MEASURES AND SERVICEABILITY INDICATORS LINKED TO A DRAINAGE SYSTEM ASSET PERFORMANCE AND DETERIORATION MODEL

Adrian Saul University of Sheffield

June 2006
FRMRC Research Report UR1
Project Web: www.floodrisk.org.uk

FRMRC Partners

The FRMRC Partners are:

- University of Bristol
- Heriot Watt University
- HR Wallingford
- Imperial College, London
- University of Lancaster
- University of Manchester
- University of Nottingham
- University of Sheffield

Project Secretariat

ARP
Directorate of Planning and Academic Services
University of Manchester
Sackville Street,
Manchester
PO Box 88
M60 1QD

Tel: +44 (0)161 306 3626
Fax: +44 (0)161 306 3627

Web: www.floodrisk.org.uk

Summary

This report describes the research that has been completed to meet the UFMO related to improved serviceability indicators and performance models. The following deliverables are available to the industry:

- A model that predicts deterioration with time in terms of internal condition grade
- A model that predicts the number of blockages
- A model that predicts the number of collapses
- A model that links the blockage and collapse rate to flooding incidents.

These models present a first attempt to provide a methodology that will subsequently be refined as more data becomes available and new approaches to predictive modelling are developed.

Document Details

Document History

Version	Date	Lead Author	Institution	Joint authors	Comments
1.0	Feb 2006	Adrian Saul	University of Sheffield		Final draft
1_0	June 2006	J Bushell	HR Wallingford Ltd		Formatted for publication; filename changed from 'WP6_1 Measures and serviceability indicators.doc'

Acknowledgement

This research was performed as part of a multi-disciplinary programme undertaken by the Flood Risk Management Research Consortium. The Consortium is funded by the UK Engineering and Physical Sciences Research Council under grant GR/S76304/01, with co-funding from:

- Defra and the Environment Agency through their Joint R&D programme on Flood and Coastal Erosion Risk Management,
- UKWIR
- NERC
- The Scottish Executive
- Rivers Agency Northern Ireland

Table of Contents

Table of Tables

Table of Figures

1. Introduction

This report describes the research that has been completed to meet the UFMO related to improved serviceability indicators and performance models. The following deliverables are available to the industry:

- A model that predicts deterioration with time in terms of internal condition grade
- A model that predicts the number of blockages
- A model that predicts the number of collapses
- A model that links the blockage and collapse rate to flooding incidents.

These models present a first attempt to provide a methodology that will subsequently be refined as more data becomes available and new approaches to predictive modelling are developed.

Firstly, at the start of the project, there was a need to define the way in which the UK Water Industry would wish to see the development of such models and as to how they may be used in practice. The primary need was to link the performance of the system to a parameter (or parameters) that is (are) routinely monitored as part of the industry asset data base. In terms of the future, there is a need to link the performance of the system to the likely deterioration in the assets, and, following discussions with members of the WPA 6 Steering Committee, and other representatives from the industry, the primary parameter selected for the analysis was the internal condition grade (ICG) of the pipes, as classified in the Sewerage Rehabilitation Manual. The condition of the pipes is split into 5 categories, ranging from Class 1 (as new) to Class 5 (collapsed or near collapse). It is usual for companies to extract condition data from CCTV surveys of the pipes in the sewer system. A total of 7 data sets from catchments located in the North West of England and in Yorkshire have been analysed in this study.

2. Deterioration model

This deterioration model was developed using CCTV data from Blackburn, Bolton and Stockport. In these catchments many of the pipes in the system have been subjected to two CCTV surveys with a known time interval between the surveys. A total of 125 pipes with repeat surveys have been used in the study but of these some show a negative change in the peak ICG between the two surveys and hence an improvement in the condition of the pipe over the intervening period. ICGs are recorded for each defect on a pipe, the peak ICG represents the most serious defect for an individual pipe length. This probably highlights evidence of intervention or replacement, and, in many cases, this improvement is accompanied by evidence that records a change in the pipe material or diameter. As a consequence, all data that records a negative change in peak ICG have been discounted. This reduced the data set to 85 pipes, on which the deterioration model was based.

