# Sewer Performance Reporting: Factors That Influence Blockages

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**Abstract:** Managing sewer blockages represents a significant operational challenge for water utilities. In Australia, company-level blockage rates are used to compare the effectiveness of the management strategies of different utilities. Anecdotal evidence suggests that this basis may not be a fair one for comparison because blockages are influenced by a range of factors beyond management control and vary from company to company. This issue was investigated as part of a broader research effort on sewer-blockage management undertaken in conjunction with the Water Services Association of Australia (WSAA) and its members. A Web-based survey was used to collate expert opinion on factors that influence blockage rate. The identified factors were then investigated in an exploratory analysis of blockage-related data provided by two participating utilities, supported by literature reviews. The results indicate that blockage rate is influenced by a range of factors, including asset attributes, climatic conditions, water consumption, and soil type. Because these factors vary from utility to utility, this research supports the finding that company-level blockage rate in itself is not an appropriate metric for comparing management effectiveness.
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## Introduction

Sewer systems are intended to transfer sewage from one location to another without loss. They fail to fulfill this function when blockages occur. Blockages (also called *chokes* in Australia) can result in the release of sewage to the natural and built environments. In turn, this can result in significant adverse impacts, including contamination of waterways, social and commercial disruptions, and public health incidents. Thus, managing sewer blockages is of significant concern to a water utility; yet, blockages still affect almost 70,000 properties across Australia every year [Water Services Association of Australia (WSAA) and National Water Commission (NWC) 2008] and approximately 1 in 1,000 households in the United Kingdom (Arthur et al. 2008) or approximately 250,000 households per year (inferred from Office for National Statistics 2009). Similarly, up to 75,000 properties across the United States are affected by sewer overflows [U.S. Environmental Protection Agency (U.S. EPA) 2007]. The cost of clearing these blockages and responding to spills is significant, as is the cost of measures undertaken to prevent blockages from occurring (U.S. EPA 2004; WSAA and NWC 2008).

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To help improve the management of blockages, a collaborative project was developed in conjunction with WSAA and its member water utilities. As part of this research, it was investigated whether company-level blockage rates (i.e., number of blockages per 100 km of sewer per year, reported at the company level) provide a useful metric for comparing the effectiveness of management strategies adopted by utilities. This paper presents results from this investigation.

A brief overview of the problem domain is first given, focusing on the different causes of blockages and the approach in reporting management effectiveness in Australia. Factors that influence the occurrence of sewer blockages are then explored. In particular, factors identified through a Web-based survey as being beyond immediate management control are explored statistically by using data provided by two water utilities. The analysis is further supported by information drawn from the literature. Finally, a synthesis of the results is provided and conclusions are presented.

## Problem Domain: Management of Sewer Blockages

Under normal operating conditions and with appropriately sized pipes, the hydraulic capacity of a sewer is able to contain the flow of sewage. Abnormal flows (e.g., caused by storm events) can, however, result in spills to the natural and built environments. Spills can also occur under normal flow conditions if the hydraulic capacity is reduced by restrictions in the pipe; such restrictions are usually termed *blockages* or *chokes*. A range of factors can cause blockages, including sediment buildup, physical objects within the sewer, sewer defects, and accumulation of fats, oils and grease (FOG), and tree roots, as discussed in the following. It is noteworthy that causes of blockages can compound one another. For example, the Water Environment Research Foundation found that a single, highly concentrated FOG discharge was sufficient to accumulate on tree roots and cause a sewer blockage (Ducoste et al. 2008).



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## *Solid Deposition and FOG Accumulation*

Accumulation of solids within a sewer leads to an effective reduction in capacity. Such accumulation can occur through a number of mechanisms. For example, inadequate flow regimes can lead to the accumulation of sediment and other solids (Rushforth et al. 2003). Foreign objects (i.e., those that ideally should not be disposed of via a sewer) such as disposable nappies (i.e., diapers), sanitary products, and rags can also act as a dam within the sewer. Structural defects also act as points of accumulation (Roberts et al. 2006; Davies et al. 2001).

The discharge of wastes containing FOG is another cause of blockages [Water Research Centre (WRc) 2009]. FOG coagulates to form a semisolid mass that deposits on pipe walls and any root masses within the sewer. Interestingly, the *Wall Street Journal* reported that 75% of sewer systems in the United States operate at only 50% capacity because of the accumulation of FOG (Russell 2002).

## *Tree Root–Related Blockages*

Industry performance data (discussed further in the following) indicate that tree roots are the cause of many blockages in Australia. For example, Fig. 1 was generated from the data in the *National Performance Report 2006–2007* (WSAA and NWC 2008); 17 of 53 utilities reported sewer blockages by tree root intrusion from 2002 to 2007, except for two companies that only reported tree root–related blockages for the previous 2 and 3 years. The error bars in Fig. 1 indicate the variation in tree-related blockages within this reporting period. As shown, of the 17 utilities that provided information for the years 2001–2007, six reported that on average $> 75\%$ of all blockages were related to tree roots, and only one utility reported that on average $< 50\%$ of blockages were related to trees.

The U.S. Environmental Protection Agency (U.S. EPA) also states that root-related blockages are a priority defect experienced in sewers within the United States (e.g., Randrup et al. 2001; U.S. EPA 2009). Given their importance in Australia and the United States, it is interesting to consider tree root–related blockages in more detail.

