# Real-time Operational Modelling of Sewers: A Case Study

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**Keywords:**

Operational modelling, forecasting, hydraulic modelling, telemetry, predictive asset management, pilot study

**Abstract:**

Computer models have been used for many years for designing and evaluating the performance of sewer networks. These models are easily updated to reflect any changes, proposed or existing, in the study area, and they provide invaluable information to network planners and managers. With the increased availability of real-time gauged data, in addition to both observed and forecast radar data, converting the offline models into real-time operational models can maximise the return on the investment already made in these modelling studies.

In 2009, Thames Water and Innovyze embarked on a pilot study to convert an existing offline InfoWorks CS model into a real-time operational FloodWorks system. The pilot system, located in the North West of London, contains approximately 30,000 modelled nodes and covers the Hammersmith and Fulham area of the Beckton catchment. The aim of the study was to obtain a better understanding of how the network responded to meteorological conditions, in terms of flooding and CSO spills and the day to day operational regime of key network assets such as tanks and pumping stations. Also of interest was investigating the potential for predictive asset management and if this could influence the costs of routine maintenance and renewal. With on-going pressure on capital investment programmes, these represent critical issues for every utility and service provider.

This paper discusses the pilot study process and what lessons were learned. It also assesses the performance of the system from the end of the pilot study period up to the current time, during which time the network model has been upgraded and an operational system, generated for the London 2012 Olympic Games, has been running.

## Introduction

In 2009, discussions began between Thames Water and Innovyze, then Wallingford Software, about setting up a pilot study for an operational forecasting system of an urban drainage network. Thames Water had already modelled many piped networks using InfoWorks CS and by working with Innovyze and utilising the FloodWorks software, the investment made in setting up these network models could be maximised. At the project outset, there were a number of broad objectives, both from Thames Water's and Innovyze's perspectives. The main driver was to investigate just how an operational system could be used to benefit Thames Water's business, both during the pilot phase and into the future. Other objectives ranged from understanding how an operational system could be run within the Thames Water business, to investigating the hardware, configuration and performance issues for real time applications of large InfoWorks CS models. This paper describes the pilot study process and the lessons learned along the way. It also discusses how the objectives have evolved throughout the pilot study and how the system is being used today.

## Project Objectives

At the outset of the pilot study, the uses of an operational system to predict the response of an urban catchment to meteorological conditions seemed to be multiple. The proposed uses ranged from looking at seasonal variations in flow and assessing the impact of operational strategies in real time, right through to pump optimisation and maintenance scheduling. Whilst these uses are perfectly viable, it was decided fairly soon after the project inception that the aims of the pilot study should be kept simple, with the more complex uses to be considered if the pilot study was a success.

The initial uses of the FloodWorks system were to confirm that the live rainfall and sewer level data could be brought together on one server and loaded into the FloodWorks system. Once the data feeds were secure, the study looked at a flood risk site in Shepherd's Bush and how system alerts could be relayed and company action taken on site. The operation of a number of CSO's was also monitored.

The system was also used to address model verification issues. Most offline models are verified against short term flow surveys, typically of 5-10 week duration. It is common for these short term flow surveys to not coincide with periods of significant rainfall or be able to fully test the influence of spatial rainfall and therefore calibrating large catchments, such as Beckton (approx. $450km^2$) can be problematic. Low return period events do not place great stress upon the system and consequently the interaction between the local sewers, trunk sewers and, within London, the deeper storm relief sewers, is rarely captured by the temporary flow surveys. By collecting data over a long period of time it is more likely that the models can be calibrated to higher return period events. It should therefore increase the confidence associated with the applying of synthetic rainfall to the models for the design of future capital schemes.

## What does a FloodWorks System do?

In order to understand what is involved in setting up such an operational system it is useful to describe, in very broad terms, what tasks are being carried out automatically by the FloodWorks software. FloodWorks is a modular system, which can be used for the operational forecasting of flows within rural or urban catchments. FloodWorks allows live data sources (for example telemetry data streams and radar rainfall) to be automatically harvested, quality controlled and fed as boundary conditions to underlying model(s). The live data streams will be read from flat files from network locations and/or ftp sites. Simulations of the hydrologic and hydraulic models will be automatically launched based on a schedule, generating forecasts of the network response. The forecasts will be compared to known thresholds (e.g. depth of flooding or flow through a CSO etc.) and if the thresholds are exceeded then warnings are displayed in the FloodWorks Event Manager software, which can be used within the control room, as well as sent by SMS and/or e-mail to the relevant stakeholders. If a warning is generated, operators can react accordingly, either issuing warnings to the public, or sending out maintenance teams. It is also possible to carry out ad-hoc or 'what-if' simulations using pre-determined models set up with different network control strategies or enhancement schemes to assess the benefit of possible operational interventions on site.

Each simulation carried out by a FloodWorks system has a hindcast and a forecast period. This means that every simulation carried out by FloodWorks has two uses: during the hindcast, observed data can be compared to model predicted behaviour, ensuring that the model is producing predictions which reflect reality, whereas during the forecast, predictions of future behaviour can be produced. FloodWorks operates in a 'continuous simulation' mode; that is, snapshots of simulation results (flow, stage, catchment wetness etc.) are saved during each run and used as initial conditions for subsequent forecasts, ensuring accurate antecedent conditions.