Work published by Coombes *et al* (2002), Micevski *et al* (2002) and Wirahadikusumah *et al* (2001) has shown that Markov probability matrices present a useful way to predict deterioration of assets. The functioning of the matrix can be best seen in Table 1, the peak ICG values of 1 to 5, are shown for ti in the left hand rows and the peak ICGs for t_{i+1} along the top of the columns, where t_i is timestep i. The values $p_{j,k}$ denote the probability of a sewer deteriorating from peak ICG j at timestep t_i to peak ICG k at t_{i+1}. It is assumed that the peak ICG of a sewer will only deteriorate (i.e. increase) with time, thus the probabilities for a decrease in peak ICG are zero, at condition 5, the value of $p_{5,5}$ will be 1 as the pipe cannot deteriorate to a lower grade. It is sometimes assumed that the peak ICG can only remain the same, or deteriorate to the next grade (e.g. if peak ICG = 1 at t_i, then only $p_{1,1}$ and $p_{1,2}$ can have values, $p_{1,3}$, $p_{1,4}$ and $p_{1,5}$ are zero). However, the relatively random nature of sewer deterioration, and the desire to create a model which is sufficiently versatile to consider long time steps, mean that multiple grade changes in a single time step should be allowed, although the probabilities will be low for extreme deterioration (e.g. $p_{1,5}$)

Table 1 Probability matrix for change in ICG

		ICG at t_{i+1}				
		1	**2**	**3**	**4**	5
ICG at t_i	**1**	$p_{1,1}$	$p_{1,2}$	$p_{1,3}$	$p_{1,4}$	$\mathbf{p_{1,5}}$
	2	0	$p_{2,2}$	$p_{2,3}$	$p_{2,4}$	$\mathbf{p_{2,5}}$
	3	0	0	$p_{3,3}$	$p_{3,4}$	$\mathbf{p_{3,5}}$
	4	0	0	0	$p_{4,4}$	$\mathbf{p_{4,5}}$
	5	**0**	**0**	**0**	**0**	$\mathbf{p_{5,5}}$

The change in peak ICG and time between surveys has been calculated for each pipe and this information has been used to assess the change in peak ICG over a five year (AMP) timestep, assuming the change to be linear. The frequency of each peak ICG transition has then been calculated, allowing the transition probabilities to be derived to populate the matrix shown in Table 2. Initially only one transition matrix has been produced for the entire dataset, however given more data, multiple matrices would be produced to allow parameters such as material to be included to produce more accurate predictions.

Table 2 Probability of change in peak condition grade over time period 5 years

		Peak ICG at t_{i+1}				
		1	**2**	**3**	**4**	5
Peak ICG at t_i	**1**	0.77	0.23	0	0	**0**
	2	0	0.83	0.17	0	**0**
	3	0	0	0.9	0.1	**0**
	4	0	0	0	0.95	**0.05**
	5	**0**	**0**	**0**	**0**	**1**

The transition matrix in Table 2 could be used in two ways – either to change the peak ICG of each sewer pipe in the asset database, or to assess the change in the number of sewers at each peak ICG. To change the peak ICG of each pipe, a random number generator could be used for each pipe, if for example the pipe initially has a peak ICG of 1, then a number between 0 and 0.77 would result in no change, but a number greater than 0.77 would mean the peak ICG would increase to 2 for the second timestep. To assess the number of sewers at each peak ICG, the number in the initial state should be calculated, this number would then be multiplied by the probability values to give the number which stay in the initial state and the number which deteriorate.

3. Blockage and Collapse

A more extensive dataset has been used to develop the blockage and collapse models. The models have been based on data from Blackburn, Bolton, Bury and Stockport. Ultimately, this resulted in the analysis of 1006 blockage events and 61 collapses from a dataset of 16150 assets which were surveyed. The dataset was classified according to pipe characteristics such as diameter, length, gradient, cover depth and ICG (note, in general, material was observed not to have a significant influence), for each of these classes, the total length of sewer and the number of blockages/collapses was calculated. This allowed the incident rate to be calculated, expressed as the number of incidents per km per year.

4. Blockage model

There are many parameters that may cause a pipe to block. These include, for example, deformities in the pipeline construction, root intrusion, the accumulation of sediments and fats etc. It is necessary therefore to relate the occurrence of a blockage to the properties and characteristics of the pipes in the system where the blockage has been observed to occur. A study of the important parameters concluded that, in addition to the peak ICG, the relative velocity, given by Diameter$^{2/3}$ × Gradient$^{1/2}$; and length were variables that provide the best correlation with the blockage rate. A plot of the data used to create the spreadsheet model is presented in Figure 1. It can be seen that peak ICG values of 2 – 3, and 4 – 5 have been grouped together as regressional analysis showed that these peak ICGs have similar relationships with the blockage rate.

