) and vitreous clay (VC), were used. There were some other materials present within the data set; however, these contained insufficient numbers to justify analysis.

Two major soil types, alluvial (all) and podzolic (pod), were used. The alluvial soil consisted of Fullerton alluvial soil only. The podzolic soil is a collection of three separate soil types, those being Duckhole podzol, grey brown podzolic, and Thornton brown podzol soils. The combination into a single grouping is acceptable because these soils are similar – all have been formed through the weathering of similar parent rock.

The exposure classifications – A2, B2, and C – were derived from the AS3600 (Standards Australia, 1994) exposure classifications, and are summarised in Table 3. The AS3600 exposure classification system is intended for concrete members, and was considered appropriate for use here because over two thirds of the pipes are concrete.

Table 3: Modified AS3600 classifications

Classification	Description
A2	Pipes more than 1 km from the coastline
B2	Pipes within 1 km from the coastline
C	Pipes within 1 km from the coastline and within tidal zones

The serviceability ratings – serviceability conditions 1, 2, and 3 (s1, s2, and s3 respectively) – were obtained directly from SEWRAT surveys of the pipes. The serviceability condition provides a measure of the severity of the defects that affect the hydraulic performance of a pipe. Serviceability conditions 1 and 3 respectively represent the pipes that are the least and most affected by serviceability defects.

Markov Model

The Markov model describes a stochastic process where the probability of jumping into a state at time t+1 only depends upon the state previously occupied at time t. The transition probability matrix **P** describes the probability of changing states within each time interval. The **P** matrix used in this study is based on the four state model previously described in Table 1. Hence:

$$\mathbf{P}=\begin{bmatrix} 1-(P_{12}+P_{13}+P_{14}) & P_{12} & P_{13} & P_{14} \\ 0 & 1-(P_{23}+P_{24}) & P_{23} & P_{24} \\ 0 & 0 & 1-P_{34} & P_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

where P_{ij} is the transition probability from state i in year t to state j in year t+1. Note that $P_{ij} = 0$ for $i > j$. This imposes the constraint that pipes cannot improve in condition. Also, $P_{44} = 1$ because state 4 is the worst possible state. State 4 is known as an absorbing state, that is, once entered it cannot be left. It is further noted that P_{ij} are independent of pipe age – representing a homogeneous Markov model.

The probability of being in state j, in year t+1, can be determined through the application of the total probability theorem:

$$p_j^{t+1} = \sum_{i=1}^{j} P_{ij} \times p_i^t \quad (2)$$

where p_i^t is the probability of being in state i in year t.

The Markov model provides a conceptually sound model for the deterioration process. The Herz and Weibull models, as used in sewer deterioration models, were considered inappropriate models for stormwater deterioration. These models assume that a pipe can be in one of two possible states – either a functioning or a failed state (Høyland and Rausand, 1994, p. 214). However, when a pipe fails, we only know that it has left its current state – we do not know which state it has then entered. In some circumstances it may be reasonable to assume, upon failure, that the pipe progresses to the next worst state; although, this does not seem appropriate for stormwater pipes because the structural condition of a stormwater pipe does not necessarily deteriorate gradually. Gradual deterioration is more likely to occur for the serviceability condition, due to the progressive build up of sediment and debris, and through increased root intrusions. The structural condition is most likely to deteriorate through a damage event, such as an earthquake, an overladen truck, or through mine subsidence. Hence, the Herz and Weibull models are not appropriate – a pipe may deteriorate into the next worst state, or may skip one or more states in accordance with the severity of the damage event. These multi-state transitions are permissible within the Markov model.

Model Calibration and Validation

Micevski et al. (2002) describe in detail the calibration of the Markov model to the data set, and the procedures used to verify that the Markov model is consistent with the deterioration process. Briefly the calibration was undertaken using a Bayesian analysis. The objective was to infer the posterior distribution of the parameters which describes all that is known about the parameters given the data. The Metropolis-Hastings (M-H) algorithm was used to evaluate the posterior distribution.

The verification process took the form of hypothesis testing. Hypothesis testing allows one to establish whether the proposed probability model is consistent with a set of observations. Within this analysis, there were two separate hypotheses to be tested. The first hypothesis to be tested was that the observations are distributed according to the (hypothesised) Markov model. This assesses whether the Markov model is appropriate for stormwater pipe deterioration. This testing is performed using the entire data set and through split sample analyses. Note that the split sample analysis is a more rigorous test because it uses data independent of that used in the model calibration.