### Tree Roots in Urban Environment

Tree roots have three basic functions—anchor the plant and hold it upright, store food, and absorb and conduct water and nutrients. Approximately 90% of tree roots grow laterally in the top 1 m of soil and have an even spread under unrestrictive soils of approximately two to three times the diameter of the tree crown (Jim 2003). However, Roberts et al. (2006) indicated that the extent of the tree-root system is dependent on the species, the age of the tree, nutrient availability, and the physical limitations of the surrounding soil (including depth, density, pore size, oxygen, and moisture content).

Changes within the soil environment also influence root-system development. For example, adequate moisture availability leads to horizontal root growth, whereas reduced soil moisture can result in a vertical one (Moore 2001; Streckenbach 2007). This latter response occurs in urban areas because a large proportion of the soil surface is impervious. Storm-water pipes and/or sewers also direct surface water away from trees, and leaf litter and other organic debris are typically removed. Nutrients and moisture are thus reduced, creating conditions for more vertical root growth. These conditions are further exacerbated in Australia, as many regions have been subjected to prolonged drought (Nowak 2007), depriving trees of water for extended periods. Hence, Errey (2008) described trees within the urban landscape as progressively becoming more "aggressive" in finding sources of water.

### Tree Roots and Sewers

In contrast to these conditions, sewers provide an excellent source of both moisture and nutrients, and given access, roots will thus proliferate inside the pipe (Dahan and Lawson 1984). It is, however, a common misconception that tree roots "attack" or seek out sewers. In reality, roots grow in response to a range of external conditions generated around a sewer. These include water and oxygen gradients, the disturbed nature of soil in the pipe trench (e.g., increased soil porosity, which offers a path of least resistance for root growth), condensation, and warm temperatures surrounding sewer pipes (Roberts et al. 2006; Streckenbach 2007; Bosseler et al. 2007; Bennerscheidt 2007).

Stål (2007) and Ridgers (2007) investigated factors that influence the intrusion of tree roots into sewers, the primary ones being inadequate leak tightness of joints, poor installation, and pipe

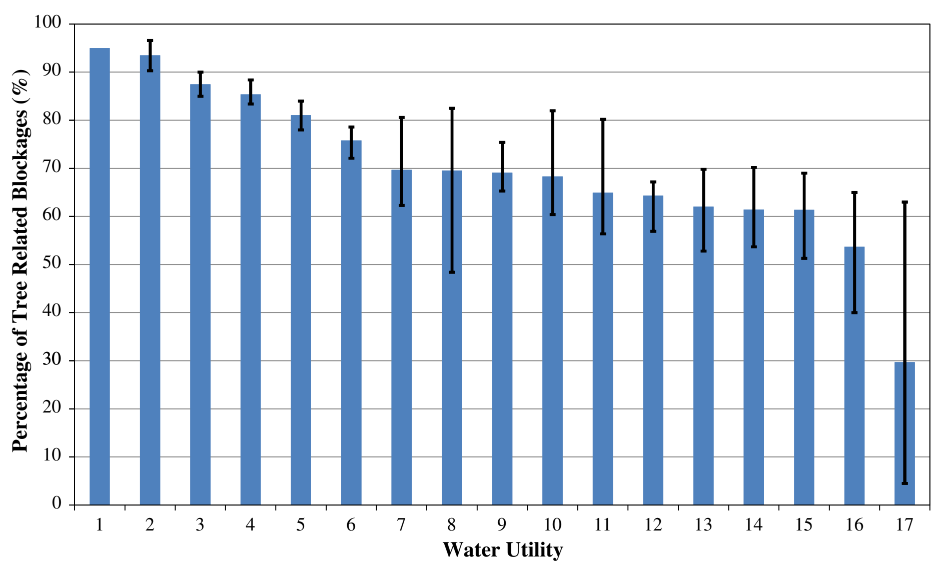


**Fig. 1.** Average percentage of tree-related sewer main breaks and chokes ($n = 17$)



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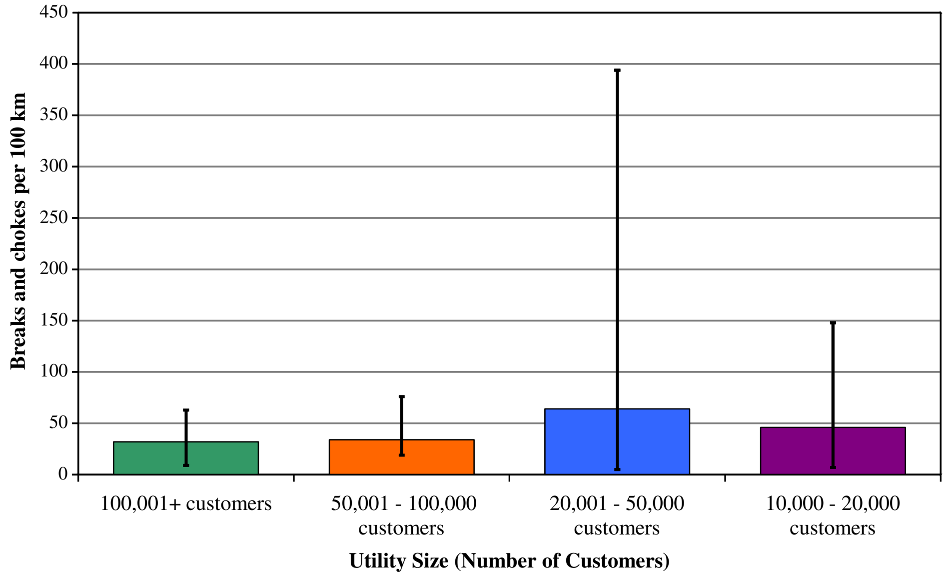


**Fig. 2.** Australian water utilities sewer main break and choke rates ($n = 53$)

damage. There is some evidence that modern sewers can resist root intrusion. For example, Sadler et al. (2001) investigated the Australian standards for PVC sewer main joints and concluded that the specified minimal interfacial pressure was more than adequate to prevent intrusion. Nevertheless, tree roots still penetrate undamaged seals, potentially because of the physical characteristics of the soil material, geometry of pipe seals, and the pipe surface (Stål and Östberg 2007). Roots girdling the sewer on the outside are also responsible for pipe damage (Peper and Barker 1994), which can provide access for roots.