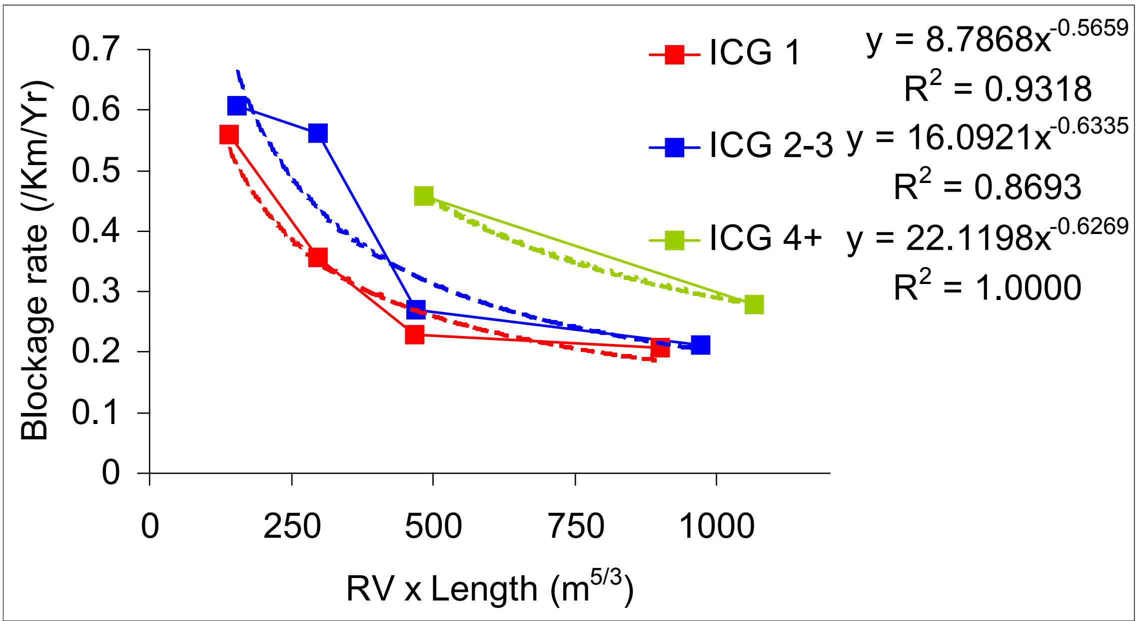

Figure 1 Relationship between blockage incident rate and relative velocity

This model has been devised so that, given the total length of pipe and the length weighted mean 'RV × L' for each sub-group, the model then outputs the expected number of blockages in each sub-group over the duration of the selected time step. Trials with the spreadsheet model are currently being completed using other datasets, but in the interim it is recommended that the relationships shown in Figure 1 may be used. These results may be used together with the probability matrix in Table 2 to assess the potential for increased blockages in the future due to changes in condition grade.

5. Collapse model

Sewer collapse is a much rarer occurrence than blockage, but the effects of a collapse can be significant and costly. There are many factors which may combine to result in a sewer collapse, and much of this data, such as soil type, ground water levels, and even pipe age are usually unknown or not available in asset databases. The collapse model presented has therefore been derived from a very limited number of variables commonly available within asset databases. Investigations of the parameters thought to influence collapse has lead to development of a model based on peak ICG and depth of cover, as shown in Figure 2. As for the blockage model, regressional analysis showed that peak ICGs could be grouped together, for collapse peak ICGs of 1 to 4 were observed to exhibit similar relationships between collapse rates and cover depth. This model is somewhat limited in scope due to the small dataset used, but does present some useful trends. One obvious flaw in the model is that very small cover depths would appear to lead to a very low risk of collapse, but this limitation is a function of lack of data for shallow sewers.