The second hypothesis to be tested is that pipes having different category values deteriorate according to the same Markov model. This test affords an understanding as to whether the pipe category value has an influence on the deterioration process. It is noted that these are split sample tests because the data, contained within each set of category values analysed, are independent of each other.

The hypothesis testing procedure used was the Chi squared (χ^2) test based on the Pearson X^2 statistic:

$$X^2 = \sum_{\mathrm{i}} \frac{(O_{\mathrm{i}} - E_{\mathrm{i}})^2}{E_{\mathrm{i}}} \qquad (3)$$

where O_{i} and E_{i} are respectively the observed and expected number of pipes in group i, where a group refers to the pipes with a particular condition rating at a particular observed age. Micevski et al. (2002) describe the rules for grouping the data to ensure that the X^2 statistic approximates the χ^2 distribution accurately.

Results

Verification of Markov Model Assumption

The verification that the data are distributed according to the Markov model was performed in two ways – using the entire data set and through the split sample analyses (split1/split2 and split2/split1). An explanation of the doublet notation (data 1/data 2) is required. Data 1 refers to the data set to which the parameters have been calibrated (using the M–H algorithm), whereas data 2 is used to test the model hypothesis (using the χ^2 test). That is, the transition probabilities are estimated using data 1, and then the model is compared with the observations contained within data 2.

The resultant transition probabilities and the χ^2 test results are detailed in Tables 4 and 5 respectively. The split sample tests suggest that the Markov model is consistent with the data (at the 5% significance level). Thus, the Markov model is an appropriate model for stormwater pipe deterioration.

Table 4: Expected posterior transition probabilities (model verification)

Transition	Analysis		
	Entire Data Set	Split1/Split2	Split2/Split1
1 to 2	0.0101	0.0087	0.0071
1 to 3	0.0016	0.0004	0.0039
1 to 4	0.0002	0.0007	0.0004
2 to 3	0.0021	0.0161	0.0005
2 to 4	0.0542	0.0219	0.0237
3 to 4	0.0009	0.0012	0.0048

Table 5: Statistical analysis results (model verification)

Analysis	X^2	df*	$\chi^2_{(0.05,df)}$
Entire Data Set	36.155	27	40.112
Split1/Split2	26.155	16	26.295
Split2/Split1	27.385	19	30.143
* df = Degrees of freedom			

It is important to appreciate that considerable parameter uncertainty exists. This uncertainty arises from limited sample data and can be displayed using posterior histograms of the transition probabilities produced by the M–H algorithm – Figure 2 presents histograms obtained for the entire data set analysis. Note that the vertical lines indicate the mean values of each parameter. The mean values of the transition probabilities pass near the peak values of the histograms, except for P_{13}. This is a result of the secondary peak near zero, which slightly skews the mean value towards this peak.

Category Analysis

The various pipe categories were analysed for category value differences, and the results of the χ^2 tests are summarised within Table 6. Four of the five pipe categories analysed (diameter, construction material, soil type, and exposure classification) rejected the null hypothesis. This indicates that the Markov models for the category values, contained within each of these pipe categories, are statistically different – implying that the deterioration process is different for each of these category values.