Once intrusion has occurred, roots typically form veil and tail structures. Veil structures occur in sewers with steady flows, whereas tail structures occur in sewers with very low or intermittent flows. Veil roots hang from upper surfaces like curtains raking the flow and accumulating solids, debris, and FOG. In contrast, tail roots grow along the pipe. In either case, root masses and accumulated materials can eventually cause flows to stop (Australasian Society for Trenchless Technology 2005).

### *Measuring Effectiveness of Blockage Management Strategies*

In Australia, WSAA compiles and releases an annual *National Performance Report* (NPR), which details the performance of each reporting water utility, as characterized by a series of service indicators (WSAA and NWC 2008). Of these, the best indicator of sewer blockages is a measure of sewer failures, expressed as the rate of sewer main breaks and chokes. Fig. 2 shows the data in the *National Performance Report 2006–2007* (WSAA and NWC 2008). Of 80 utilities, 53 reported sewer blockages. The total average is 44 blockages and chokes per 100 km of sewer mains; the error bars show the range of reported blockage rates within the utility size category. During interviews and workshops, research partners noted that most sewer failures are blockages (there is commonly an order-of-magnitude difference between chokes and breaks).

Discussions with industry representatives indicated that regulators and the boards of water utilities use the service levels reported in the NPR to make intercompany comparisons of management effectiveness. In contrast, asset managers involved in the research believe that such comparisons are not meaningful for blockages because the blockage rate is highly dependent on factors that are outside their control. An investigation was thus undertaken to determine which uncontrolled factors influence blockage rates and to assess how differences in these factors potentially affect the effectiveness of the utilities' management strategies.

## Factors Influencing Blockage Rate

A Web-based survey was used to identify factors that a utility has little control over or that are considered legacy issues. In this context, *legacy* implies a factor associated with a historical decision that affects blockage rate but can be changed with future investment (e.g., pipe type). The survey response rate was reasonably representative of the sector, with 78% of the WSAA's full utility members (21 of 27 in 2007–2008) plus an additional six associate members completing the survey.

Table 1 shows the factors mentioned by more than 50% of the respondents. A range of other factors were mentioned by a smaller proportion of the respondents ($< 30\%$). These included lack of funding, backlog in asset replacement, illegal discharges and dumping, poor quality of sewer installations, and issues related to building practices. These issues were not analyzed in more detail generally because they reflected company-specific issues or there were no available data.

Factors noted by most respondents ranged from those relating to assets and their local environment (sewer attributes, tree coverage, and planting policy) to broader considerations reflecting the utility's operating environment (drought and climate). These issues

**Table 1.** Factors Considered beyond Management Control

| Factor | Respondents | |
|---|---|---|
| | Number | Percentage |
| Drought | 20 | 74 |
| Sewer attributes | 19 | 70 |
| Tree coverage | 18 | 67 |
| Climate | 17 | 63 |
| Tree planting policy | 15 | 56 |

Note: The number of utilities that responded to the Web-based survey was 27.



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**Table 2.** Report of Blockage Numbers by Type

| Blockage type | Company A | | Company B[a] | |
|---|---|---|---|---|
| | Total blockages | Percentage | Total blockages | Percentage |
| Damaged pipe | 227 | 3.1 | 38 | 0.6 |
| Foreign object | no data | no data | 265 | 3.9 |
| FOG | 1552 | 20.8 | 517 | 7.5 |
| Sediment | no data | no data | 248 | 3.6 |
| Tree roots[b] | 5001 | 67.2 | 4981 | 72.4 |
| Unknown/other | 664 | 8.9 | 830 | 12.1 |

[a]Represents Company B blockage data from June 2004 to 2008. Between 1999 and June 2004, no cause was logged for the 7,922 blockages experienced.
[b]Includes FOG-related tree-root blockages (Company A, $n = 351$).



were investigated in more detail, as described in the following, building from asset level to broader considerations.

### *Sewer Blockage Data*

Two water companies (in different Australian states) supplied data sets of sewer attributes (for sewers of 300-mm diameter or less only), blockages, and other relevant factors. Company A supplied asset data relating to 6,944 km of sewers, with blockage data from 1996 to 2004. Company B supplied asset data relating to 6,086 km of sewers, with blockage data from 1999 to 2008. Company A also provided an additional data set of monthly blockage rates and water consumption for the period 2002–2008, which was used in an exploratory analysis between drought and blockage events. Table 2 presents the blockage types reported by Companies A and B. Company B did not record the blockage cause before June 2004.

### *Pipe Attributes*

The previously described Web-based survey was also used to identify cohorts of assets that are considered to be problematic from the perspective of sewer blockages. In this context, a *cohort* is a group of pipes delineated through shared attributes, e.g., the same age, diameter, and material. As shown in Fig. 3, respondents defined problem cohorts by pipe material (with 17 respondents indicating vitreous clay as a problem material and seven noting concrete) and diameter (those with 150–225 mm were commonly mentioned as problematic). Some pipe attributes mentioned confound one another; for example, joint type is often associated with a given pipe material, and the frequency of joints is higher for smaller-diameter vitrified clay pipes because of the short pipe length used (commonly 3 m). In the latter case, root intrusion occurs at the joints rather than at the pipe body, but vitreous clay (VC) is still commonly mentioned as a problem material.

