Cost Effectiveness of Inflow/Infiltration Remedial Works

Anthony Maker

Kecheng Shen
School of Mechanical and Chemical Engineering

Ted Evans
CEED Client: Water Corporation

Abstract

The Water Corporation, like many water utilities, is attempting to address the issue of freshwater entering the wastewater system, known collectively as inflow and infiltration. To aid in this endeavour, this project has involved an assessment on the effectiveness of past remedial attempts including pipe refurbishment and smoke testing for illegal connections. It has also involved a quantification of the impact of existing flows on wastewater assets and the risk these flows pose to overflow events. Catchments over the entire metropolitan area were investigated and had their inflow/infiltration quantified in order to determine significant contributing factors such as soil conditions and pipe materials. Informed by these factors, this project then took on a theoretical perspective,by quantifying the potential spread of inflow/infiltration sources, such as illegal stormwater connections, required to cause observed patterns of excessive rain derived flow. Finally, with the support of all the information gathered, a cost benefit analysis is being carried out to assess the cost and potential benefits associated with different management options available to the Corporation. Final recommendations will be based on their financial, operational, environmental and social merit.

1. Introduction

Wastewater systems are an essential sanitary service offered by water utilities and in Western Australia, are handled almost exclusively by the Water Corporation. As of the past few decades, almost all of urban WA is now serviced by interconnected wastewater pipes (sewers). Generally, gravity sewers are used to collect wastewater from customers, both residential and industrial, subsequently feeding into one or more pumping stations responsible for a 'catchment' in order to transport the waste to wastewater treatment plants which are often installed on elevated land. The treated water is then usually pumped or gravity fed into local waterways, to an ocean outfall, or recycled, while treated solids are put into landfill or used to enrich crops. The capacity of pumping stations and wastewater treatment plants are designed for particular flows based on the number of customers, expected or planned growth in the area, as well as a number of other factors such as wetness of the soil. Naturally, there is wide variation in flows of wastewater with regular daily, weekly and yearly (seasonal) trends as well as growth and event based variations. One longstanding problem facing wastewater asset managers as well as operators is the occurrence of unusually high flows due to the introduction of groundwater and stormwater into the gravity pipes of the wastewater reticulation system.

These flows are known as Inflow and Infiltration [I/I], describing the likely origin of the water. Inflow refers to the entry of water from above ground sources such as roof gutters illegally connected to the sewer or broken seals on access chambers. This type of flow is typically of short duration, in the order of hours and of high intensity in direct response to rainfall. This is in contrast to infiltration, which refers to below ground entry of freshwater to the wastewater system. This type of flow is of longer duration, generally with an annual pattern, and of lower intensity in response to longer term rainfall. Infiltration is generally due to soil conditions, including water table levels, which is in part related to the amount of rainfall received in the preceding months.

There are a number of significant detrimental effects of excessive I/I all with associated economic, social and environmental costs. Ongoing economic costs include excessive pumping power use, pump wear and additional treatment costs. More directly however, one of the biggest costs is associated with making additional provision for rain induced peak flows at the pumping stations and wastewater treatment plants. Potentially, overflows can occur during rainfall events which can result in environmental and health issues as well as negative media exposure causing damage to the Water Corporation's reputation.

Managing I/I has a number of benefits that are specific to the remediation options chosen and to the particular needs of the water utility. These benefits however often include cost savings with respect to the reduced volumes of wastewater requiring pumping and treatment as well as delaying or eliminating the need for increasing the capacity of the infrastructure. An additional benefit is seen in the form of increased capacity for the existing wastewater systems, thus facilitating growth where the asset capacity is restricting urban expansion (more relevant to dense city areas).

Best practice in the management of I/I will assist the Water Corporation in operating sustainably and meeting their many obligations to the public and the environment (Murphy, 2010). Specifically, this means disruption to services as well as impacts on the environment are to be minimised whilst operating within budgets. In managing I/I, the most socially acceptable, environmentally responsible, and economically viable option is sought. Currently, there is very little in the way of direction for managing I/I with several previous studies indicating the scale of the problem, yet not considering the Water Corporation's available options, nor the practicality of implementing such options. There have also been a number of different attempts to address I/I which have lacked an objective analysis as to their effectiveness and applicability to the rest of WA.