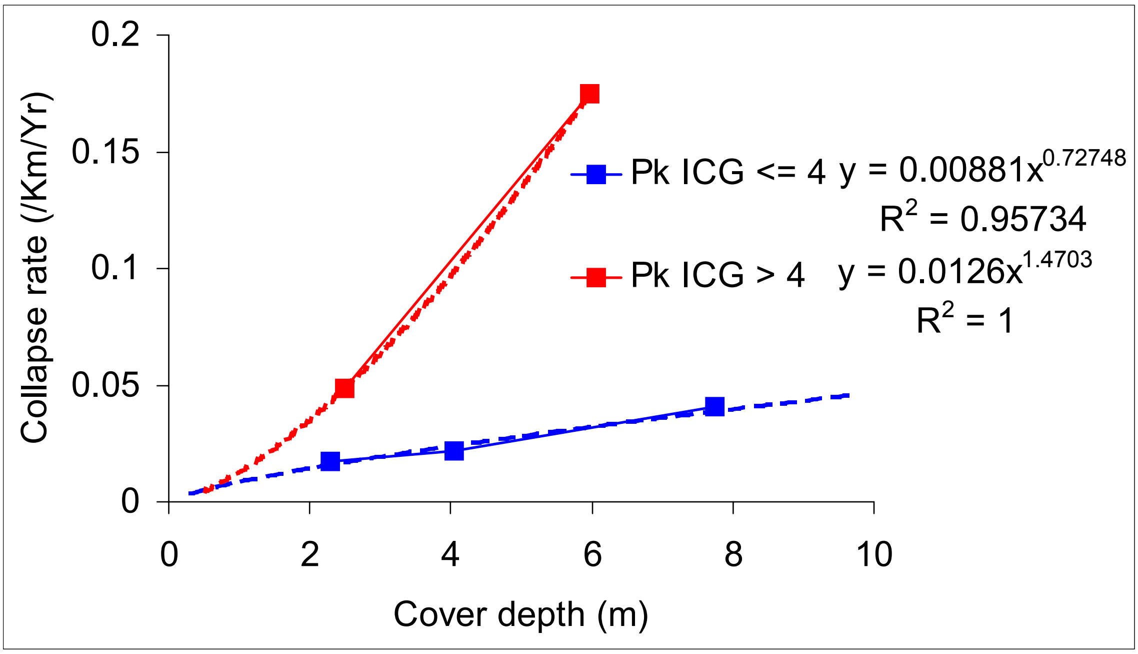

Figure 2 Relationship between collapse incident rate and cover depth

The model shown in Figure 2 would be used in basically the same manner as the blockage model in order to predict how the number of collapses on a system would increase with time, assuming no remediation takes place.

6. Summary of blockage and collapse models

It is clear that the models have been developed from a limited quantity and quality of data, and from a small number of catchments. However, they do show that it is feasible to link rates of blockage and collapse to characteristics of the sewerage network, and to predict deterioration. Given further data, it should be possible to improve these models and determine what level of calibration is required for different catchments. Further work is ongoing to assess the influence of age, as historic maps have recently become available to the researchers. These maps show the extent of urbanisation at several points in time, and hence a reasonable estimate of the sewer pipes can be made.

7. Flooding model

The database containing records of blockage and collapse incidents, used to develop the above models also included information on the number of associated flooding incidents. This information has been used to calculate the probability of flooding associated with both blockage and collapse. Figures 3 and 4 show this frequency of flood events for approximately 15,000 blockage events and 780 collapse incidents respectively. Details of the extent of sewer system surcharge and of odour incidents are also shown in Figures 3 and 4.