The figure below gives an overview of the data flow through a FloodWorks system.

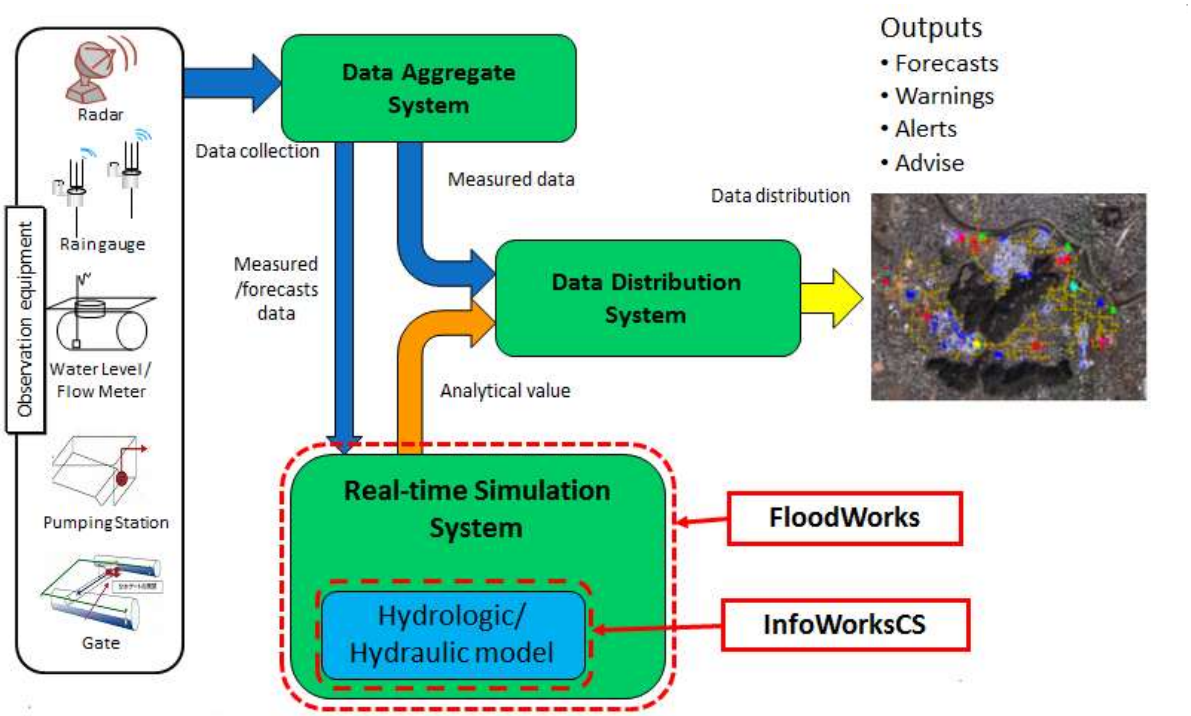



**Figure 1 - FloodWorks Information Control Algorithm**

# Setting up the Pilot Project

## The Project Area

The Beckton Catchment was selected for the pilot study because Thames Water had invested considerable time and money into enhancing the strategic London macro models and this process was well underway in the upper reaches of the Beckton catchment. A pilot study to test and understand the benefits of permanent depth loggers was also underway in this catchment and telemetry data from strategic points within the catchment were being received. The upstream catchment model had also been independently audited and had been used for developing long-term flooding solutions, making this catchment model the most suitable one to choose for the FloodWorks study.

## Data Requirements

In order to set up the pilot system there are a number of fundamental requirements:

- Verified InfoWorks CS model
- Time varying boundary data
- Gauge data for comparison purposes

- Threshold levels for alert generation

An InfoWorks CS model was available which had been verified against a 16 week short term survey in 2009. The permanent depth loggers installed at the same time and the same sites as the short term flow survey are still working today and are building up a long term data set from within the catchment.

For this pilot study it was decided that radar data only would be used as boundary conditions. Thames Water already had access to a live supply of observed radar rainfall which was supplied in Nimrod format at 1km resolution received at 5 minute intervals. However, in order to provide a forecast capability, forecast radar data was also required. The UK Meteorological Office (UKMO) six hour Nowcast data was used to meet this requirement. The Nowcast data is in the standard Grib1 format. There was some concern over how accurate the radar data would be over both the observed and forecast periods. The forecast data, supplied in the Nowcast format, has been improved by making use of the STEPS 2 algorithm, which was implemented in February 2012 and the UKMO are continuing to look at increasing the ensembles to improve accuracy. Comparisons between simulations using the observed radar data and rain gauge data were made. In general the observed radar data provides a lower rainfall intensity than the rain gauge data for the same location, leading to a lower volume of water entering the system from runoff. However the effect of the areal distribution provided by the radar gave an insight into the response of the network that could not be derived from a limited number of rain gauges. It was simply not possible to install the required density of rain gauges across central London to pick up this spatial variation in rainfall, meaning that use of rain gauge data to drive the underlying hydrological models was not feasible.