#### Pipe Type

Previous studies have indicated that VC and older concrete pipes without rubber gaskets are prone to blockages (e.g., Rolf and Stål 1994; Pohls et al. 2004). Other studies have shown that the frequency of blockages increases in proportion to the number of joints in the sewer (Davidson and Orman 1999). Similarly, older (more rigid) joints are believed to be associated with a higher frequency of blockages than newer welded or joint-free systems (Littlewood 2000).

The exploratory analysis of the two data sets supported these views. For example, Table 3 shows the blockage rates for the sewer pipe material, indicating that concrete and VC pipes have a high blockage rate relative to PVC and polyethylene (PE) pipes. Pairwise t-tests using the Bonferroni correction on the pipe attributes showed the differences to be significant ($p < 0.01$; 95% confidence level) for all classes except PE (noting the number of blockages for PE was in any case too low for a reliable test). The blockage rate for VC pipe is much higher for Company B. Although this difference cannot be explained with the available data, this observation does suggest that blockage rate is not dependent on pipe type alone.

#### Pipe Diameter

Davidson and Orman (1999) identified a high frequency of tree roots in smaller-diameter pipes, partly attributed to smaller diameter sewers being laid at shallower depths. Similarly, in an Australian study, Pohls et al. (2004) identified that pipes 150 mm or less laid within 1 m of the surface accounted for 70% of all tree-related

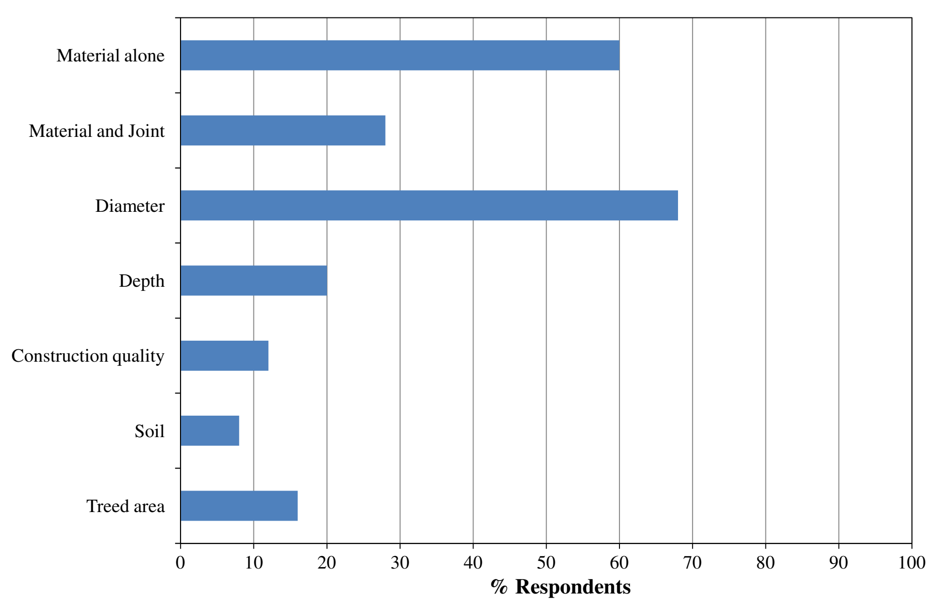


**Fig. 3.** Pipe and environmental attributes used to define problem cohorts; percentage is based on number of respondents participating in Web-based survey ($n = 25$)

**Table 3.** Blockage Rate by Material

| Material | Company A | | Company B | |
|---|---|---|---|---|
| | Blockages (total) | Blockage rate (100 $km^{-1}$ $year^{-1}$) | Blockages (total) | Blockage rate (100 $km^{-1}$ $year^{-1}$) |
| Concrete | 1,153 | 23.82 | 4,558 | 25.17 |
| Polyethylene | 21 | 8.86 | 10 | 7.98 |
| PVC | 308 | 2.70 | 227 | 4.72 |
| Vitreous clay[a] | 5,983 | 14.58 | 7,665 | 32.64 |
| Asbestos cement | — | — | 1,932 | 15.66 |

[a]Vitreous clay includes earthenware (EW) and salt-glazed ware (SGW) materials.

**Table 4.** Blockage Rate by Sewer Diameter

| Material diameter (nominal) | Company A | | Company B | |
|---|---|---|---|---|
| | Blockages (total) | Blockage rate (100 $km^{-1}$ $year^{-1}$) | Blockages (total) | Blockage rate (100 $km^{-1}$ $year^{-1}$) |
| 100 | 235 | 29.59 | 50 | 65.20 |
| 150 | 6,195 | 15.18 | 13,705 | 23.55 |
| 225 | 1,015 | 7.12 | 772 | 11.83 |
| 300 | 42 | 1.69 | — | — |



blockages. Beattie and Brownbill (2007) observed an increase in blockage rates (up to three times more) in 100- and 150-mm-diameter sewer pipes.

The exploratory analysis confirmed this view, as shown in Table 4. As indicated, the failure rate for 100-mm pipes is the highest, and the failure rate is reduced as the diameter increases. Pairwise t-tests (using the Bonferroni correction) showed that the difference between 150 mm and larger diameters was significant ($p < 0.01$; 95% confidence level). The difference between 100- and 150-mm diameters was also significant for Company B ($p = 0.012$; 95% confidence level), but not for Company A ($p = 0.2$).