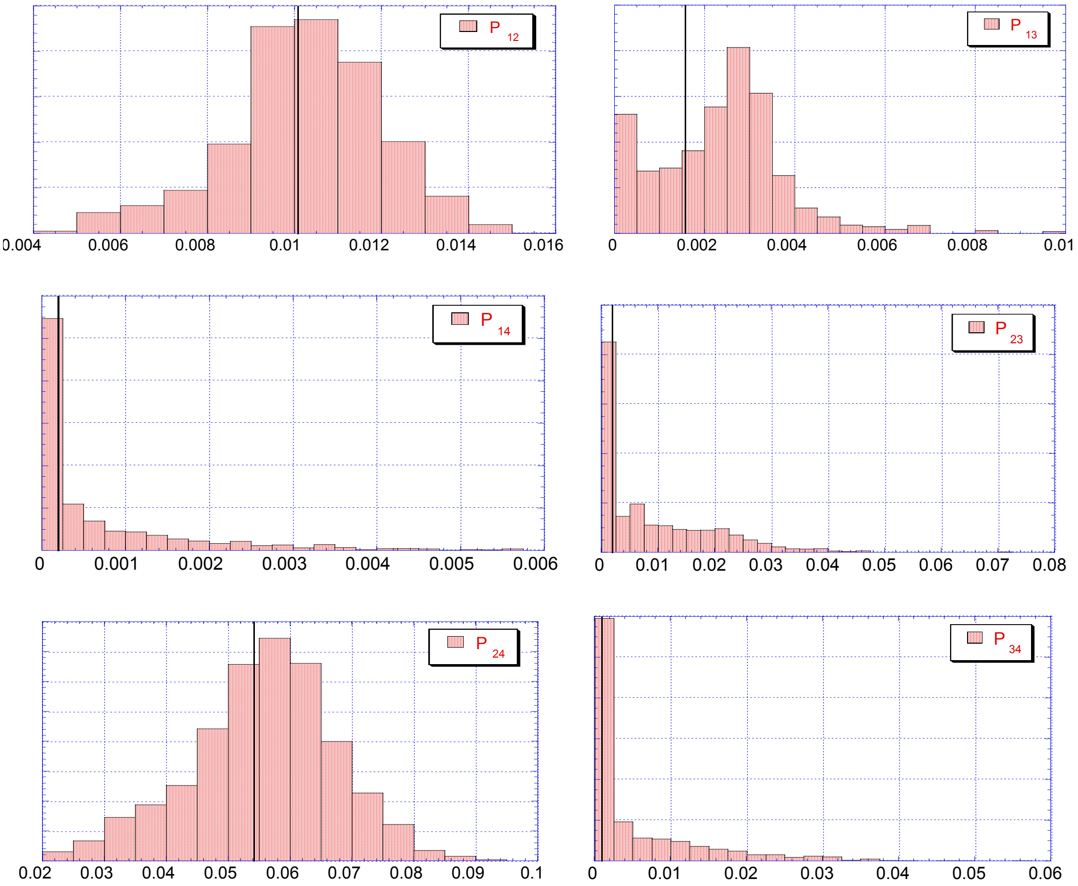


Figure 2: Histograms of transition probabilities (entire data set).

Table 6: Statistical analysis results (category analysis)

Analysis	X^2	df*	$\chi^2_{(0.05,df)}$
d<600/d≥600	32.557	8	15.507
d≥600/d<600	64.965	21	32.670
conc/VC	117.551	4	9.487
VC/conc	370.271	30	43.772
all/pod	30.480	18	28.868
pod/all	44.009	10	18.306
A2/B2	57.640	7	14.067
B2/A2	55.687	18	28.868
s1/s2	7.280	4	9.487
s1/s3	4.378	5	11.070

* df = Degrees of freedom

Pipe diameter was found to affect deterioration. The deterioration of smaller pipes was greater than that of larger pipes. A possible explanation for this is that pipe designers are underestimating the traffic loadings or the cover requirements for these smaller pipes, resulting in increased pipe damage for smaller pipes.

Pipe construction material affects deterioration. The results show that concrete pipes are stronger and more durable than vitreous clay pipes, as one would expect.

Soil type was found to affect deterioration. Pipes in alluvial soils deteriorate more rapidly than those in podzolic soils. This might be a result of the different formational environments of the soils. The podzolic soils are formed through the weathering of rocks, whilst the alluvial soils are deposited from a saline environment. Also, the alluvial soils are much more likely to be acid sulphate soils (Fityus, 2001, pers. comm.). These factors may increase the rate of deterioration due to the increased salt (chloride) content accelerating corrosion within the predominantly concrete pipes, and also through the sulphuric acids, formed by the acid sulphate soils, attacking the pipes.

The exposure classification influences deterioration. It should be noted that no statistical comparisons using the category value C were possible, due to insufficient data being available for use in the χ^2 test. Nonetheless, an effect was still obvious with B2 pipes deteriorating at a faster rate than A2 pipes. This effect might result from B2 pipes being located near the coastline (see Table 3). This could increase the rate of corrosion, and thus deterioration, of the predominantly concrete pipes due to the increased salt (chloride) content.