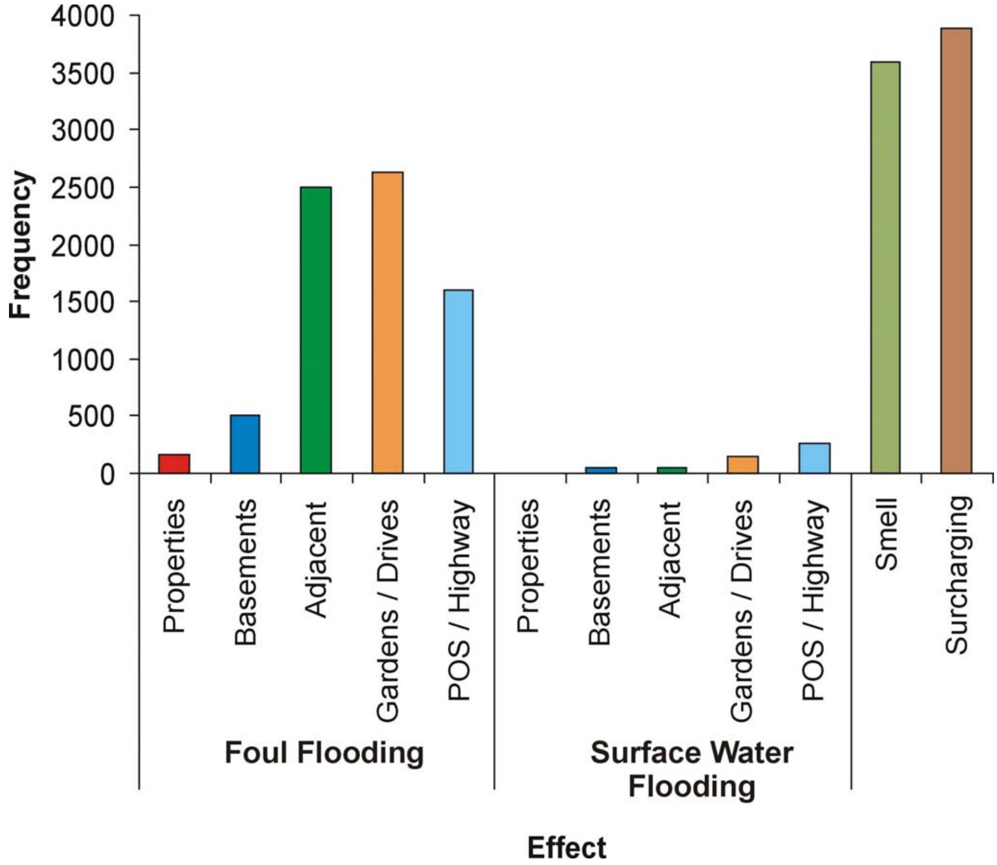

Figure 3 Blockage effects from 14968 blockage records

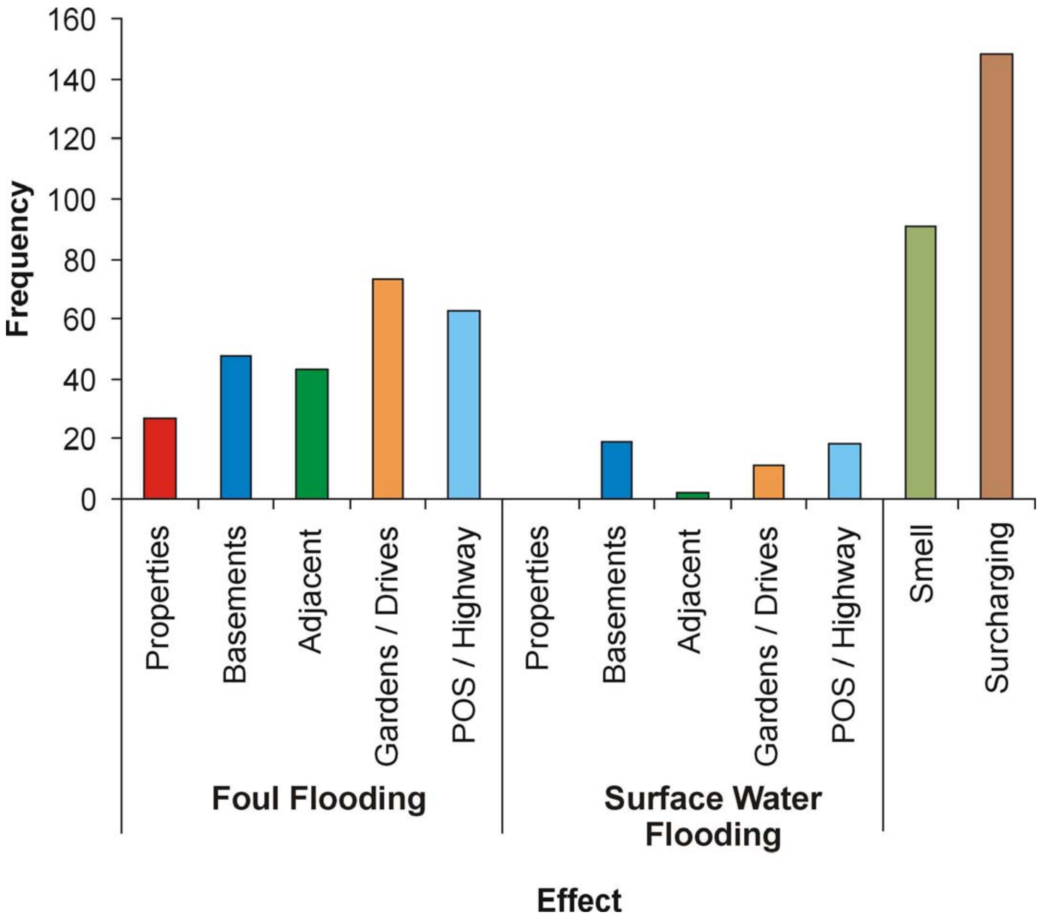

Figure 4 Collapse effects from ~ 780 collapse incidents

From the number of each type of flood event, basic probabilities have been calculated as shown in Tables 3 and 4. Within the database, it is possible to record upto 4 'effects', where an effect is flooding, surcharge, etc. related to the blockage. Any foul flooding refers to the number of blockage / collapse incidents in which one or more of the effects is a type of foul flood. The surface water flooding and any flooding types are calculated in a similar manner.

Table 3 Probability of flooding related to blockage events

Type of incident	No of incidents	Probability
Foul Flooding of Properties	157	**0.010**
Foul Flooding of Basements	498	**0.033**
Foul Flooding Adjacent To Property	2501	**0.167**
Foul Flooding of Gardens/Drives	2629	**0.176**
Foul Fl. of Public Open Spaces/H'way	1608	**0.107**
Any Foul Flooding	7175	**0.479**
Surface Water Flooding Properties	4	**0.000**
Surface Water Flooding Basements	51	**0.003**
Surface Water Flooding Adj. Props	41	**0.003**
Surface Water Flooding Gardens/Drives	153	**0.010**
Surface Water Flooding P.O.S./H'way	268	**0.018**

Type of incident	No of incidents	Probability
Any Surface Water Flooding	497	**0.033**
Any Flooding	**7660**	**0.512**

Table 4 Probability of flooding related to collapse events

Type of incident	No of incidents	Probability
Foul Flooding of Properties	27	**0.035**
Foul Flooding of Basements	46	**0.059**
Foul Flooding Adjacent To Property	43	**0.055**
Foul Flooding of Gardens/Drives	73	**0.094**