The Nimrod data arrives every five minutes and the Nowcast every 15 minutes. The forecast radar has a six hour lead time with intensities at a 15 minute timestep. Level data is recorded every two minutes and is transmitted every 2 hours, except when predefined thresholds are exceeded at the level recording sites. If this occurs then the data is sent every 12 minutes for a 3 hour period, or until the threshold is no longer exceeded. The data is loaded into FloodWorks as soon as it has been transmitted.

Level data is recorded with the piped network at 30 locations within the pilot study area. This data was used for comparison to model results only.

The pilot study area is affected by tides and ordinarily it would be desirable to apply tide levels at all outfalls in the network. This was not, however, one of the study drivers. In addition, there was no measured data available and predicted tidal levels, which would usually be calculated using tidal harmonics, could not be used as the effect of the Thames Barrier would not be included. To this end outfalls were assumed to freely discharge into both the River Thames and the River Lea.

## Testing the system

One of the fundamental requirements of an operational system is the timely provision of a forecast. This means that it is imperative that the underlying mathematical models should be able to process the data and produce the forecast results quickly. At the outset of the pilot study the time the Beckton InfoWorks CS model took to run was investigated. Model simulations covering a period of 12 hours (three hours hindcast and nine hours forecast) were carried out on the desktop machines used for the offline InfoWorks CS modelling. These simulations took about three to six hours to complete, depending on the amount of rainfall entering the system. Simply by carrying out the simulations on a more powerful machine meant that the model ran in about five minutes for DWF and approximately 25 minutes during heavy rain. Details of the original desktop machine are not available but the new machine spec is detailed in the section 'IT requirements' below.

Given the large size of the model and that the time of concentration through the system is approximately three hours, this was deemed to be an acceptable simulation time.

As model robustness is an essential part of a flood forecasting system, the model was run under a large range of boundary conditions. Historic rainfall analysis of past events has provided confidence in the system. This confidence is also provided by the on-going checks that model predicted data compares well to the observed flow and level data.

## IT requirements

A common misconception about operational systems is that very high specification hardware is required, this is not the case. In this study the machine specification that was identified to be used for the pilot study was:

- Windows Server 2008 (x64bit)
- Dual Core, Intel ® Xeon 2.67 GHz
- 8Gb RAM, 1TB HD

The live data feeds (radar and level) were harvested from the UKMO's ftp site and from Technolog's website via ruby scripts. These ruby scripts were run using the automatic task functionality built into FloodWorks.

## Challenges encountered during the set up

The majority of the challenges faced during the pilot set up were IT related. The primary issue was ensuring that communication with the IT department was clear and that they understood what was required. These included details about the emailing of alerts, ftp access, hardware purchase and software installation. For example, Thames Water's IT department were worried about letting 3rd party data to be pushed inbound through their firewall, so instead the data had to be pulled from an ftp site. There were also some unforeseen problems that were software specific. These included issues with regards the size of the InfoWorks CS model being imported into FloodWorks. This had implications upon some of the hard-coded array sizes. The ability to turn off the automatic initialisation of the hydraulic model was required to allow the models to hot start from the results created from a previous simulation. Another software related challenge which quickly became apparent due to the number of data streams being handled, was that more efficient reading process of forecast data was required.

## Launching the Operational System

The hardware required for the operational system was set up in the Thames Water Server Room at Reading STW. Copies of FloodWorks Event Manager, which is the operational interface, were installed in Reading as well as at the Waste Operational Control Room, which was situated in a neighbouring office in Reading. An example of FloodWorks Event Manager is shown below. A mirror system was also installed for the first year after the system launch in Innovyze's offices in

Wallingford. This allowed Innovyze to easily and quickly support the operational system and identify solutions when problems arose. The operational system launches two simulations, one on the hour and one on the half hour. This was because the Olympic model required a combination of models to cover all the venues and principal routes across London. This also ensured the most efficient use of the hardware.

