Planning and Managing a Large Flow Survey – Experience in Upper Don

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Introduction

During AMP5, Clear was commissioned by Yorkshire Water to prepare a Drainage Area Planning (DAP) tool to investigate the performance of its assets, serviceability in the sewerage network and the potential for future development for each Drainage Area Zone (DAZ) within the Upper Don catchment of Sheffield. This area contains 20 DAZs covering approximately 25,000 Ha with a total population of around 430,000. The catchment contains four wastewater treatment works (WwTWs) but over 99.9% of the population is served by a single works, Blackburn Meadows.

Clear was also asked to provide a modelling tool for the assessment of intermittent discharges as part of the Water Framework Directive (WFD) water quality driver on the River Don downstream of Blackburn Meadows WwTW. The outputs of this study would be required by June 2012, well before the outputs from the DAP studies.

The Upper Don sewered catchment covers approximately 200km² and the topography varies across it; some parts are very high and steep whilst others are flat and low. The catchment contains 170 operational CSOs, 63 pumping stations, 92 detention tanks, 1207 dual manholes and 2090 bifurcations. There is a history of sewer flooding due to hydraulic overload and other causes.

Blackburn Meadows WwTW accepts flows from three main high level trunk sewers and the low level Don Valley Intercepting Sewer (DVIS).

The DVIS was constructed between 1970 and 2000 to intercept flows from numerous CSOs along the River Don to improve water quality. It is approximately 10km in length with a maximum pipe size of 5.1m diameter at the downstream end; it is approximately 25m deep at its deepest. The DVIS was originally intended to carry storm flows only but it now carries the majority of DWF down to Blackburn Meadows where it passes through the 6xDWF overflow before it is pumped up to treatment. Flow is transferred from the high level trunk sewers to the low level DVIS via 32 large bifurcations.

Modelling Strategy

In order to produce the outputs required for the WFD study within the tight programme constraints, a simplified catchment-wide model would be produced with detailed modelling focused around the trunk sewers, the DVIS, Blackburn Meadows WwTW and at any other major ancillary structures around these assets. The more detailed DAP models would be built and verified in sequence alongside the WFD model.

In order to expedite the modelling phase, the catchment was divided into eight separate 'hydraulic sections'. In most cases, these sections could be described as being relatively hydraulically independent (or at least easily separated) from any other section. However, the area in which the DVIS is located, dubbed the 'CZone' (or 'complicated zone'), spans several hydraulic sections and receives inputs from all other surrounding sections.

Unusually, the first phase of the flow survey would be focused on the CZone in order to deliver the complex WFD outputs within the required timescale, with the outlying, more strategic, DAP studies delivered later. This paper details the challenges faced, knowledge gained, and innovations developed in planning, managing and running this flow survey.

Flow survey strategy

CZone

Flow monitor locations were planned around the trunk sewers, the DVIS, Blackburn Meadows and any other major ancillary within the WFD zone of interest. 214 flow monitoring locations were identified in this way.

In order to use the monitors as efficiently as possible, the DAP monitors within the CZone would be installed along with the WFD sites. The data for these sites would not be required for WFD purposes, but would be used later in the more detailed DAP studies. An additional 237 DAP flow monitoring locations were identified, meaning that 451 monitoring locations would be installed simultaneously and run as one CZone flow survey.

201 rain gauge locations were identified across the entire Upper Don catchment. All of these RGs would be installed as part of the CZone flow survey to ensure that rainfall response was well represented.

The CZone flow survey was undertaken by IETG and managed by Clear on behalf of Yorkshire Water. The survey started on 28th February 2011 and had yet to be fully terminated at the time of writing.

DAP

An additional 1,100 flow monitor locations were planned for the DAP flow surveys at flooding and pollution locations; operational issues; at any ancillary; on trunk sewers; and at strategic bifurcations.

These would be installed in sequence, by DAZ, following the completion of the CZone flow survey. Should monitor availability allow, all 1,100 DAP monitors could be installed at the same time.