The serviceability condition did not affect deterioration. The serviceability condition is based on defects that affect the hydraulic, not structural, performance of a pipe. Thus, it is not unexpected that no influence on structural deterioration was detected. The reason for the model only being calibrated to the data in serviceability condition 1 is that this category value contained almost twice the amount of data compared to the other two category values (serviceability conditions 2 and 3). Also, these two category values had the vast majority of the data clustered into the age groups of 51 and 56 years.

This difference in the deterioration rates, for the various category values, is illustrated within Figure 3, which gives the expected proportion of pipes in condition 4 as a function of age. The graph shows that the deterioration rates for the category values vary significantly, confirming the results obtained in Table 6.

Comparison to Accounting Standards

The depreciation curves derived to meet AAS27 requirements assuming useful lives of 70 and 100 years for stormwater pipes are significantly different to the deterioration curve estimated by the Markov model. This is illustrated in Figure 4, which shows that the AAS27 depreciation curves quite significantly overestimate the deterioration of stormwater pipes. This highlights the need to derive infrastructure deterioration models from observed performance, rather than notional performance. Assuming that the average age of stormwater pipes in a Local Government area is 60 years and the replacement value of the pipes is $145 million the impact on the Council's fiscal position is shown in Table 7.

Table 7: Impact of different depreciation strategies on a Councils' fiscal position

Item	AAS27 (70 years)	AAS27 (100 years)	Markov
Average structural condition at 60 years	4.5	3.5	2.5
Written down value	$20.8 M	$87 M	$108.8 M
Annual depreciation cost	$2.07 M	$1.45 M	$0.6 M

As shown by the written down values in Table 7 the use of straight-line depreciation methods substantially under estimates the structural value of the stormwater pipe infrastructure. This dramatically increases the annual depreciation costs that the council will have to pay.

