INFILTRATION/INFLOW STUDIES IN SINGAPORE

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Introduction

This paper is a result of work that Binnie Black & Veatch have carried out for the Singapore Government over the past 8 years. The work is a programme of infiltration inflow (I/I) studies initiated by the Department of the Environment (ENV) for sewer rehabilitation.

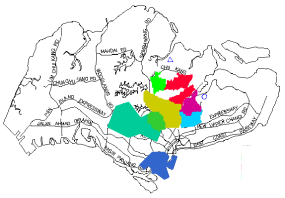
Large portions of the separate foul sewer network in Singapore were laid during the 1970s, and there is concern that these may be prone to structural deterioration. A related problem is that many of the pumping stations in Singapore are receiving larger flows than anticipated, leading to increased pumping and treatment costs, surcharge and even pumping station failure due to overloading.

ENV have started a programme of sewer rehabilitation across Singapore. Their approach has been to require the rehabilitation contractor to identify the sewers most at risk of structural deterioration. This has been done by infiltration studies. In addition to the infiltration assessment, storm inflows into the foul systems have been quantified. The purpose of this was to identify areas where surface water connections into the foul sewer resulted in significantly increased flows to pumping stations and sewage treatment. These areas will then be targeted to reduce inflow.

Study areas

Singapore is an island 618km^2 in size, with a population of 3 million. The three studies that Binnie Black & Veatch have undertaken cover the areas of:

- Holland Road - 18km^2
- Pulau Saigon - 7km^2
- Braddell - 14 km^2
- Bartley - 2km^2
- Thomson - 2km^2
- Jalan Tauge - 5km^2
- Teck Hock - 7km^2
- Serangoon Garden 3km^2



Singapore I/I study areas

This covers nearly 10% of Singapore.

The first study of Holland Road and Pulau Saigon was carried out in 1992. Braddell, Bartley and Thomson were the subject of a study in 1997, and Jalan Tauge, Teck Hock and Serangoon Garden in 1998.

Philosophy

The approach adopted to identify infiltration and inflow combines flow surveys, desk study and empirical data. Three main assumptions were made:

- Unit dry weather flows were assumed for residential and trade contributors, where water consumption data was not available. An average occupancy for the different types of residential development was derived from census figures.

- There is a direct link between the quantity of infiltration and the structural condition of the sewer. Most infiltration is assumed to enter the sewer network through deficiencies in the structural fabric of the sewer, open joints and badly made connections.
- An initial assumption that Singapore has separate foul and surface water sewer networks was found to be incorrect. A second assumption was made that storm inflow (flow directly related to rainfall) was from legal connections and could be related to the number of foul contributors in residential areas.

In our experience, infiltration is difficult to pinpoint and quantify. Storm inflow is a different case, as the mechanisms of rainfall contributing to overland flow and its entrance and impact on piped sewer networks are well researched, proven and documented.

To combine the two elements of infiltration and inflow, the following approach was adopted. A detailed hydraulic model of the sewer network in each catchment was constructed, and calibrated using data from a flow survey. The flow monitors were located directly downstream of areas considered to have a high risk of infiltration, and were also used to divide the catchment up into a number of small sub-catchments. A total of 178 flow monitors were used in the 3 studies, with an average sub-catchment size of 32.5ha.

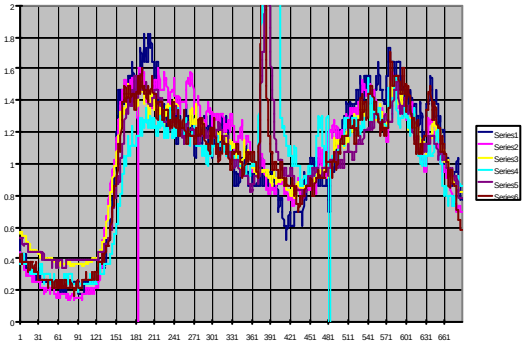
A comparison between the theoretical and observed dry weather flows enabled the dry weather infiltration contribution (and thus the risk of structural deficiency) from each sub-catchment to be quantified. The process of storm calibration quantified the area contributing storm flows in each sub-catchment. In this way, the areas likely to contain illegal connections into the foul sewer network were identified.

Contributing flows

The three studies that we have carried out in Singapore identified 6 types of contributing flow:

- Domestic
- Trade
- Tidal inflow
- Dry weather infiltration
- Wet weather infiltration
- Storm inflow from connected impermeable area

Domestic



This was calculated using a combination of census figures, site survey work and data from the Housing Development Board of the Singapore Government. A diurnal profile was developed for each catchment. This was done by first identifying the sub-catchments where the contributing area was predominantly residential. Up to 10 sub-catchment hydrographs for several

dry days were used to produce an average dimensionless profile for each study area. Separate profiles were developed for weekdays and weekends.