The same rain gauge locations that were identified for the CZone survey would be used for the DAP surveys, though they would be installed on a DAZ by DAZ basis alongside the DAP flow monitors.

The outlying DAP flow surveys are scheduled to commence in late 2011.

Challenges

Planning the survey

Rain Gauge Planning

Although 201 rain gauge locations were identified for the CZone survey, not all of these sites would be required for the following DAP surveys. 31 long term rain gauges across the catchment were selected to remain installed alongside the long term flow monitors and subsequent DAP flow surveys. Once the CZone survey was complete, all rain gauges apart from the long term sites would be removed and then the rain gauges within each hydraulic DAP section would be re-installed in the same locations alongside the DAP flow monitors. Clear sent out letters to the affected customers early on in the CZone phase explaining the situation to maintain customer relationships and goodwill. This is a simple task, but one that is often forgotten and one that can have a significant impact on the management of a flow survey, particularly where survey extensions are necessary.

Flow Monitor Planning

Planning flow monitor locations was done as a desk study exercise but in such a complex system with so many potential hazards, it was essential for Clear and IETG to involve Yorkshire Water staff as early as possible. Before finalising flow monitor locations, every effort was made to consult staff regarding problem or key customers, operating regimes, trade discharges, pollution, flooding, clean water discharges and any other significant discharges within the system. This proved to be a valuable exercise because as well as highlighting a number of hazards, the additional catchment knowledge input highlighted particular areas of interest that had not otherwise been documented.

Similarly, early discussions were held with Sheffield City Council, as the local highways authority, to explain the scope, size and benefits of the surveys and the subsequent studies. This proved to be crucial in managing the traffic management aspects of such a large flow survey programme.

Flow monitoring equipment

The flow monitoring equipment that was used to conduct this flow survey was highly innovative and very new to the industry, particularly regarding use on such a large scale. This emerging technology presented challenges to both IETG and Clear.

As the flow monitors were complicated to install and required detailed configuration once installed, the installation process was much slower than it would have been using conventional equipment. On average, four monitors were installed per night per site crew.

The flow monitors consist of two sensing heads – one on the invert and one on the soffit of the pipe, and a logger box which holds the battery, data logger and wireless modem. Each of the sensing heads houses at least three different sensors (i.e. for depth or velocity) and each of these sensors record to a different data 'entity'. Just one depth and one velocity entity would be provided to the Consultant so the onus would be on IETG to deliver the 'best' data. Figure 1 shows a typical installation of the sensing heads and the data entities available.

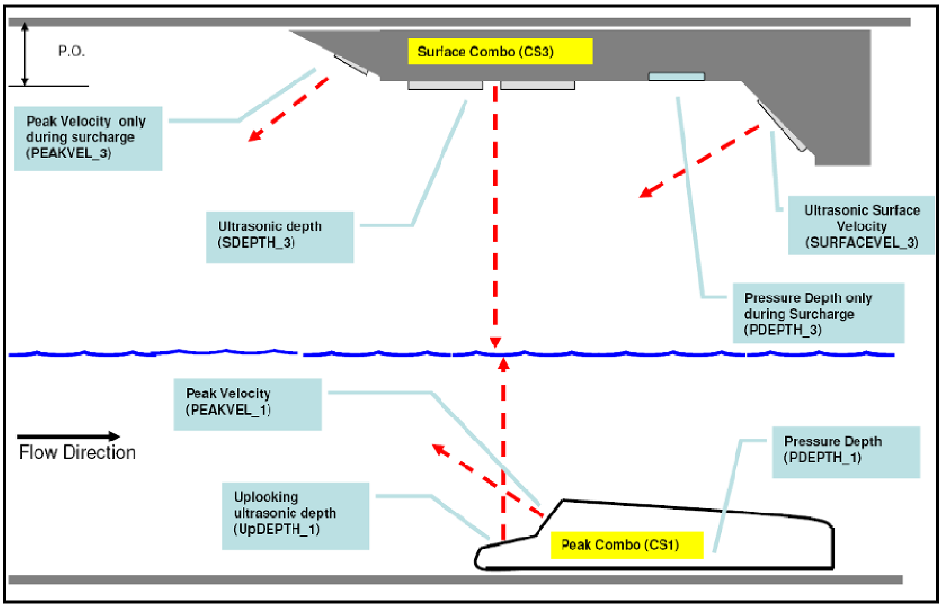

Figure 1 – Typical sensor configuration.