Despite the significant operational problems it causes, in a global context, the Inflow problem in WA is relatively minor. Singapore, for example, experience storm peak flows of up to 20 times the average dry weather flows (Turner & Sharpe, 1999). This is compared with a peak flow of around 3 times the average dry weather flow during rare storms for some of the Water Corporation's most affected wastewater treatment plants such as Beenyup. A similar observation can be made for Infiltration in WA, with rates being very modest and very few catchments exhibiting noticeable seasonal flow increases. In the United Kingdom, average flow increases attributable to infiltration are significantly greater than in Australia with many catchments experiencing an average flow increase of more than 50% of the legitimate flow, and flow increases of 90% in England and Wales (CIRIA, 1998). In contrast, this study has not found any metropolitan catchments with more than a 38% increase.

A number of methods are used to correct for or manage flows due to I/I, some of which have been trialled by the Water Corporation in recent years. Generally, the targeting of infiltration involves various wastewater reticulation refurbishment methods, the effectiveness of which can vary wildly (for example, Kurz, Woodard & Ballard, 2001). The targeting of inflow also involves many different methods, each tailored to specific causes of the flow. Outlined below are some of the commonly used techniques.

Infiltration	Inflow
-Excavation and replacement of pipe	-Flow monitoring and dye testing/Repair
-Pipe relining or patch repairs	-Manhole cover repairs
-Injection grouting into cracks/holes/joints	-Smoke testing for illegal connections

Each of these methods of source detection and/or repair have had varied success in reducing I/I flows likely due to the difficulty associated with attributing the flow to a particular source, since many causes are not readily observable. It is generally accepted that to completely eliminate I/I is unrealistic, as there will be levels of flow that are not worth correcting for.

The main objective for this project is to inform the Water Corporation on the best course of action regarding I/I in an economic sense within the constraints imposed by Water Corporation policy and legal regulations. Specifically, this project investigates the viability of conducting source detection and remedial works on various sources of I/I versus managing these flows through capacity upgrades. The secondary objective of this project is to assist the Water Corporation to further understand the nature of the problem and specific sources of I/I as it relates to WA. This will also have implications for current practice regarding long-term planning and asset management.

2. Methodology

2.1 Performance analysis

The performance analysis has involved statistical comparisons of I/I levels in selected catchments in Bunbury and Perth prior to and immediately following trialled remedial works. This included one smoke testing project and two pipe refurbishment projects. Specifically, t-tests and regression models were used to define the changes in flow with statistical confidence. Where available, detailed data obtained via live monitoring equipment was used to characterise the I/I and finally assess the impact of the programs. This forms much of the basis of whether the techniques used may prove viable in a final recommendation.

2.2 Overflow Risk Analysis

The overflow risk analysis has involved an analysis of the historical impact rain events have had on wastewater treatment plants. From this, the frequency with which overflow or bypass events can be expected was extrapolated, aided by equations provided by the Bureau of Meteorology relating rainfall intensity, duration and frequency for specific locations. This task essentially assesses the current risk of overflow events as well as the effect of bypass and storage facilities on the expected recurrence interval of excessive flows. This is vital in assessing whether a “business as usual” approach is a viable option in the final recommendation.

2.4 Factor Analysis

The factor analysis involved the testing of a series of multiple regression models in order to find factors associated with I/I. This task tested the power of various parameters such as pipe age, pipe material, soil conditions, pipe depth beneath the water table, and joint type in predicting measures of catchment I/I. This task is important in assessing the potential effectiveness of untested technologies in managing and targetting I/I flows.