## Pipe Age

Pohls et al. (2004) identified a peak in sewer blockages in assets aged between 30 and 59 years (representing 20.1% of the asset stock but accounting for 49% of all sewer blockages), with assets older than 60 years experiencing significantly fewer (representing 20.9% of the asset stock but accounting for 15% of all sewer blockages). Davidson et al. (1999) and Pohls et al. (2004) suggest that the more recent the construction of sewers, the fewer the blockages. This result was further supported through discussion with participating water utilities from the Web-based survey; it was generally accepted that assets were relatively trouble-free within the first 20 years, as newer developments have no mature trees within the pipe and sewer flows are still manageable.

As illustrated in Fig. 4, the exploratory analysis on blockage rates and the age distribution of the asset stock for Companies A and B confirmed this view. For Company A, a peak in blockage rate from 40 to 60 years, followed by additional secondary and tertiary peaks at approximately 80 and 120 years, was observed. For Company B, the observed blockage rate follows a similar pattern—an observed peak in the blockage rate at approximately 40 to 60 years, followed by a secondary peak at approximately 90 years. However, the peaks for Company B are less pronounced than those for Company A. The variation in blockage rate for assets under 30 years of age is also important to note. Company B experiences a significant

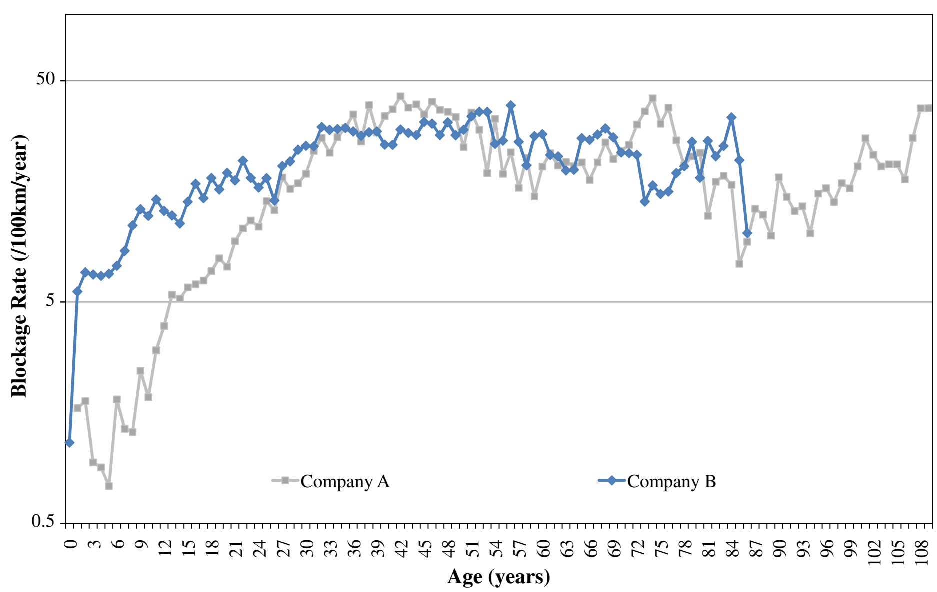


**Fig. 4.** Sewer blockage rates of Companies A and B against age distribution of asset stock



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increase in blockages compared with Company A, but from 30 years onward Companies A and B both follow similar trends in blockage rates compared with the age of the asset stock.

Although the asset age can be a precursor for asset deterioration, which, in turn, can indicate an asset that potentially can allow tree roots to intrude, it is evident in the exploratory analysis that the influence of asset age is complex. Any claim about older assets having fewer failures can reflect the fact that problem assets have been removed by that time, leaving only the assets less susceptible to blockages. However, in this context, the writers are not aware of this; but it is an issue in modeling asset condition over time.

### Tree- and Soil-Related Factors

As noted in Table 1, respondents felt that tree coverage and tree planting policy are factors that influence the blockage rate but are outside of management control. Furthermore, as shown in Table 2, both water companies experienced a significant proportion of tree-related sewer blockages. Thus, it appears logical to assume that differences in tree coverage and type of tree will affect the number of blockages. Information gleaned from the literature supported that tree planting policy has a significant influence on blockages. For example, Stål and Rolf (1998), Coder (1998), Peper and Barker (1994), Randrup et al. (2001), and Roberts et al. (2006) all identified problematic tree species (from the perspective of blockages).

Unfortunately, meaningful data on tree coverage and type were not available, which prevented explicit analysis of tree-related issues. As noted previously, however, the literature indicates that soil characteristics and changes in the soil environment have a significant influence on root development. For example, Kozlowski (1987) suggested that the lateral spread of roots can 3, 2, and 1.5 times differ from the crown diameter in sand, loam, and clay soil, respectively. Because extensive root systems are more likely to intersect with sewers, it can be inferred that pipes buried in soil types that favor root growth are more likely to have blockages caused by tree root intrusions.

With this inference in mind, exploratory analysis was undertaken to investigate the linkage between soil type and blockages, considering soil as a surrogate for tree root development. As shown in Table 5, Company A experienced a higher blockage rate for sandy and sandy-clay soils. Company B experienced a higher blockage rate in soils classified as silt and rock (although the "rock" was actually defined as sedimentary bedrock or similar, with clay, sand, or silt cover). A pairwise t-test (Bonferroni corrected) performed on the categories showed that the difference was significant ($p < 0.01$; 95% confidence level), excluding silt for Company A and sand for Company B, which had too few blockages to generate a meaningful statistic.