Trade

Trade flow figures were obtained from PUB metered water consumption, telephone survey and particular flow monitor recordings. These were allocated to the HydroWorks model as QIN files.

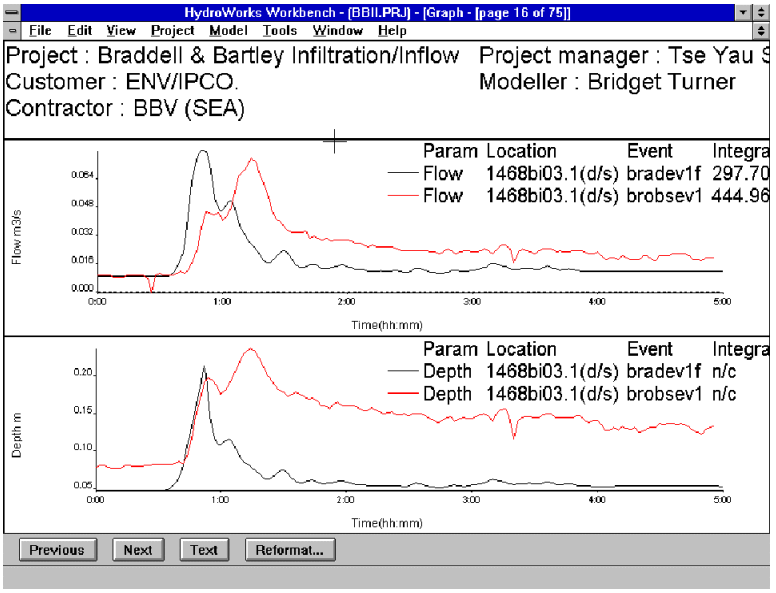
Tidal inflow

Tidal inflow was only evident in the Holland Road and Pulau Saigon catchments. This was surprising, as Singapore is relatively flat and low lying, and we were expecting a significant tidal response right across the island. The impact of tidal inflow was identified from the flow survey. It is easy to identify, as there is a 12.2 hour cycle, which coincides with high tide times. Tidal infiltration was added to the model as QIN and LEV files.

Infiltration

Dry weather infiltration was identified after dry weather flow calibration. Having successfully modelled the residential and trade contributions, the observed and predicted dry day flows were compared at minimum flow times (2am – 4am). Where there was a discrepancy, and observed flows were higher than predicted, this was assumed to be due to infiltration in dry weather.

In some areas, a phenomenon was identified which we termed wet weather infiltration. This appeared as a higher than anticipated flow in the system, continuing for several hours after cessation of rain. This wet weather infiltration is assumed to be due to a temporary rise in the groundwater level following heavy rain. *As* the groundwater level rises above the pipe invert level, infiltration increases through deficiencies in the fabric, poor connections and manholes. Also, more pipes come within the groundwater table, so there is more opportunity for infiltration. Unfortunately, in our I/I studies there was no allowance for monitoring of groundwater levels, so the theory was not tested.

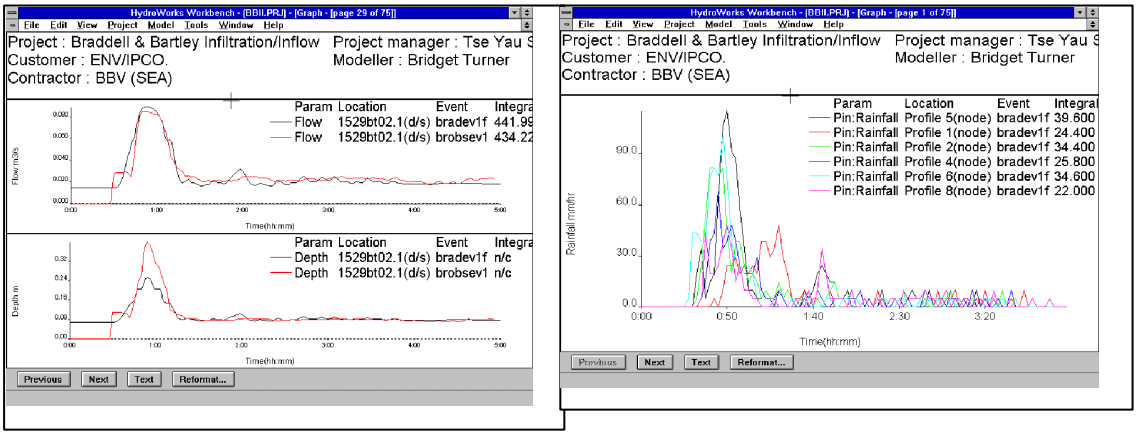


Wet and dry weather infiltration were quantified and ranked using a l/s/mm-km analysis, which relates the amount of infiltration (l/s) to the surface area of upstream

sewer (mm-km). Infiltration was assumed to occur through the circumference of pipes and at joints, so could be related directly to *diameterxlength* of sewer upstream of a particular flow monitor. Infiltration through manhole walls was not considered significant in the analysis.