Foul Fl. of Public Open Spaces/H'way	63	**0.081**
Any Foul Flooding	237	**0.304**
Surface Water Flooding Properties	0	**0.000**
Surface Water Flooding Basements	19	**0.024**
Surface Water Flooding Adj. Props	2	**0.003**
Surface Water Flooding Gardens/Drives	11	**0.014**
Surface Water Flooding P.O.S./H'way	18	**0.023**
Any Surface Water Flooding	47	**0.060**
Any Flooding	**284**	**0.364**

Further analysis of the flooding data shows that the peak ICG not only affects the probability of a blockage or collapse will occur, but also the probability of that blockage or collapse resulting in a flood event, as presented in Tables 5 and 6. This increase in probability is most significant for collapses.

Table 5 Variation in blockage related flooding probability with peak ICG

Peak ICG	Flooding type		
	Foul	**Surface Water**	Any
<= 1	0.395	0.034	**0.427**
2-3	0.422	0.027	**0.448**
4+	**0.429**	**0.030**	**0.459**

Table 6 Variation in collapse related flooding probability with peak ICG

Peak ICG	Flooding type		
	Foul	**Surface Water**	Any
<= 4	0.255	0.055	**0.309**
> 4	**0.526**	**0.105**	**0.632**

8. References

1. Coombes, P.J., Micevski, T. and Kuczera, G., 2002. Deterioration, depreciation and serviceability of stormwater pipes. Stormwater Industry Association 2002 Conference on Urban Stormwater Management, Orange NSW, 23-24 April 2002.

2. Micevski, T., Kuczera, G. and Coombes, P., 2002. Markov Model for Storm Water Pipe Deterioration. *Journal of Infrastructure Systems*, 8 (2), 49–56.

3. Wirahadikusumah, R., Abraham, D. and Iseley, T., 2001. Challenging Issues In Modeling Deterioration Of Combined Sewers. *Journal of Infrastructure Systems*, 7 (2), 77–84.