Predictive Geospatial Statistical Modelling of Sewer Blockages

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Abstract

In the 2016 calendar year the Water Corporation (WC) spent approximately $2 million clearing Fat, Oil and Grease (FOG) and Tree Root Blockages (TRB) from gravity sewers. Each time a reactive blockage clearing occurs the cost is twice the amount of planned maintenance. The WC has not conducted predictive work on FOG blockages and analysis on TRBs has also been very limited. The UrbanMonitor cooperative governed by LandGate delivers highly detailed aerial photography of Western Australia. This imagery includes NVDI maps which have enabled tree maps to be developed. Previously there has been no work completed that has quantified imagery to help maintain assets. Research has led to the quantification of tree foliage imagery, a metric which has shown that on average pipes that have observed a TRB will have twice as much tree foliage above them as unblocked pipes. Along with tree foliage; age, length, proximity to main roads and material are associated with sewer blockages. Factors including population density and time of year have also been correlated with blockages, however further research is being conducted. Overall the data shows that Perth has a Blockage Belt; an elongated region of Perth has been shown to have characteristics that make it the area most susceptible to sewer blockages.

1. Introduction

The Water Corporation (WC) is a State Government owned entity that maintains Western Australia's drinking water, wastewater and drainage services. Everyday 2.6 million West Australians (June 2016 ABS 3101.0) create 450 million litres of wastewater. The WC works hard to manage their assets in order to provide an acceptable level of service while minimising costs and charges. Many causes of blockages are social and difficult to control, though ultimately blame will be placed on the WC. From 2010 – 2016 inclusive there were 43,397 work order faults associated with the sewer. From these faults 29,526 have been given a cause. The two largest causes are Tree Roots (11,381) followed by Fat, Oil and Grease (5,219). Currently the WC cannot predict FOG blockages and has a limited understanding of TRB. This is increasing costs across the organisation and limiting its ability to reach operating standards.

The blockage anecdote

- Sewer blockages occur in the older areas of Perth in old town-centres that were the first to receive a sewer service.

- Vitrified Clay pipes are especially bad and appear to be a good surface for FOG blockages to grow while their joints allow for tree roots to enter the sewer.
- Blockages seem to be more apparent in areas with high restaurant and fast-food density.
- Blockages seem to be more apparent in areas of high population density.
- Blockages tend to follow major roads.
- Blockages are found along river banks.

The blockage anecdote was built from the decades of insight WC engineers have graciously shared. The anecdote will help drive this analysis allowing these beliefs to be proven or not.

1.1 Fat, Oil and Grease Blockage

FOG deposits build up and cause blockages that contribute to the global deterioration of wastewater networks. Western Australia is not immune and in December 2016 the WC launched the *Stop the Monster* initiative, appealing to the WA community to apply the *"Soap and water down the sink. Paper, pee and poo down the loo!"* philosophy. He et.al. 2011 showed that FOG deposits are similar to calcium-based saponified solids. These solids are products of a chemical reaction between free fatty acids and calcium ions (Iasmin et. al 2016). As they are generally calcium based metallic salts, FOG deposits are referred to as *soaps*. The physical and chemical characteristics of soaps are similar to household soap. Insolubility in water highlights how easily FOG deposits can cause blockages (Keener et. al. 2007, He et. al. 2011 and He et.al. 2013). Work to predict a FOG blockage has been limited within the WC and a *starting from square one* approach will be used.

1.2 Tree Root Blockage

A TRB occurs when tree roots enter a sewer pipe and negatively impact the flow rate through that section of pipe. TRBs are likely to enter through cracks and joints of sewer pipes which are seen at joints, joins and broken sections. Historical WC records indicate that TRBs cause over 50% of all sewer blockages. As there are higher costs in pipe replacement than clearing a pipe, prevention is the best approach to deal with TRBs on a financial basis. TRBs are generally dealt with using chemical treatments. After a blockage is reported and cleared an asset can then potentially be given a TRB Maintenance Plan (MP). This involves periodic checks and cleaning. The assigning of TRB MPs has historically been reactive, however a culture change in the way assets are managed within the WC aims to change this.

1.3 Previous work

This project will take a similar path to Nazimek et. al. (2013), with some statistical differences. Statistical sampling of data for the model will be reassessed and redeveloped. Nazimek et. al. suggests pipe characteristics (age, diameter, length, flow and material) are the key parameters in predicting the presence of TRB. The model Nazimek et. al. developed is shown below:

$$Y_i = -1.042 + 0.015 \cdot Age_i - 0.008 \cdot Diameter_i + 0.019 \cdot Length_i + 0.003 \cdot Flow_i + 1.143 \cdot VC_i$$

Where *i* is a particular pipe

A VC flag had the largest effect on TRB probability from a Binary Logistic Model developed by Nazimek et. al. (2013). Xie et. al. (2016) used a Cox proportional hazard model to understand the risks of VC pipe blockages, this suggested: length, depth, gradient (flow), pipe diameter, joint type, install decade, purpose and land code all have a strong association with sewer blockages. Both pieces of work suggest that pipe characteristics heavily impact a pipe's likelihood of blocking.