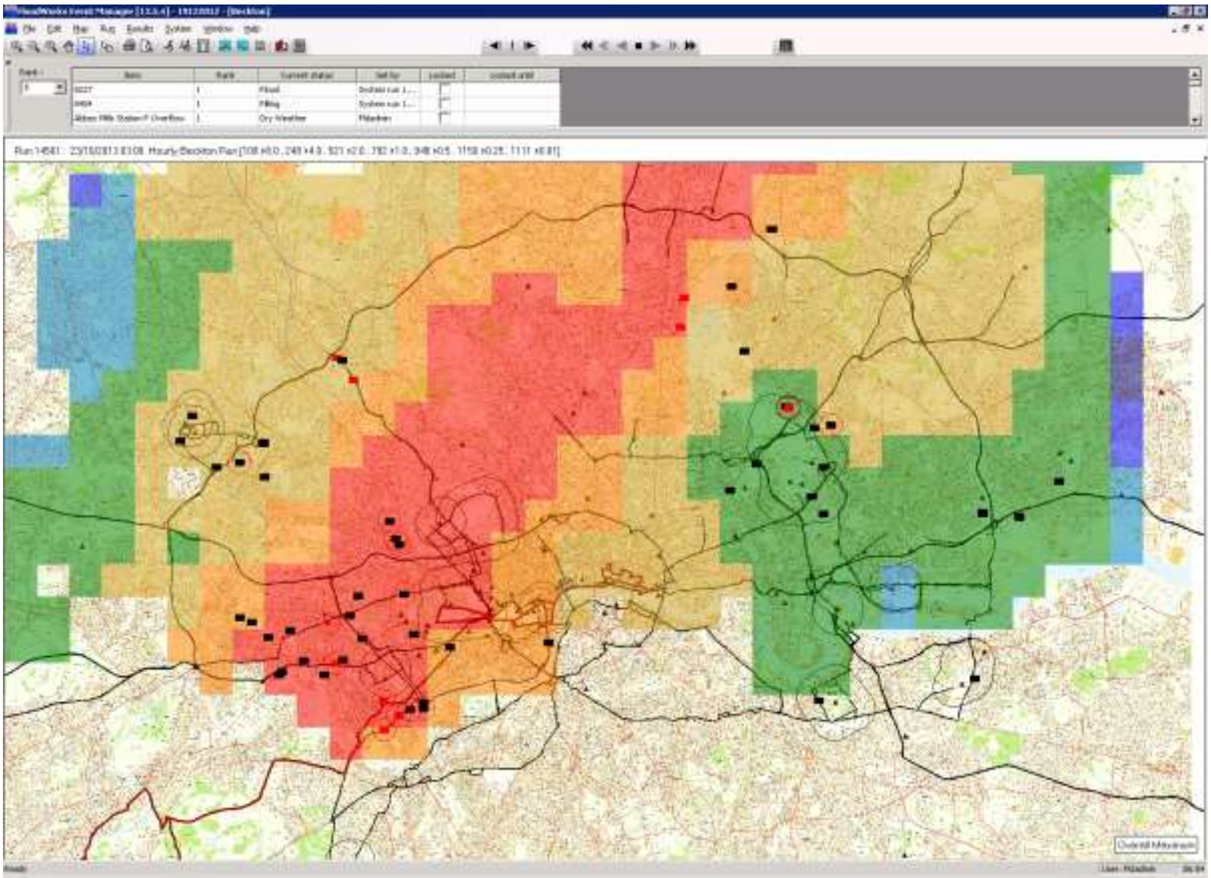


Figure 2 - FloodWorks Event Manager

## Initial feedback

Once the system was launched its performance was, on the whole, very good. A number of issues did arise regarding server space and run times but these were quickly addressed, either through software fixes or through system configuration changes.

Alerts were defined so that if flooding was predicted at key locations, or if one or more CSO's of interest were predicted to spill, then appropriate staff could be alerted by email. A standard set of documents were prepared for the operations staff outlining what should be done in the event of a particular alert being generated.

Until now the main use of the system has been real-time calibration of the underlying hydrologic and hydraulic models, along with the prediction of flooding at a few key sites. When flooding is predicted, Thames Water has been able to respond. Whilst there have been many false alarms, partly due to the conservative set up of the model which were in the most part related to operational settings from the 2008/9 verification that are no longer current, and partly to the inaccuracies in the forecast radar rainfall, the feedback from customers has been very positive.

Thames Water has been seen to be proactively dealing with these on-going flooding problems. The system was extended ahead of the Olympic Games. Additional alarms were created to inform the operations staff if the system was predicted to surcharge near the sporting venues and principal routes. Due to the generally dry weather during the Games period, very few alerts were generated. However, the system was in place to deal with events had the wet summer continued.

## Continued assessment of the operational System

The system has been operational long enough for a number of wet weather events to have been recorded, and alarms generated. Therefore, in order to quantify how well the operational system is performing, Thames Water has been comparing when FloodWorks has generated an alarm against the level/depth logger data (see appendix 1). This analysis is carried out on past simulations.

In general, the model performs well. The model performance was good for December 2012 and January 2013. A number of spot checks were carried out from February 2013 through to June 2013 and these were also in general agreement. The comparisons became less reliable over July/August 2013 when convective summer storms passed over the catchment. This is not greatly surprising as convective storms are not easy to forecast and the quality of the forecast radar rainfall is lower, particularly in the 3 to 6 hour forecast period.

The analysis also looked into how far into the future the alarms were triggered. It was found that alarms occurring 3-6 hours into the forecast period tended to be less reliable. However, alarms within the 1-3 hour range tended to be much more reliable, particularly for steady frontal rainfall. This is important when considering the site response times. Many of the alarm points had a 1 to 2 hour response time and so alarms raised 3-6 hours out, although not generally deemed to be reliable enough to respond to, were useful in preparing the business to possible forth coming events.

The original pilot study covered the Beckton catchment only. The operational system was subsequently extended to cover a small part of the Mogden catchment (90km$^2$) and all of the Deephams (250km$^2$) catchment. The section of the Mogden catchment which was included in the system lies to the northwest of the Beckton catchment and Deephams to the north (as shown in Figure 3 below). These two catchments are run together as a single FloodWorks network. Like the Beckton catchment the Deephams/Mogden network runs hourly, but the simulations are run at half past the hour.