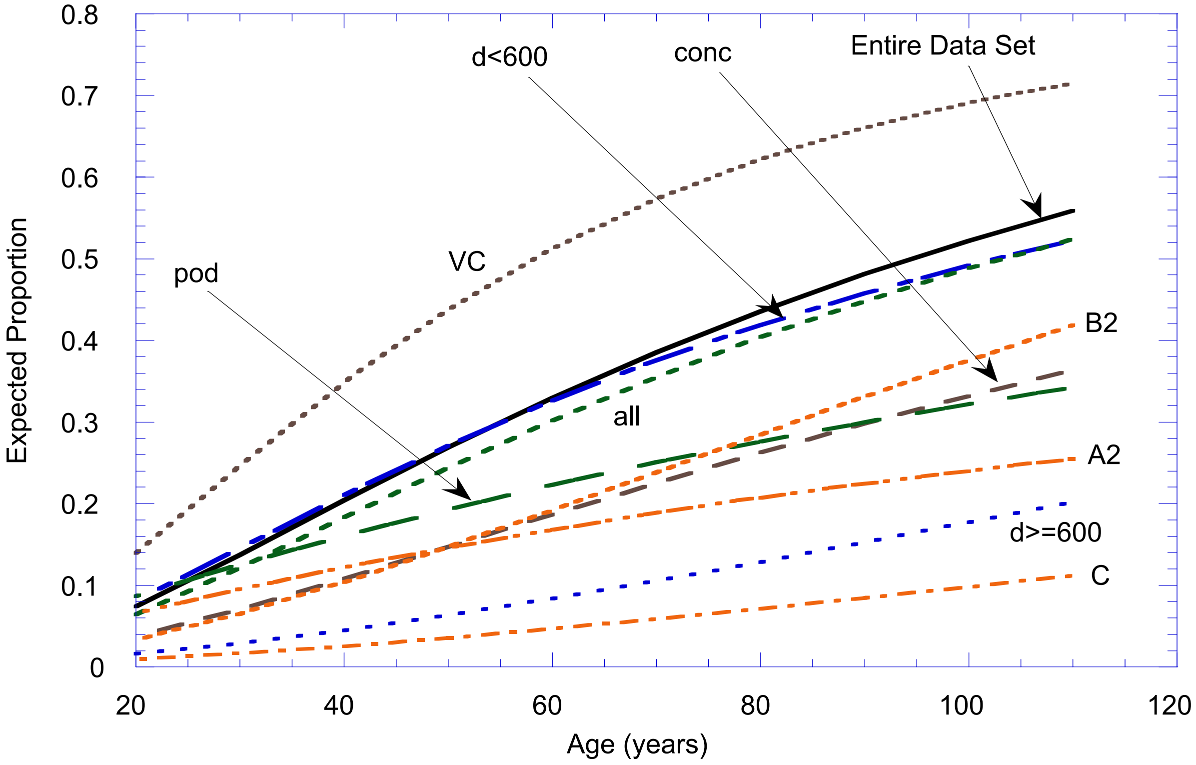


Figure 3: Comparison of Markov Model deterioration curves for structural condition 4.

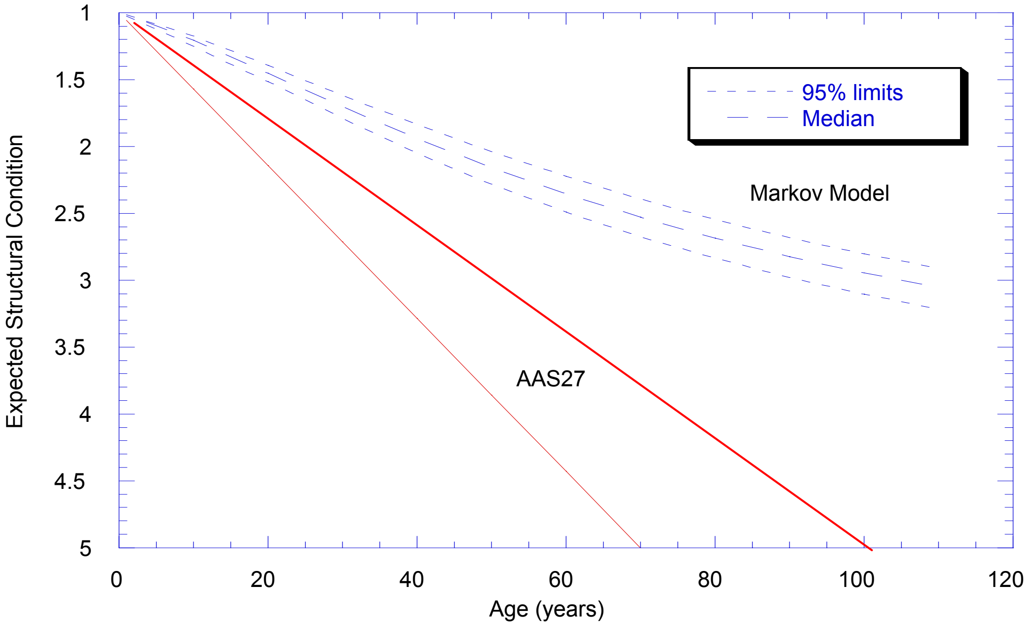


Figure 4: Comparison of AAS27 depreciation and Markov model curves.

Serviceability

Stormwater drainage systems are constructed to provide a service to the community. Stormwater pipes are provided to convey stormwater from streets and adjoining properties without nuisance. No structurally unserviceable pipes were found during the CCTV surveys although 35% of pipes in the NCC survey were found to be functioning in a badly damaged state (structural condition = 4). No relationship between the SEWRAT structural and serviceability ratings was found.

The serviceability condition is an indicator of the hydraulic performance provided by the pipe and [illegible] should be an important factor in stormwater pipe network management. As the hydraulic performance of a pipe decreases, the number of pipe surcharges becomes more frequent due to the associated blockages and intrusions within the pipe. When these surcharges become too frequent, the pipe needs to be refurbished or replaced. This suggests that a combination of both structural and serviceability conditions should be considered when determining a stormwater pipe network management strategy.

An examination of the serviceability rating process from the Australian Conduit Condition Evaluation Manual (Water Board, 1991) revealed that the weighting of the serviceability rating is dominated by non-structural events such as intrusion into pipes by tree roots (Figure 5) or blockage by silt and debris (Figure 6).

Figure 5: Intrusion into pipe by tree roots

Figure 6: Sedimentation of a stormwater pipe

Processes that partially block a stormwater pipe such as sedimentation, intrusion by tree roots and collection of debris will affect the hydraulic capacity of the pipe resulting in a reduced level of service. Inspection of the CCTV surveys revealed a number of common blockages in pipes including concrete debris, sedimentation, vertical displacement, tree roots and combinations of concrete debris, tree roots and sedimentation.