2. Methodolgy

2.1 Data acquisistion, data mining and dataset creation.

After a true understanding of available variables is developed, a statistical model can be applied. The data used will come from many alternative sources and will be arranged in a longitudinal dataset, allowing for blockage status' for each three-month interval from 2010 to 2016 inclusive. Using PDA operators mean a location can be entered using a pin dropping interface and the data can be mapped spatially. The majority of data has come from the WC Business Warehouse, a storage facility for the entirety of WC operations data. Blockage data from 2010-2016 inclusive has been the backbone of this analysis. This is field operator recorded data that included a pin drop to X & Y coordinates. Further data came from WC repositories which included spatial data from state government organisations such as LandGate and MainRoads WA. The data will be linked so that a longitudinal dataset is created. This dataset will hold point of time data for every pipe in the Perth Region from 2010-16.

2.3 Tree Coverage

The UrbanMonitor initiative lead by LandGate produces highly detailed 4 band aerial photography of Western Australia. The imagery allows for a NVDI index to be calculated and different forms of vegetation can be mapped. Using 2014 imagery UM output a tree dataset of Perth, a Geographic Information Systems raster file that indicated locations of tree foliage. Vegetation type data was unavailable when previous work was completed and has been heavily recommended by Nazimek et. al. (2013). The 2014 UM data is 17 terabytes in size and requires strong computing power and concise management. The obvious idea is that tree root blockages occur in the vicinity of trees, but how is this quantified? Initially the use of a NVDI index was suggested as this data is available through UM. NVDI maps are coloured to show what type of vegetation (if any) is present, creating complex problems such as what amount and type of vegetation indicates a tree. Initially a count of pipes within a prescribed vicinity of a pipe was suggested but this idea is problematic. Calculation of K was completed relying on simple geometry. For our purposes the buffer protrudes 5 metres either side of the pipe and rounded on each end. The area α is easily calculated as:

$$\alpha_{\text{rounded}} = 2 \cdot l \cdot b + \pi \cdot b^2$$

Through the geospatial expert of the Asset Registration Team (WC) the tree foliage data was overlapped on the pipe data which allowed for the calculation of the amount of foliage over each pipe's buffer, k.

$$K = \frac{k}{\alpha} \quad \text{where} \quad 0 \leq K \leq 1$$

As K is a unit less ratio, the obvious limitation of K is that it is bounded i.e. the foliage coverage can never exceed the overall area of the buffer zone. Although not a classifying variable, in this case K is not strictly continuous either. Each pipe was given a *K* value and once linked to the longitudinal data set we see a clear difference between *K* means.

	Blocked	Unblocked
Mean (μ_K)	0.2982	0.1436
Count	6,676	6,802,508

Table 1 Sample means of the ratio variable (*K*) for both blocked and unblocked pipes.

Shown by Figure 2 there is a difference between the distributions of the ratio variable (*K*) of blocked and unblocked pipes. The distributions appear to be of the Gamma family but more investigation is required. Figure 2 shows clearly that majority of unblocked pipes have a *K* value very close to zero while more than half of blocked pipes have a tree coverage greater than 25%.

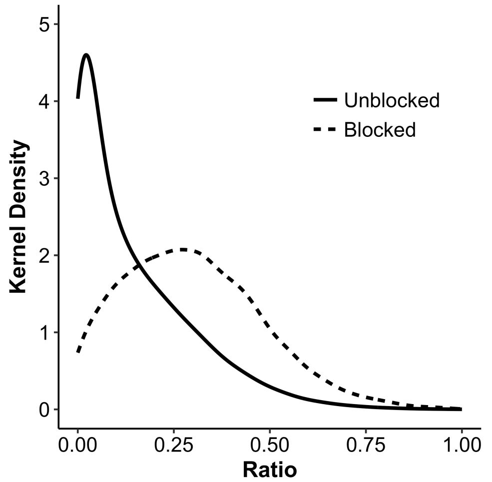

Figure 2 Observed probability density funtions of ratio (*K*) for both blocked and unblocked pipes (2010-2016).

3. Results

Presently the statistical modelling is being completed, hence finals models and accuracy is unfortunately not ready for publication. All work completed to this point of time indicates that the majority of the blockage anecdote is correct. Exploratory analysis has shown:

- **Tree Foliage Cover** is not only correlated with TRB there is also evidence to suggest the ratio can help predict FOG blockages.
- **Main Roads Proximity** is very highly correlated. Approximately 35% of blockages occur within 500 metres of main road. This is a believed case of correlation not being causation, i.e. if you build a main road today – tomorrow you will not see an increase in blockages close by.
- **Vitrified Clay (VC)** was the material of choice in the early 20th century. VC pipe though is manufactured in small segments which increased the number of joints allowing for more tree root intrusion. VC appears to lose its smoothness over time and FOG blockages are more prevalent in comparison to other materials.
- **Length** has a strong correlation with blockage likelihood. Intuitively this makes sense, as the longer a pipe is the higher the chance of a blockage forming.
- **Age** is a good indication of asset deterioration. The older the pipe, the greater likelihood of a failure.