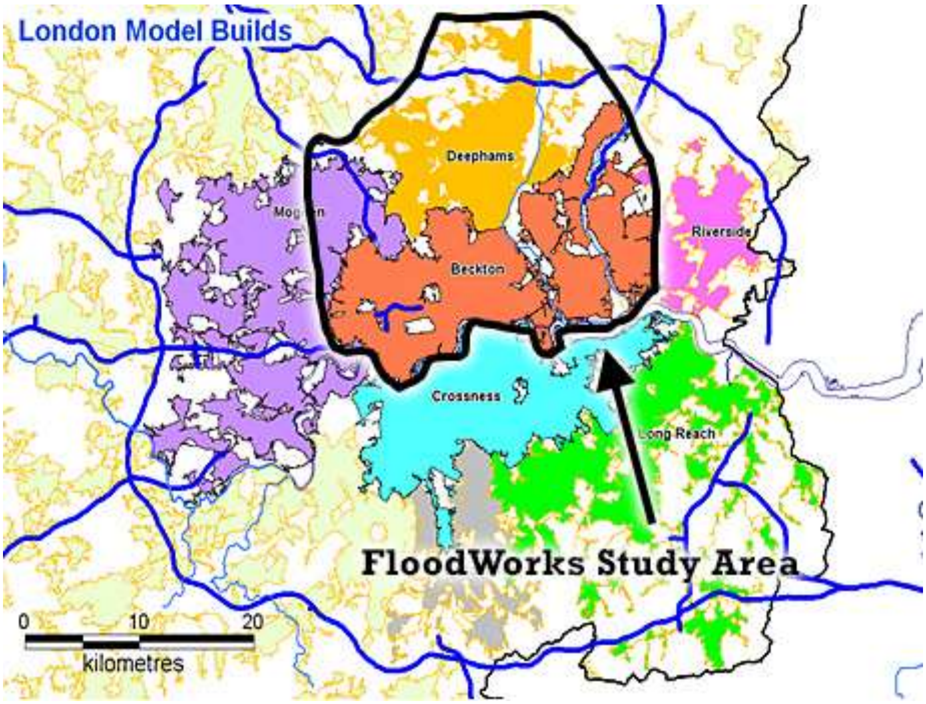



Figure 3 Catchment locations

## Looking to the future

The future plans for the FloodWorks system are to expand the analysis to review non-hydraulic causes of flooding, such as blockages, pumping station failure and CSO spills. This is because the sewerage networks run in dry weather flow mode for 95% of the time and it is the day to day running costs that offer the greatest potential to develop efficiencies. Looking at future investment plans the opportunity to undertake long-term testing network enhancement strategies to fully explore whole life costs is another area that Thames Water keen to investigate with FloodWorks. It is likely that Thames Water will look to continue with the primary task of improving the understanding of how the networks are operated on a day to day basis and making sure that the models reflect this. The move to use FloodWorks to monitor changes in levels around past non-hydraulic flooding and pollution incidents is potentially a huge area of interest particularly after the adoption of an additional 40,000km of private sewers in October 2012 This should help improve scheduled maintenance programmes and enable Thames Water to respond before repeat incidents occur.

## Conclusions

The FloodWorks system for the Beckton catchment has provided some very interesting results and improved Thames Water's understanding of the complex operation of this very old and complex sewerage network. The network model for this catchment has also been enhanced by the move to long term collection of live sewer level data, the on-going analysis of historic radar rainfall data and the on-going calibration that has been carried out.

The initial study aim of proving that live data sets could be brought together and models run in near real time has been a complete success and has proved albeit on a limited scale, that it is possible to forecast how the network may operate in the near future of 1-3 hours.

Forecast sites do have to be carefully selected in terms of potential site intervention and there has to be a high level of confidence in the model. There also has to be a significant commitment in terms of setting up a dedicated team to receive, analyse and act on alarms as and when they are raised by the FloodWorks system. The latest set of site telemetry data will link into the Waste Operations Control Centre and so it is planned that the alarms will also be routed through this centre. This means that the ground work carried out by this study will be adopted into a more permanent operation system.

Looking to the future, it is Thames Water's intention to move from utilising the InfoWorks CS and FloodWorks platforms to InfoWorks ICM and ICMLive. The FloodWorks model has already been transferred into a working ICMLive model in Innovyze's Wallingford Offices and testing is underway to ensure that the newer ICMLive product does not suffer from any of the issues encountered during the Thames Water FloodWorks pilot study.