To assess the hydraulic capacity, and hence serviceability of stormwater pipes it is necessary to relate obstructions observed in the pipe to expected loss of serviceability. Obstructions to flows in a pipe will cause a head loss (h_L). Typically such a head loss is assumed to be proportional to the velocity head or the kinetic energy of the flow

$$h_L = K\frac{V^2}{2g} \tag{4}$$

where V is average velocity in the pipe (V), g is the gravitational constant and K is a dimensionless coefficient. Depending on how much the pipe is over-designed the increase in head loss associated with an obstruction may increase upstream water levels to cause surcharging from pits and a resultant loss of serviceability.

Values of K for different types of obstruction can be estimated experimentally. Laboratory experiments were conducted by Dao (2000) and Konetschnik (2001) using a 100 mm diameter pipe, retrofitted with various types of obstructions, for various discharges ranging between 0.008 m^3/s to 0.017 m^3/s. These experimental scenarios are shown in Figure 7 and described in Table 8.

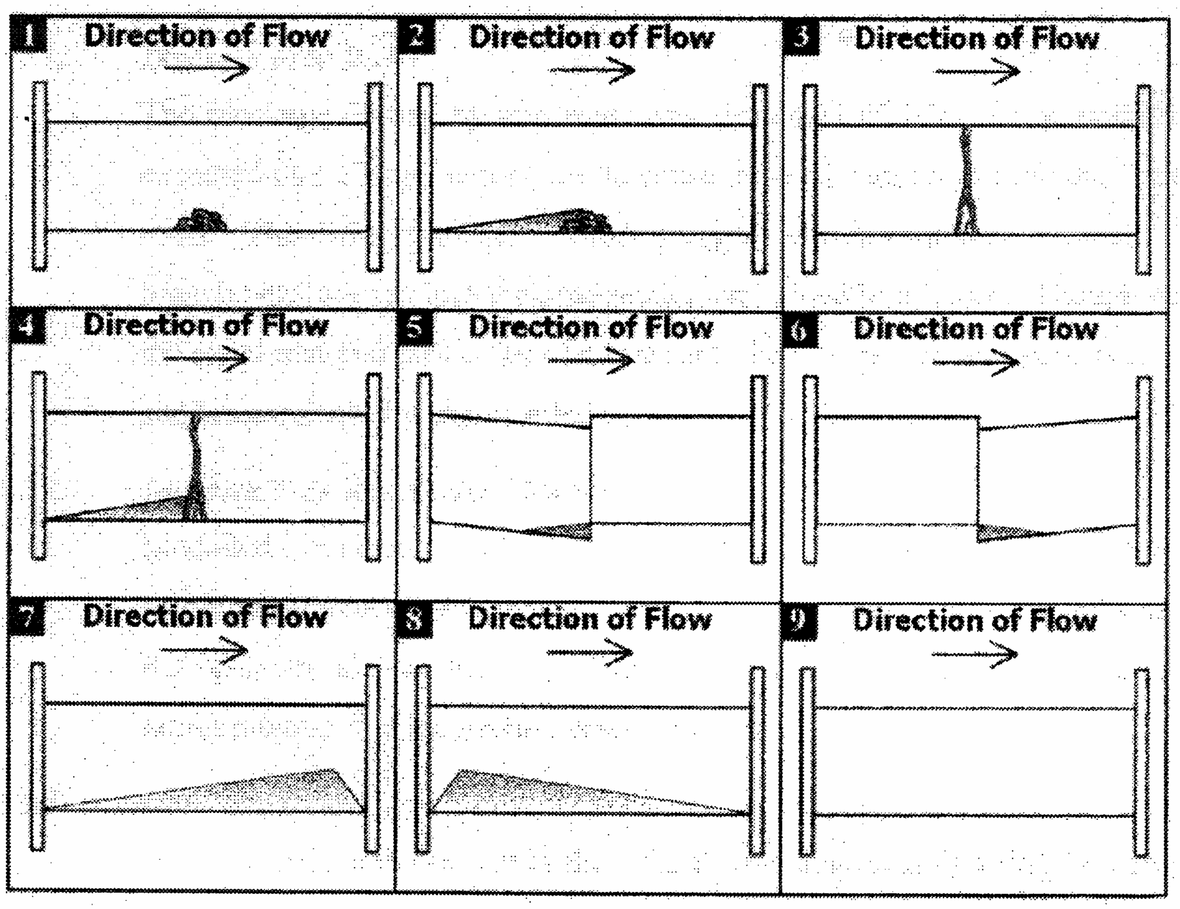
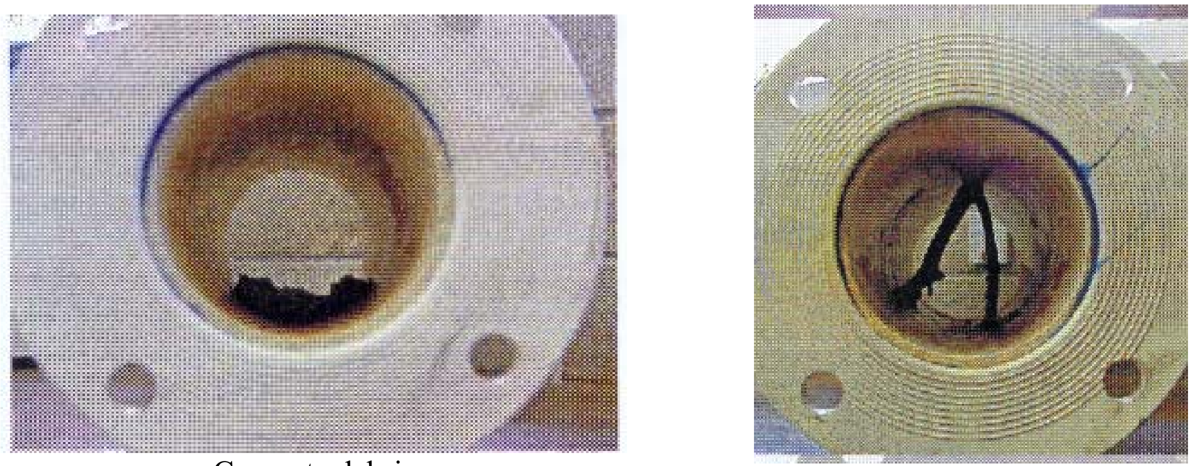