The recorded flow data was uploaded to IETG remotely, via the digital telephone network, at the majority of sites hence the sensors relied much more heavily on self-checking and remote adjustments and less on weekly checks, adjustments and downloads by site crews. In general, sites would only be visited by IETG if maintenance was required or a specific request was made by Clear during the weekly assessment of data. This placed a high importance on keeping a record of exactly what data was returned from each site visit so that it could be referred to later, as a site may only be visited a couple of times throughout the entire duration of the survey.

The absence of weekly site confirmations by the Contractor meant that assessing the individual sensor performance was a challenge. The interim data assessment focused on assessing flow balance between monitors and the loss of data that would prompt a site visit by IETG. More reliance was also put on looking for consistency in the data (i.e. comparing it with the previous weeks). If any anomalies were suspected in either case, then an IETG visit was requested to address it as quickly as possible. More importance was put on thorough physical site checks on the infrequent visits by IETG. The emphasis was also put on IETG to deliver the correct data 'entity' first time; a particular challenge in instances where the entities conflicted significantly.

With several different entities to choose from, the main challenge here was understanding exactly what was possible with the monitors (i.e. the windows in which they seem to record most accurately) and the quality of data they record. This was a steep learning curve with data from 450 monitors needing to be assessed weekly.

Survey-specific Difficulties

Installing in the DVIS

In any large and complex system, there will be areas of the network that pose a risk to anyone entering the assets. In the case of Upper Don, the biggest challenge was developing a safe working procedure for accessing the DVIS – a feat not achieved by anyone else since its completion.

Most of the manholes on the DVIS are at least 20m deep and they were constructed with several landings in them to provide working access to the invert. Many of the manholes also contain large vortex drop shafts, at a high level, with no protection to prevent somebody from falling down them. The DVIS manholes surcharge to two or three metres below cover level in large storm events and levels can rise very quickly (e.g. within 30 minutes).

Due to the high risk of entering these sites, large safety grills are present over the main shaft to prevent straight-down access. Investigations on site also revealed that many of the manholes did not actually contain ladders past the first landing and that some of the ladders that were present were thought by Operations to be unsafe due to becoming weakened through constant submersion.

A specialist access team was employed to install all sites on the DVIS at significant extra cost. Access was achieved by using an A-frame and specialist climbing equipment and the work could only be undertaken during a sustained period of dry weather. The special rope access team (external to IETG) were trained by IETG in how to install the flow monitoring equipment and once the flow monitors had been installed a CCTV camera was lowered into the manhole to inspect the installation.

Two monitors, each with two sensing heads on, were installed at each site in order to provide some redundancy should the primary monitor fail. This was done to mitigate against having to regularly access these sites for maintenance, thus reducing the potential for greater health and safety risk and costs to be incurred. A total of 15 sites were installed with 'doubled up' monitors on the DVIS.

Highway Restrictions

There are many restrictions on the highways of Sheffield with a high proportion of roads being traffic sensitive, requiring traffic notices or night works. In order to minimise the requirement for serving traffic notices, the majority of the site work was completed between the hours of 22:00 and 06:00. Good communication and coordination between Contractor and Consultant was required to ensure efficient use of the traffic notices, which expired after 24 hours, and minimal disruption to the survey. In total, it is estimated that over 600 different traffic notices will have been served by the time the CZone survey is complete.

Well before any site work commenced, a meeting was held between the Highways Authority, the Contractor, the Consultant and the Client to establish a healthy working relationship and to discuss any special requirements any of the parties had.

Cold Winter and Liberal Democrat Conference

The UK experienced the coldest winter for over 30 years and many parts suffered heavy snowfall. Sheffield was no exception with up to 15" of snow in places falling in December 2010. This left many of the sites inaccessible or unsafe to work on for two weeks and caused a significant delay to programme.