2.4 Sensitivity Analysis

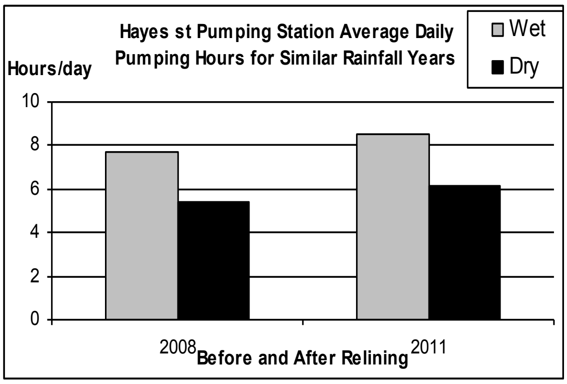
The sensitivity analysis has involved theoretical analyses and calculations of the potential spread different sources of I/I may have. For example, the number of illegal roof connections necessary to cause the flow increases seen during storm events was calculated as well as the size of a pipe defect necessary to cause significant rates of Infiltration. This task is important in assessing the spread, and therefore the associated location and repair costs, of various sources of Inflow and Infiltration. This task also provides a supporting theoretical account for the scale of the different sources of flow.

2.5 Cost Benefit Analysis

With the assistance of past research and current findings as evidence, the cost benefit analysis is involving an assessment of the numerous remedial options available to the Water Corporation. These options are to be compared with a “business as usual” option with no active source detection or remediation programs. If one or more of the options presents as financially beneficial as well as practically, environmentally and socially viable, this will form the basis of a final recommendation.

3. Results and Discussion

3.1 Performance Analysis



In assessing the effectiveness of the relining project in the Hayes st catchment, t-tests were used, comparing years of very similar rainfall from before and after the relining. It should be noted that analyses which account for rainfall statistically were preferrable, however the data violated assumptions central to such techniques. The data indicated that the pumping hours and energy consumption increased.
In assessing the effectiveness of this relining program, it was also found that pumping hours and pumping energy could be reliably predicted given the previous 1.5 months of rainfall with (significant) Pearson correlations prior to the relining of 0.86 and 0.91 respectively.

The reasons for this result may be found in the application of the relining which consisted of a PVC spiral wound insert. The liner itself is watertight when installed and acts as a structurally independent pipe within the host pipe. A problem arises however when one considers that house laterals need to be cut into the newly installed pipe. Whilst “tophat” liners are installed at every junction, these are not designed to be watertight. Thus any water that has infiltrated into the space between the host pipe and the insert, can enter the system through the newly cut house laterals. In addition, even if the liner and junctions were entirely watertight from the surrounding host pipe, it would only take one defect in the liner to allow the infiltrated water back into the relined system.

Similar results are seen at the Rose st catchment which underwent two sets of relining, one being the PVC spiral wound insert, identical to Hayes st, and the other being a fibreglass resin pipe (FRP) insert which is a flexible insert expanded to conform to the host pipe and cured in place. With only coarse data available, a regression model was used to compare pump hours and energy consumption (accounting for rainfall) before and after each set of relining. No change in hours or energy was seen at Rose st, indicating that both types of relining were ineffective at reducing Infiltration.

Due to a lack of data preceeding the smoke testing program conducted in Mindarie, analysis of its effectiveness could not be assessed statistically. Instead however, alarms indicating excessive flow, in response to rainfall, were assessed and were found to reduce in frequency following the smoke testing for two separate catchments involved in the program. The number of illegal connections found through the program (10 out of 1700 tested houses) is also consistent with this result.

3.2 Overflow Risk Analysis

The main findings of the Overflow Risk Analysis are that all metro wastewater treatment plants [WWTPs] displaying inflow have adequate capacity in terms of their biologically constrained process capacity, their hydraulic capacity and their bypass capacity (see Figure 2). It was also found that none of the plants were at risk of breeching their licences with respect to nutrient output due to I/I.