Figure 7: Longitudinal plans of the physical modelling scenarios.

The physical models of the pipes, including obstructions, are shown in Figure 8. Small pieces of concrete were glued to the bottom of the pipe to simulate a small-scale collapse in the pipe, a tree branch was glued in the pipe to simulate a blockage by a tree root, a pipe was split in two to simulate a vertical displacement and a build up of sediment in the pipe was simulated using resin.

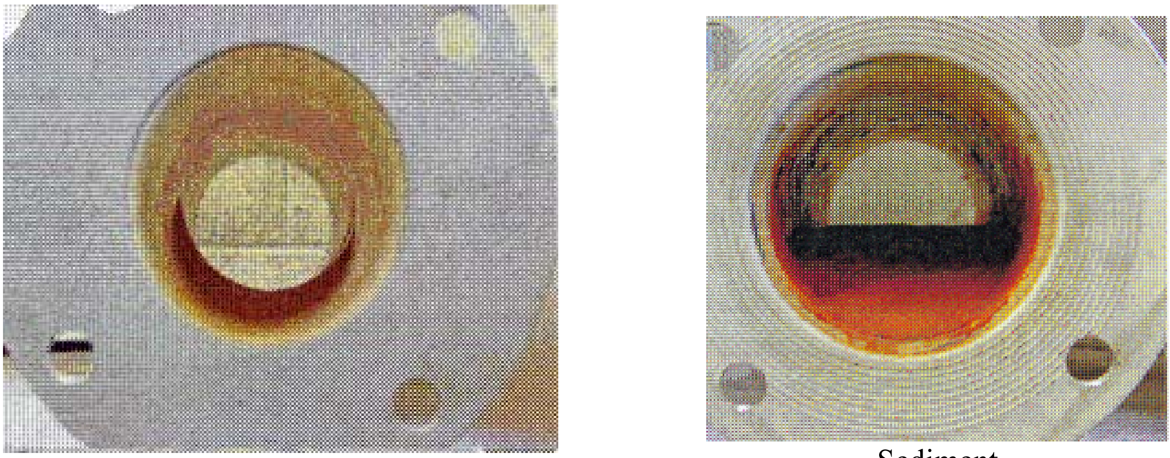
Table 8: Description of the pipe obstruction scenarios tested in the laboratory