The Liberal Democrat party conference was also held in the centre of Sheffield in March 2011. This placed additional, very stringent, security restrictions on many of the highways in the study area and basically prevented any work taking place in the affected areas for 10 days.

Extended Installation Period

Despite IETG assigning four installation site crews to this survey, for the reasons discussed above the installation period was extended to three months which was much longer than had been anticipated. One of the biggest challenges was keeping track of exactly what equipment had been installed and where it had been installed. Good communication between IETG and Clear was required throughout the installation period, this involved regular transferral of information (photos, installation sheets etc) and daily conversation between the parties. It was necessary to maintain an organised filing system to hold the relevant data for each site for access throughout the project.

Flow Survey Data

Once the CZone survey was under way (451 monitors), the flow survey data was delivered to the Consultant in eleven discrete 'catchments'. This was done to ensure that sufficient resources could be allocated to the processing of the data on the Contractors side. As well as three or four crews on site, IETG had six or seven different data analysts working on the project at any one time along with two supervisors and a project manager. Together, they were responsible for processing and delivering the raw data to Clear on a weekly basis. The data was also assessed by the Consultant and this was a full-time job for three modellers at Clear. Another engineer also spent a day or two per week assessing the data and managing IETG.

2011 saw the driest spring for over 100 years in the UK. Whilst a significant amount of dry weather flow data was recorded, storm events were few and far between which placed increased pressure on both the Contractor and Consultant to ensure that the monitors were working at all times, to reduce the chance of missing the event when it did occur. This required constant dialogue between all parties to ensure that any issues (data quality, access, H&S) were resolved as quickly and effectively as possible.

Despite the challenges faced by this large survey, data capture was good - even in the DVIS where flows up to 20m deep were successfully recorded (i.e. both depths and velocities recorded). Due to the steep nature of the catchment, many of the flows studied were very fast in both DWF and storm conditions. The fast flows were recorded well in a number of locations, in both deep and shallow flows. Velocities of over 5m/s were well recorded in storm conditions at many sites. Velocities upto 3m/s were successfully recorded at less that 50mm depth in DWF.

Survey Termination

It took 26 weeks to capture three WaPUG compliant storm events; this was far longer than the anticipated 14 week flow survey period, due mainly to a prolonged dry period in Spring.

A termination report was completed showing the data quality at each site for each storm event and this was used to instruct a partial termination of the survey as at the end of the process, it was found that not all sites had recorded sufficient data to be removed. This was a very complicated exercise with over 470 sites to consider (including monitor relocations) as many of the sites were dependant on, or necessary for, at least one other site (i.e. a monitor and its dependants would all have to be working together to get the required data). At this stage, flow monitors were clustered in to one or more groups. These groups were determined by the purpose of the flow monitors and were used to ensure that monitors were not removed where they may have been required to be left in with another site (e.g. upstream and downstream of a CSO).

The initial termination process took Clear a week to assess and confirm and then a further two weeks for the recommendations to be audited by an external consultant.

Benefits of a large survey

Data Redundancy and Self-checking

Detailed, high resolution, monitoring of ancillaries allows a thorough understanding of the assets and provides confidence in the verified model. It also provides some redundancy which may serve to reduce the length of the survey when a monitor fails. A simple example in this survey was a bifurcation to the DVIS that had monitors installed on the incoming, continuation and spill pipes. The monitor on the continuation pipe failed for two out of the three WaPUG compliant storm events so in this case, if the monitor on the spill from the bifurcation had not been installed then the monitors upstream and downstream of the bifurcation would have had to remain installed to capture a fourth WaPUG compliant storm event. The planned redundancy was in place however; so all three monitors were removed after three WaPUG compliant storm events as sufficient data had been captured to understand the operation of the bifurcation.

With a ‘high resolution’ of monitors there is a greater capability for the data to ‘self-check’. This improves the process of interim data assessment and verification as incorrect data can stand out when looking at flow balance. This is particularly applicable when comparing dry weather flows as one could expect monitors upstream and downstream of CSOs and bifurcations to record the same flows.