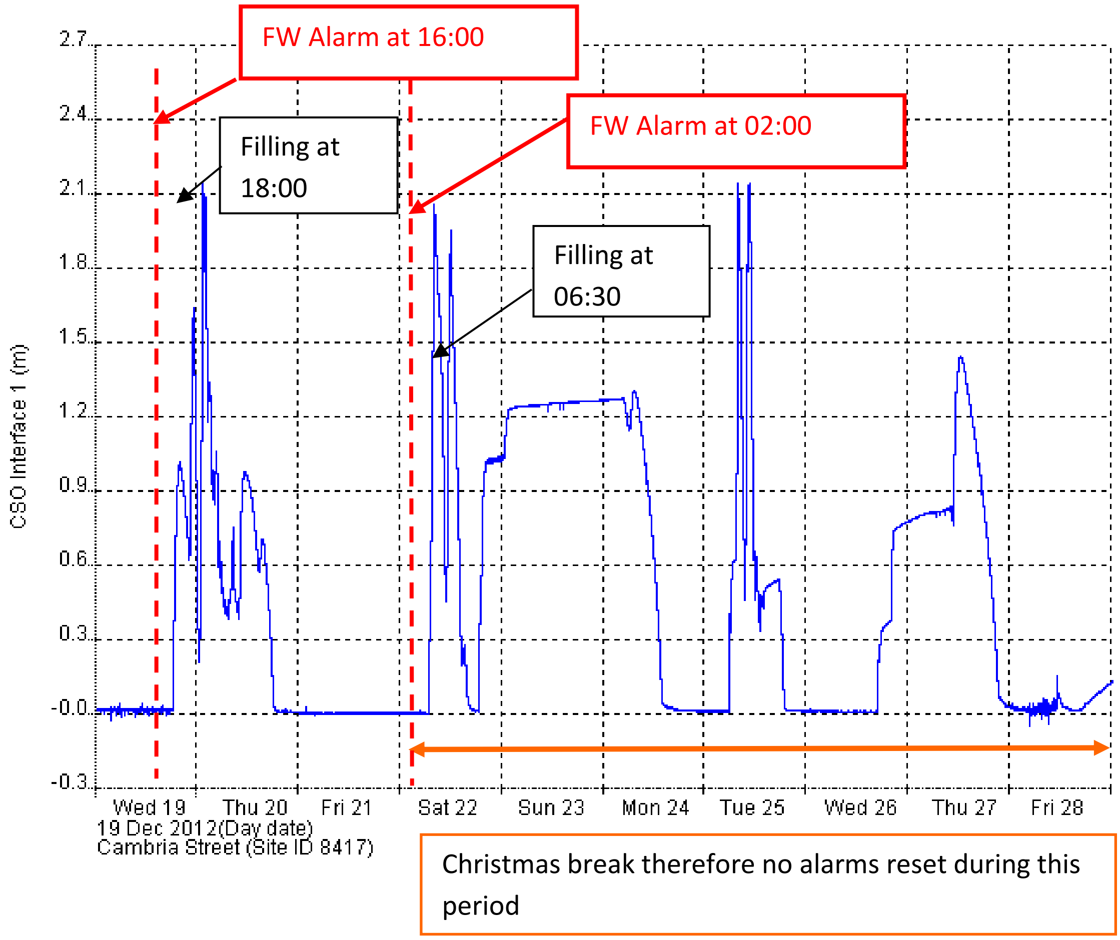
# Appendix 1

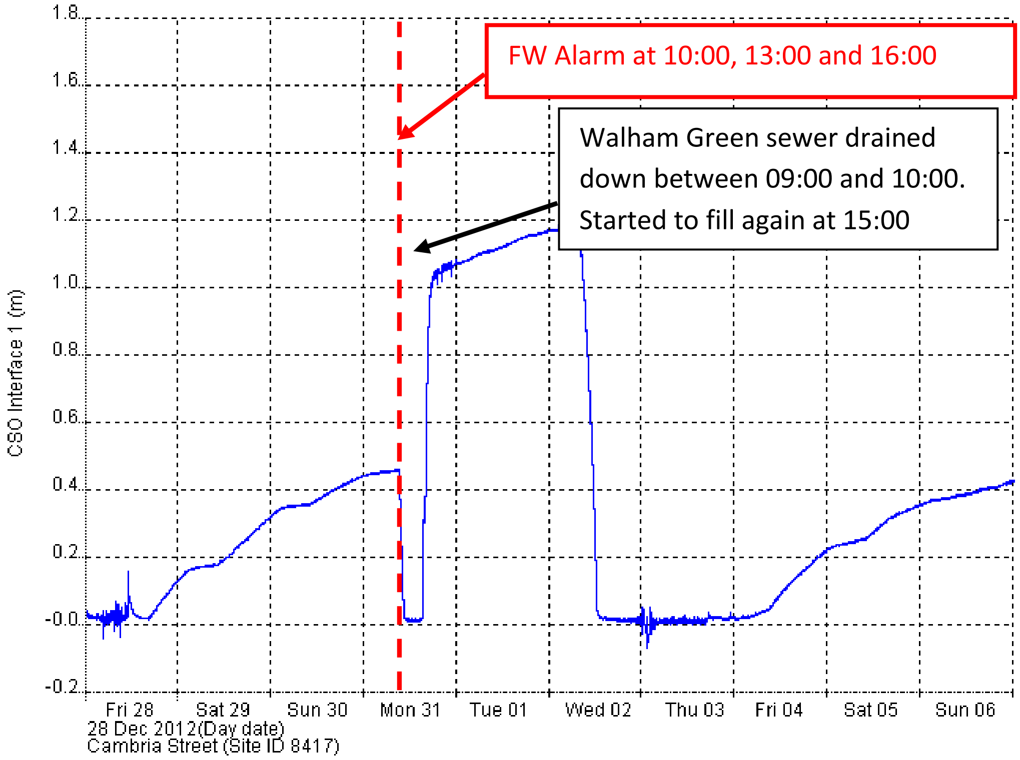
Comparisons between observed level data and FloodWorks Alerts