Scenario	Obstruction
1	Concrete debris
2	Concrete debris + sediment
3	Tree root
4	Tree root + sediment
5	Vertical displacement
6	Vertical displacement reversed
7	Sediment
8	Sediment reversed
9	Control with no obstruction



Concrete debris

Tree root



Vertical displacement

Sediment

Figure 8: Cross-sections of pipes with obstructions used in the modelling

The experimental values for K are listed in Table 9. The results show that K is affected by both the area obstructed and the nature of the obstruction. For example, scenarios 4, 7 and 8 have similar obstructed areas but quite different K values. The tree root penetrates the whole cross section disturbing the whole flow field whereas the sediment presumably only disturbs the lower part of the flow field.

Table 9: Loss coefficients (K) for pipe obstruction scenarios.

Scenario	Obstruction	Reduction in pipe area (%)	Experiment K
1	Concrete debris	18.7	0.099
2	Concrete debris and sediment	24.4	0.085
3	Tree root	34.1	0.172
4	Tree root + sediment	48.8	0.408
5	Vertical displacement	17.2	0.08
6	Vertical displacement reversed	16.6	0.079
7	Sediment	43.4	0.094
8	Sediment reversed	43.4	0.094

The ability to estimate the value of K for different types of obstruction in pipes is important. The serviceability defects recorded during SEWRAT surveys in accordance with the Australian Conduit Condition Evaluation Manual identify the obstruction type, severity and location in pipes. If a reliable relationship between the serviceability rating from SEWRAT surveys and expected losses in pipes can be developed the opportunity exists to rationally assess the level of service provided by a pipe.

A complicating issue in assessing the level of service is network interaction. In flat networks obstructions can cause extensive upstream surcharging for the design storm. In contrast, in steep networks, surcharging may be very limited or even non-existent because pipes may be considerably overdesigned from a conveyance perspective. An exploratory analysis by Konetschnik (2001) of stormwater drainage systems in the Newcastle area using the WUFS rainfall/runoff model (Kuczera et al., 2000) demonstrated that obstructions in pipes operating close to their design capacity can increase the incidence of surcharges from nearby upstream drainage pits. Furthermore it was found that as the number of obstructions in pipes increased the adequacy of the network to cope with short duration high intensity storms decreased significantly.

The effect of obstructions is not spatially uniform. The asset manager needs to target those parts of the system where pipes are operating close to or at their design capacity during the design storm. understanding the hydraulics of the pipe network can produce considerable savings in asset monitoring because the problem locations can be apriori identified.

Conclusion

This study has presented a homogeneous Markov model for the structural deterioration of stormwater pipe infrastructure. The Markov model was shown, both conceptually and through statistical analyses, to be an appropriate model for stormwater pipe deterioration. Various pipe characteristics were found to influence the deterioration process. These were pipe diameter, construction material, soil type, and exposure classification, whilst the pipe serviceability condition was found to not affect the deterioration. The depreciation requirements of Australian accounting standards and the Department of Local Government were shown to significantly overestimate the actual deterioration of stormwater pipes.

Significantly, the level of service provided by a pipe is not necessarily related to the structural condition of the pipe. Stormwater drainage systems are constructed to provide a service to the community. Although structural condition ratings used in local government asset accounting provide a value for a stormwater asset there is no apparent relationship between the structural condition of the asset and the service it provides. Stormwater pipes have a value other than their structural value because they provide a service to the community. The question that needs to be asked is what is the value of the service?

We suggest that the level of service provided by the pipe depends on its position in the network and on factors diminishing its original hydraulic capacity such as intrusions by tree roots, sedimentation and collection of debris. The defects identified in serviceability ratings from SEWRAT surveys can be assigned loss coefficients. Use of such coefficients in a hydraulic model of the pipe network will enable an assessment of surcharge frequency and hence the serviceability of the pipe. It is suggested that a combination of both structural and serviceability conditions should be considered when determining a stormwater pipe network management strategy.

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