The exploratory analysis thus suggests that soil type characterizes a difference in blockage rates. Given the influence of soil on tree root development, some of the observed difference between soil classes is presumably related to tree root growth. However, the differences observed can be attributed to other factors being correlated with the distribution of soil types (e.g., all soils of a given type being associated with areas of relatively low or relatively high rainfall). Examination of the data suggested that there was no such systematic correlation between soil and other factors such as rainfall. For example, for Company A, two distinct zones of clay were noted, each with markedly different average rainfalls—one coastal area with 600–800 mm of average rainfall (low rainfall area), the other an inland and hilly area with 1,000–1,300 mm of average rainfall (high rainfall area).

Interestingly, the blockage rates for the two areas were 18.74 blockages/100 km/year (low rainfall area) and 6.33 blockages/100 km/year (high rainfall area), and a pairwise t-test showed that this difference was significant ($p < 0.01$; 95% confidence level). However, the reason for the difference in blockage rate between the two zones is not clear, although it is interesting that the blockage rate in the low rainfall area is similar to that observed for sandy soil at the company level (see Table 3). The high rate can relate to tree root development in response to lower rainfall, the reactive nature of clay soils in response to different rainfall patterns, or (more likely) a combination of factors, some of which are not reflected in the data.

These results demonstrate the difficulty of taking one explanatory factor in isolation. Nevertheless, because soil-rainfall interactions will vary across a company (and between companies), the assertion that a range of factors beyond management control influence blockage rate is still supported.

### Climate- and Drought-Related Factors

As previously noted, asset managers considered that climate has a significant impact on blockage rates. Both companies have significantly different climates, with Company A being in a moderate oceanic climate and Company B being in a humid subtropical climate (Köppen climate classification). If climate effects can be shown to have an influence over blockages, it can be inferred that the difference in climatic conditions between the two companies would influence blockage rate. With this logic in mind, approaches to considering climatic effects were investigated.

Discussions with research partners indicated that some utilities had used the southern oscillation index (SOI) to represent climate effects in analyzing blockages (Franks 1999). The SOI indicates seasonal fluctuations in the air pressure differences between Darwin and Tahiti and has been found to be a significant indicator of rainfall patterns and drought in the eastern regions of Australia (Bureau of Meteorology 2009). This factor can be of particular importance for Company B, as it is located on the eastern coast of Australia. It was also suggested that the Indian Ocean dipole (IOD) can be a good indicator for Company A, which is in the southeastern part of Australia (Ummenhofer et al. 2009).

**Table 5.** Blockage Rate by Soil Class

| Soil class[a] | Company A: Blockages (total) | Company A: Blockage rate ($100\ km^{-1}\ year^{-1}$) | Company B: Blockages (total) | Company B: Blockage rate ($100\ km^{-1}\ year^{-1}$) |
|---|---|---|---|---|
| Clay | 3,237 | 9.89 | — | — |
| Rock[b] | — | — | 12,564 | 23.27 |
| Sand | 918 | 14.16 | 10 | 7.98 |
| Sandy-clay | 3,318 | 17.62 | — | — |
| Silt | 13 | 8.29 | 1,925 | 19.32 |

[a]Both companies allocated soil class on the basis of a five-category soil code.
[b]Bedrock covered with a layer of clay, sand, or silt.



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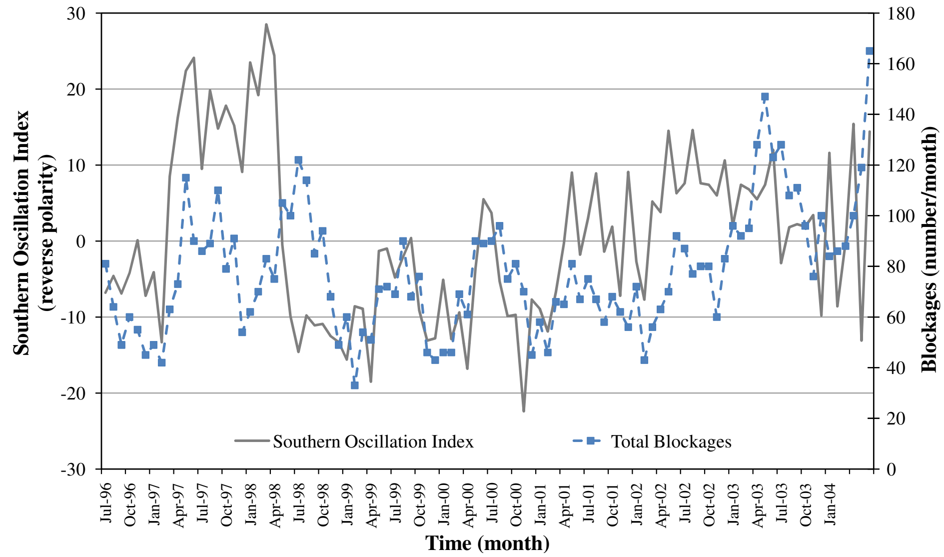