The following plots show two different periods of time at two different locations. The first location is the Walham Green Storm Relief Sewer. The first plot shows that two alarms were triggered prior to the Christmas break. The system was not reset after the second alarm, as this is an offline example and the modelling team were resetting the alarms. Due to the Christmas break, these alarms were not being reset. This explains the period during which incidents occurred but no alert was triggered.

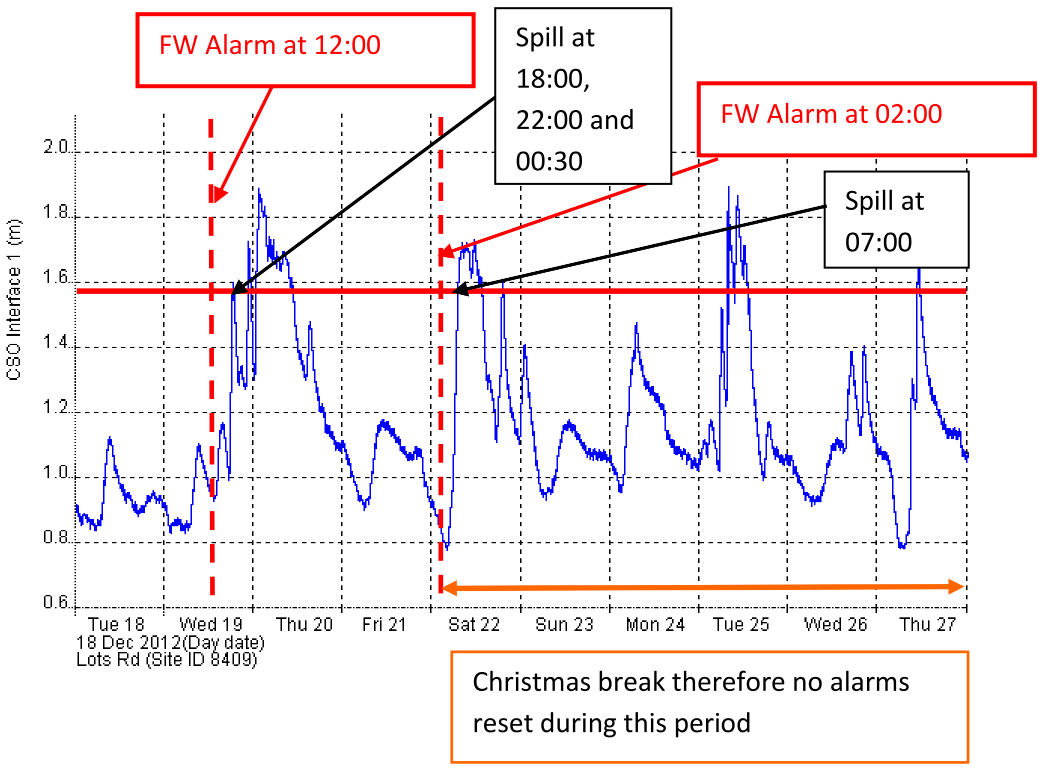
The second location shows the levels in the vicinity of one of the CSOs spilling to the storm relief sewer.