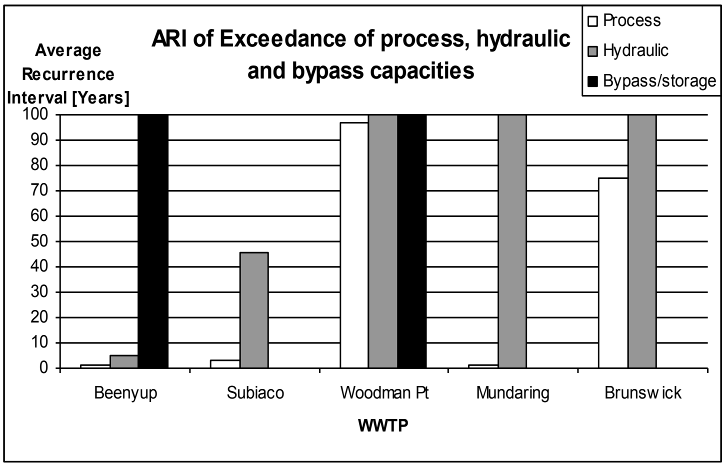


Figure 2: Expected frequency of exceeding WWTP capacities

Importantly, the analysis also highlighted the role bypass and storage facilities can take in managing excessive flows whereby the risk of overflow or damage to biological processes can be greatly reduced with only moderately sized bypass/storage capacities. For example, if the capacity of a pumping station or a wastewater treatment plant is exceeded, doubling the on site storage will reduce the probability of an overflow by approximately 3.5 times due to the exponential nature of rainfall intensity and duration probabilities. In terms of frequency, or the average reccurence interval [ARI] of a storm event, if one can reasonably expect an overflow every 3 years, doubling the onsite storage decreases this frequency, by a factor of 5, to once every 15 years.

3.3 Factor Analysis

This analysis involved the summation of vast quantities of data characterizing 77 separate catchments across the Perth metropolitan area. A multiple regression analysis was run through a statistical package looking for predictors of Infiltration, and to a limited extent, Inflow. The main finding of the analysis was that the strongest predictor of Infiltration was the soil type, in particular whether the gravity sewers were installed in clay or non-clay ground. To a limited extent, pipe age also contributed to the infiltration model. No factors were found to be associated with inflow.

3.4 Sensitivity Analysis

This analysis provided important contextual information for the scale of sources and how likely they are to contribute to the flow. For sources of inflow, for example, it was found that as few as 1.36% of houses need to be illegally connected to entirely account for excessive flows seen during major storms at Beenyup WWTP. This is a strikingly small percentage suggesting that it may be viable to test vast numbers of houses to find a minority of illegal hookups. In support of these figures, the smoke testing in Mindarie found that 0.6% of houses were illegally connected despite the finding that some residents deliberately, and successfully, concealed their faulty plumbing in anticipation of the smoke testing. For potential sources of Infiltration, Darcy's equation was modified to encompass a three-dimensional situation. It was found that to produce 1 L/s (approximately 200 households or 500 residents worth of flow) through typical bedding materials, a single hole with a diameter in the order of 10-35cm (depending on bedding) was necessary.

3.5 Cost Benefit Analysis

This analysis is still in progress for various options including new technologies. Some of the technologies holding the most promise include pipe refurbishment techniques targeting infiltration such as injection grouting and illegal inflow source detection methods such as smoke testing. The cost benefit analysis will quantify the long-term viability of options with final recommendations considering the social and environmental impacts particular to the Water Corporation.

4. Conclusions and Future Work

The previous analyses have established objective measures of Infiltration and Inflow in the assessment of previous remediation attempts as well as defining the nature of these flows on a large scale across Perth. Through these assessments, and a theoretical account of I/I sources, the scale of the problem, as well as the likely contributors, are now beginning to be uncovered. With support supplied by the various analyses, a set of recommendations is being developed with regards to effective management of I/I. Depending on the cost effectiveness and practical considerations, a final set of recommendations will be produced based on the current and future state of the Water Corporation, their assets, and their practices. Future work on I/I will likely consist of a trial for a remediation strategy in particular catchments, including subsequent assessment of its effectiveness.

5. Acknowledgements

In addition to his industry and academic supervisors, the author would like to thank all of the Water Corporation staff involved for their valuable contributions throughout the project.

6. References

Murphy, S. O'Connor, P. (2010). 2010 Annual Report, Water Corporation, Leederville.

Turner, B. & Sharpe, A. (1999). Infiltration Inflow Studies in Singapore. *WaPUG Spring Meeting, Birmingham*, Paper No.1.

Ainger, C. Armstrong, R. & Butler, D. (1998). Dry weather flow in sewers. *CIRIA Project R177*.

Kurz, G., Woodard, S., & Ballard, G. (2001). Nashville Cuts Wet Weather SSOs Using Sewer Rehabilitation. *Proceedings of the Water Environment Federation*, pp 175-185.