**Fig. 5.** SOI and Company A sewer blockages (1996–2004)

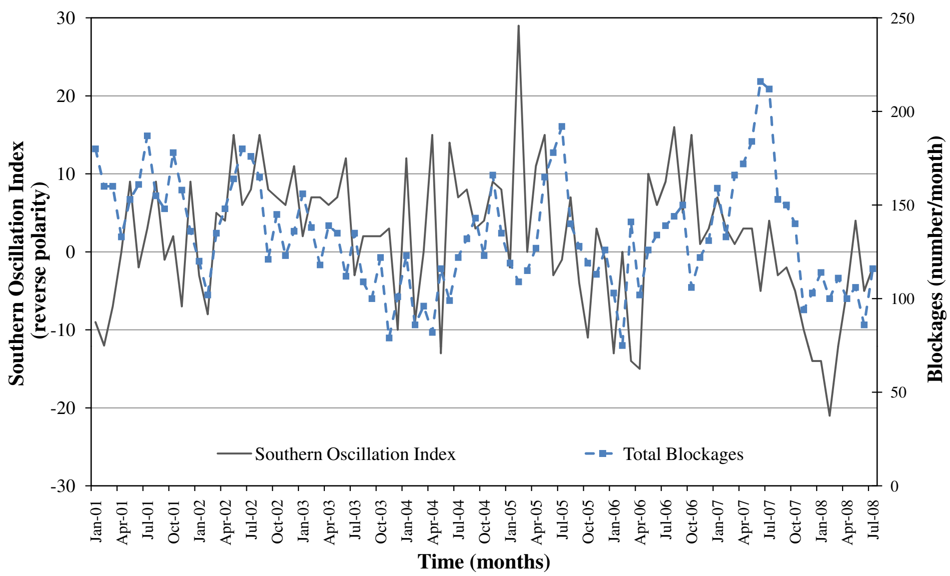


**Fig. 6.** SOI and Company B sewer blockages (2001–2008)

The IOD is the periodic oscillation of sea-surface temperatures of the Indian Ocean, which influences the southern parts of Australia (Bureau of Meteorology 2009). The impact of climate effects on blockage rate was initially investigated by using these two indicators. For example, Figs. 5 and 6 show plots of the SOI and the number of blockages over time for the two water companies.

Visual assessment of these plots suggest some level of correlation between the SOI and the number of blockages (i.e., peaks and troughs appeared to align). The strength of correlation was assessed by calculating the Pearson product-moment correlation coefficient. As summarized in Table 6, the calculated correlation coefficient indicates some correlation, albeit not very strong. Similar analysis was undertaken with lags of 3 and 6 months between the SOI and blockages to investigate whether a better correlation could be identified. However, the correlations were not significantly improved. As shown in Table 6, similar treatment of the IOD, as well as the SOI and IOD using only tree root–related blockage data, produced even lower correlation coefficients. Hence, the results did not provide much support for using either the SOI or the IOD as an indicator of climate effects on blockages.

As noted previously, results from the Web-based survey also indicated that asset managers considered drought to have a significant influence on blockage rates (see Table 1). To investigate this, the standardized precipitation index (SPI) was selected as a measure of drought. Data on SPI were obtained for both companies and were found to be mainly negative during the observation period (negative values of SPI indicating drought conditions). Equivalent analysis to that previously described for SOI and IOD was then undertaken. The correlation coefficient between SPI and the number of blockages for both companies was determined to be approximately $-0.1$, which was not significant at the 95% confidence level ($p > 0.05$). A better correlation was found when a lag was introduced between the SPI and the blockages series, with the best correlation being for a 4-month lag of SPI (correlation coefficients of 0.35 for Company A and 0.45 for Company B, which were significant at the 95% confidence level). This supported that



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**Table 6.** SOI/IOD and Blockages Statistics

| Company | Time series plot | Number of blockages | Period | Pearson correlation coefficient | $p$-value (reject> 0.05) |
|---|---|---|---|---|---|
| Company A | SOI versus total blockages | 7,444 | 1996–2004 | 0.31 | 0.02 |
| | IOD versus total blockages | | | 0.19 | 0.07 |
| | SOI versus tree root blockages | 5,001 | | 0.06 | 0.57 |
| | IOD versus tree root blockages | | | 0.06 | 0.57 |
| Company B | SOI versus total blockages | 6,879 | 2001–2008 | 0.15 | 0.17 |
| | SOI versus tree root blockages | 4,981 | | 0.22 | 0.14 |



blockage rates are influenced by drought. If there is a difference in drought conditions between the two companies, a difference in blockage rates can also be expected.

It was also recognized that although drought is linked to climate, the combination of lack of rainfall and water conservation efforts has a cumulative impact on flow regimes in sewers. For example, Butler and Graham (1995), Butler et al. (2003), and MacDougall and Wakelin (2007) investigated the effects of water conservation devices and the reduced intermittent inputs on sewer systems. Butler and Graham (1995) concluded that intermittent inputs reduced localized flow rates and increased solid/sediment retention within sewers, which was exacerbated in dry weather conditions. An asset manager involved in the research also had noted an increase in blockages whenever more stringent water restrictions were introduced in response to drought, with the increase occurring approximately 3 months after the new restrictions were enforced.

With these insights in mind, water consumption was suggested as a good indicator that would integrate the effect of both drought and water conservation efforts. Thus, an exploratory analysis was undertaken to ascertain the correlation between company-level water consumption and blockages. Fig. 7 shows a plot of blockages and water usage, which again suggested some correlation between the number of blockages and the water consumption (i.e., the peaks in consumption tend to correspond to troughs in the number of blockages, and vice versa). The analysis gave a Pearson product-moment correlation coefficient of $-0.65$. The negative sign of this correlation is consistent with the observation that lower water usage is linked with higher blockage rates. However, it is noteworthy that the equivalent analysis of water consumption data with a 3-month lag resulted in a lower correlation ($-0.4$).