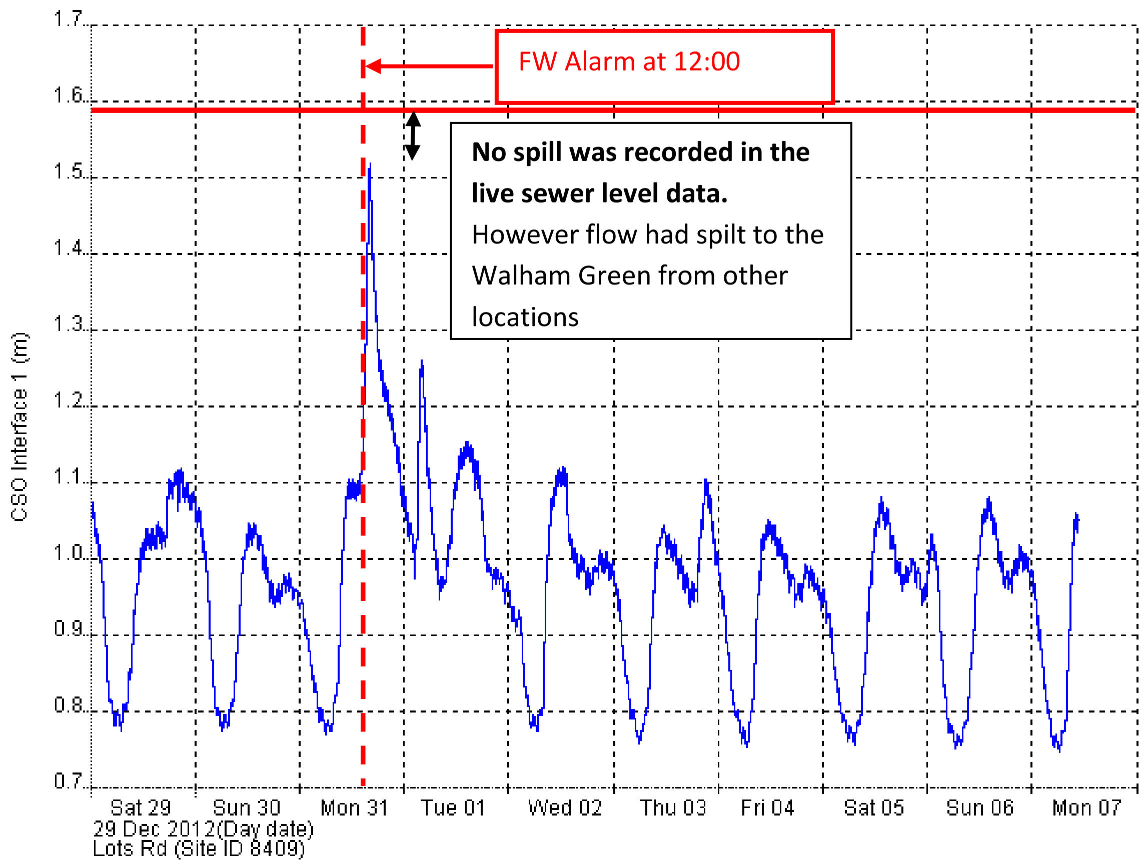
**Cambria Street – 8417** – Walham Green Storm Relief Sewer

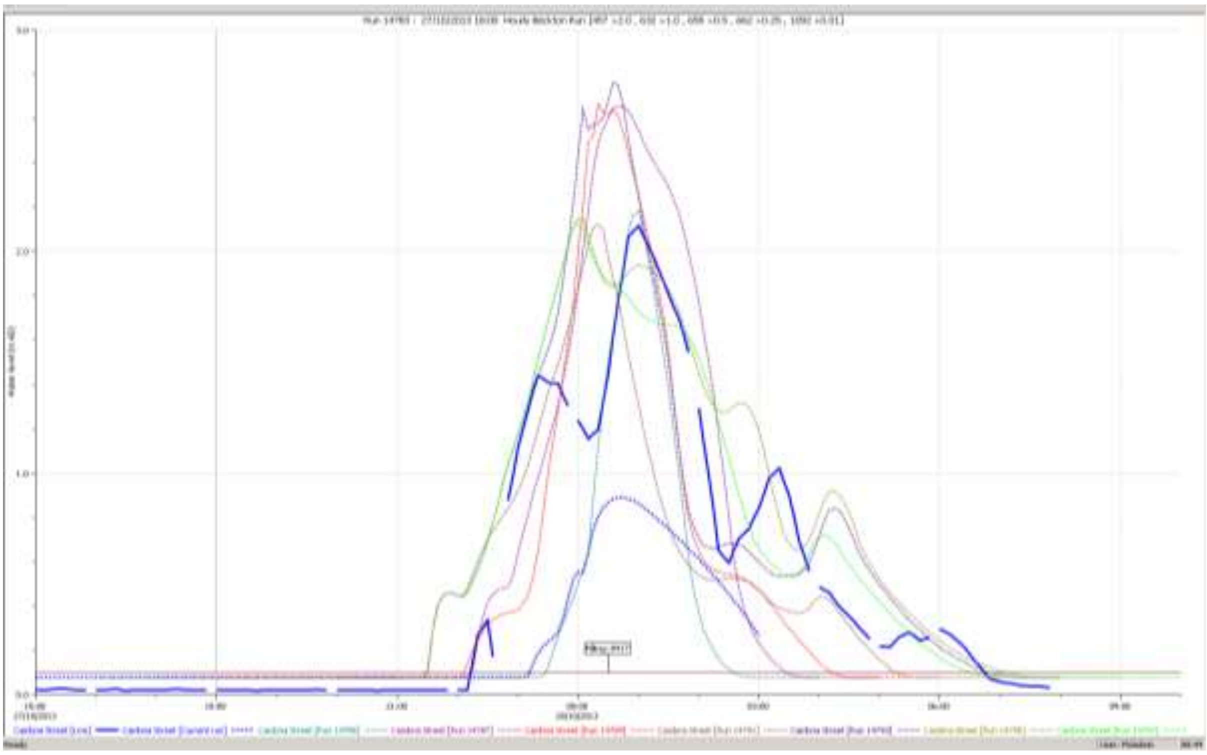





## Lots Road No90 – 8409





This graph shows the 7 modelled simulations from 18:00 through to 00:00 for the severe weather event that passed over the catchment on the evening of 27/10/2013 to the early hours of 28/10/2013. The dark blue line is the observed level data from the storm relief sewer. The predicted spills match the timing, peak and shape of the actual storm event response very well.