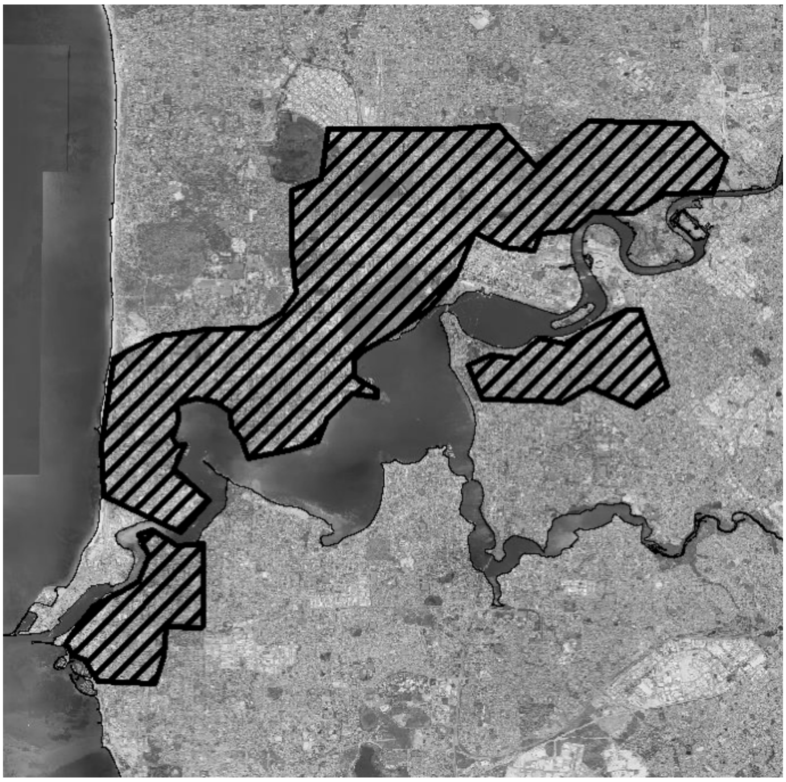

Figure 3 Map indicated the Blockage Belt of Perth

To help understand sewer blockages the issue needs to be considered as an urban growth matter. Initially Perth town had a handful of hubs – Perth CBD, Claremont, Midland, Fremantle etc. These areas were the first to receive sewer systems and roads built for locals. As time progressed these small roads became vital main roads, for example Stirling Hwy. The original towns have had their infrastructure built up and have become highly populated suburbs with the oldest sewer system.

Old sewer systems have the highest rates of blockages. Early in the 20th century VC piping was used as it was cost effective and with a long timespan, however it is very prone to both FOG and TRBs. Early into the 20th century VC pipe was the standard but as the pipe has aged its segmentation has allowed for easy tree root intrusion while its rough surface has meant FOG can accumulate easily. There is yet to be clear evidence that high restaurant/fast-food or population density impacts FOG blockages however more research is being carried out.

Research helps show truth behind the blockage anecdote and we can think of some blockage guidelines:

- Sewer blockages occur in the older parts of Perth.
- VC pipes are especially problematic.
- Blockages tend to follow major roads
- Blockages are found along river banks.

Introducing the idea of the Blockage Belt, helps illustrate the high risk areas of Perth. Following Stirling Hwy from Perth CBD to Fremantle and back to South Perth along Canning Hwy, shown in Figure 3. This area fits every part of the above guidelines. Using the knowledge that foliage ratio (K) is strongly correlated to TRB blockages makes the risk to the blockage belt clearer. Presently the longitudinal dataset is being used to fit a Binary Logistic

Regression model. This will take the collection of variables made available and use different techniques to reduce the complexity of the model and increase accuracy.

4. Future Work

VC pipes have a clear correlation with all forms of sewer blockages. Although work has shown VC pipes are especially promblematic the reason why is somewhat unknown. VC pipe is the oldest pipe in service and is promoted as being resistant to corrosion. As acids are found within sewers there is reasonable evidence to suggest that long term exposure has deteriorated the pipe surface increasing its roughness. Work is required to determine the long term (50+ years) condition and characteristics of VC pipes.

Continuation of the longitudinal dataset. Performing regression to measure asset performance is made easier when structures such as a longitudinal dataset is available. As the majority of code is developed, productionisation is easily achievable to allow for quarterly updates and further analysis.

5. Acknowledgements

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