Statistical tests indicated that the null hypothesis (i.e., representing no link between water use and blockages) was rejected, with a $p$-value of 0.01. In other words, a significant link between water use and pipe blockages was determined, which supported that drought and associated water conservation efforts influence blockage rates. Again, any difference in water conservation efforts between companies can therefore be expected to be reflected in differences in blockage rates experienced.

## Synthesis with respect to Research Aims

With the available data, it was difficult to show definite causal relationships between the various factors considered in the analysis. Furthermore, it was clear that a single factor could not explain the differences in blockage rate observed even within a single company. Nevertheless, the results still support the finding that various factors beyond management control have an influence on blockage rate. These findings have a strong bearing on using blockage rates as a measure for comparing the management effectiveness of different utilities. For example, during the research it became clear that a participating utility has a relatively new asset stock, generally constructed of unplasticized PVC and thus had a much lower company-level blockage rate than the utilities that operate older asset stocks with significant proportions of VC and concrete. Importantly, this difference in asset performance (and thus the service provided) does not necessarily indicate any difference in relative management effectiveness; it is simply a reflection of differences in the asset

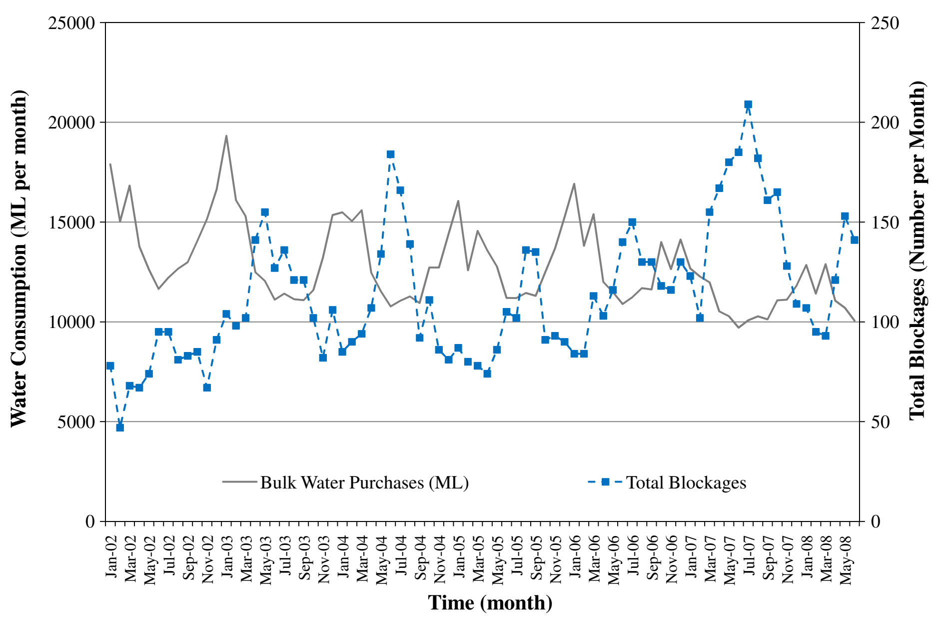


**Fig. 7.** Total blockages and water consumption over time



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stock operated. Similar arguments can be made for differences in the proportion of pipe diameters, predominant soil type, and factors associated with tree type and coverage. Similarly, any difference in climatic conditions, especially drought, is likely to have an impact on the blockages generated within a network. This latter point is important given the large differences in climatic conditions across Australia.

With such confounding factors in mind, it can be inferred that any intercompany comparison based on company-level blockage rates alone will not provide much, if any, information on the relative effectiveness of management strategies adopted. The results of the investigation supported the view of asset managers that company-level blockage rate alone is not an appropriate metric with which to compare the asset management effectiveness of different utilities. Therefore, it was recommended that this finding be communicated to utility boards and regulators.

## Conclusion

This paper has reviewed various factors that influence sewer blockages, drawing on a research project undertaken in collaboration with WSAA and its member water utilities. The research aimed to determine whether company-level blockage rates allow a meaningful comparison of the asset management effectiveness of different utilities.

The reviewed literature supported the opinions expressed by sector professionals that blockage rates are affected by a range of factors beyond their management control (e.g., climatic conditions, water consumption patterns, drought, and the extent and type of tree plantings) or factors that can only be changed with significant levels of investment (e.g., pipe materials and jointing systems). Exploratory analysis of available data provided further support of this view. However, limitations of data meant that some of the results are only considered indicative. In particular, the lack of tree data prevented explicit analysis of the impact of the extent and type of tree planting. The analysis did, however, provide insights into soil type as an explanatory variable for blockages.

Further analysis on the cause-and-effect relationships between the factors identified in this paper and the occurrence of blockages is therefore warranted. Nevertheless, given the combined evidence from the exploratory analysis, literature reviews, and opinion elicited from asset management professionals, it is reasonable to conclude that company-level blockage rates do not provide a meaningful comparison of the relative effectiveness of management strategies among companies, unless the effects of uncontrolled factors can be removed. Furthermore, the fact that blockages are influenced by variations in weather, including drought, means that the raw blockage rate does not provide a meaningful measure of management effectiveness from one year to the next even within the same utility. Analysis must again be undertaken to remove the influence of weather and drought if the impact of a change in management strategy is to be understood.

It must also be recognized that a company can always spend more money to achieve better outcomes, but achieving the same outcomes at lower cost is preferred. Therefore, a true measure of management performance would involve a cost-effectiveness aspect, i.e., reflecting not only the performance achieved but also the amount of money (and resources) used to achieve that performance. Thus, it would be necessary to extend the analysis to account for the expenditure on blockage management, but this would require consistent cost data to be collected. It is noteworthy that such data were not available for use in the study.


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