Storm inflow

In theory, the sewer system in Singapore is entirely separate, although it is known that some storm flows enter the system through legal connections. The flow survey showed that in all the catchments there is a significant response to rainfall, and that the sewerage system is, in practice, combined.



The rainfall patterns in Singapore are very different from those in the UK. Rainfall can be expected nearly every day of the year, and is much more intense than that experienced in the UK. During the flow surveys, storms with peak intensities of more than 125mm/hr and total depths of up to 77mm were recorded. The observed storm shown above is comparable to a UK 100 year return period design storm.

Storm inflow comes from a combination of legal and illegal connections. Markets, petrol stations and waste chutes from HDB blocks are examples of legal connections. Without an impermeable area survey, it was impossible to separate legal and illegal connections. For the storm verification, a broad assumption was made that inflow was only contributed from foul connections. This is obviously not entirely true. However, the development of a "contributing area per person" approach allowed us to identify areas with high connected areas. These can then be further investigated with individual impermeable area surveys. The idea is that illegal connections can then be removed, thus reducing the quantity of storm inflow reaching the pumping stations and sewage treatment works.

Storm inflow was assessed and ranked using three methods:

- l/s/mm-km analysis
- storm inflow as % of dry weather flow from residential and trade contributors
- absolute storm inflow in l/s

Results

The results from the I/I studies were used to identify the sub-catchments best targeted for rehabilitation and reduction of storm inflow. Areas with the most severe problems (as determined from the ranking analysis) are being targeted first.

Overall, infiltration in Singapore is not a serious problem, although it increases markedly in wet weather. The table below shows infiltration as a percentage of foul flow (residential and trade contributions) at the downstream end of each system.

Catchment	Dry weather infiltration	Wet weather infiltration	Tidal inflow	Storm inflow
Holland Road	40%	Not calculated	7%	954%*
Pulau Saigon	57%	Not calculated	40%	966%*
Braddell	1%	42%	-	200%**
Bartley	11%	19%	-	220%**
Thomson	26%	Trade flow masked effects	-	210%**
Jalan Tauge	6%	42%	-	128%**
Teck Hock	0%	33%	-	175%**
Serangoon Garden	0%	42%	-	97%**

* Figures for a 5 year return period storm
** Figures for a 1 year return period storm

Conclusions

Infiltration in Singapore contributes up to 57% additional flow. While significant, this is less than we have encountered in studies in the UK. Dry weather infiltration occurs all the time and should be targeted first in any infiltration reduction exercise. This will automatically reduce the overall quantity of wet weather infiltration.

Storm inflow contributions more than double the peak dry weather flow in a 1 year return period event. The results for Holland Road and Pulau Saigon show that the impact is much greater in more severe storms. Storm inflows (and to a lesser extent, wet weather infiltration) have a significant impact on pipe, pumping and sewage treatment capacity. Our studies have identified several pumping stations in the catchments that are under capacity. If the capital and operational costs associated with pumping and treatment are to be reduced, it would be best to target and remove illegal connections into the foul sewer network.

Rehabilitation work for structural renovation and reduction of infiltration is underway in 6 of the 8 catchments. We will have the opportunity to test our theories, as post-rehabilitation flow surveys and reassessment of the studies are planned in the future.

DISCUSSION

Question John West Birmingham University

In a system is there a trade off between the problems of capacity with infiltration and the effects WQ issues. Flat warm sewers with septic conditions could have these problems eased by the flushing action of infiltration. Does the storm inflow also help wash out the pollutants from the sewers ?

Answer

Yes inflow does help the flushing but you really only need a bit. Although the systems are flat there are a lot of pumping stations to help with the flushing actions and reduce septicity problems.

Question **Richard Seabert** **Oscar Faber**
Did you monitor ground water to levels to establish a relationship with infiltration ?

Answer
No but this would be a good idea.

Question **Alan Wisdish** **W S Atkins**
How did the cost of the investigations and surveys compare with the cost savings ?

Answer
The main savings would be on not upgrading the pumping stations in the catchment. The costs savings have to be offset against the cost of investigation , survey and also the costs of the remedial works and how effective they are. We do not have the figures available for this.

Question **Brian Sharman** **North West Water**
You only looked at a part of Singapore. Have studies been done in other parts? Did you share information and lessons with these other areas?

Answer
We have not shared the information directly though it has been done through the Client the Department of the Environment.

Question **David Ashworth** **AWE**
What flow measurement equipment did you use in low flows?
Did you use pumping station sites ?

Answer
ADS Quadrascan, they worked very well measuring flows of 1 l/s
We did use pumping station inlets and got good data despite the fact that at some sites the inlets drowned and were surcharged in dry weather due to incapacity problems.