Thanks to the amount of data available for flow balance checks, Clear were quickly able to identify where the potential problems were with data measurement and direct IETG to focus their time and effort on these sites. This would help to resolve any possible difficulties before the data was used in verification.

Rainfall Variability

High resolution raingauge siting allows for significant variation in rainfall to be recorded with confidence. In such a large catchment it would be difficult to achieve full compliance with the WaPUG criteria across all rain gauges. In one particularly spatially variable storm event, depths ranged from 0 mm to 42.1 mm and maximum intensities ranged from 0 mm/hr to 168 mm/hr. This storm caused flooding in parts of the catchments, whilst other parts remained completely dry.

Overall System Performance

Despite the challenges associated with planning and running such a large flow survey, there are many significant benefits for the Client that makes it worthwhile. Simultaneous catchment-wide coverage gives an overall picture of system performance and may highlight operational relationships that could otherwise be overlooked.

Ramadan

On 1st August 2011 a number of overnight discharge spikes appeared at seemingly random locations all over the catchment. They varied in magnitude from 1-2l/s to 60 l/s. These discharges were very consistent and continued to occur daily.

"Ramadan is the ninth month of the Islamic calendar, which lasts 29 or 30 days. It is the Islamic month of fasting, in which participating Muslims refrain from eating, drinking, smoking and sex during daylight hours and is intended to teach Muslims about patience, spirituality, humility and submissiveness to God." [1]

Ramadan starts on 1st August each year and, after some research, it was found that the observed night time flow peaks coincided approximately with the official fasting start times. On 1st August, fasting started at 03:22 [2]. Upon closer inspection of the data, it was also noticed that there was a second evening peak that correlated with the fasting end times. It can also be seen that the normal morning and evening peaks become flattened during this period.

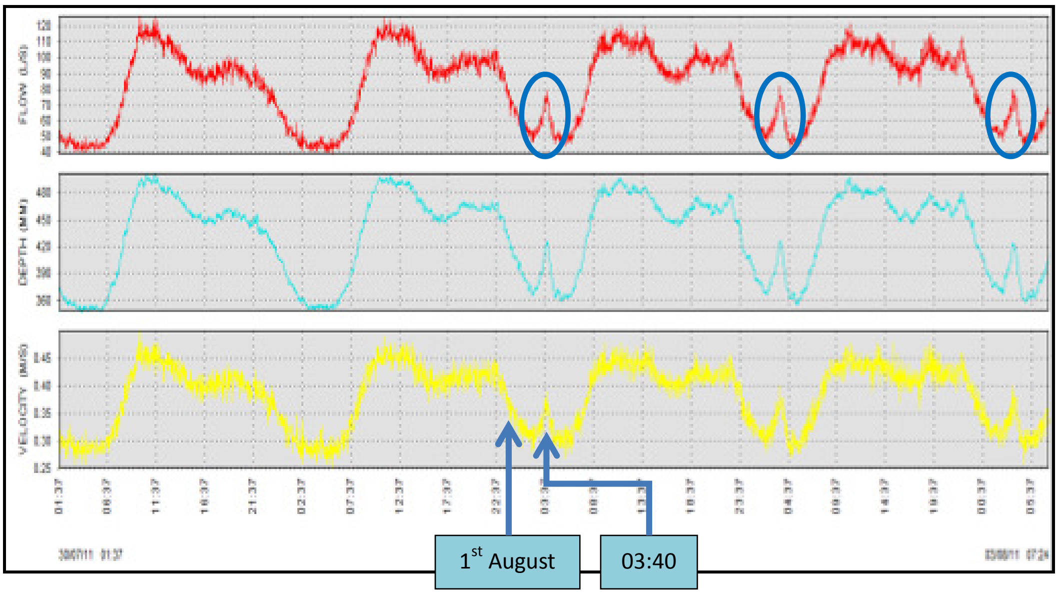

Figure 2 – Ramadan flows.

Ramadan ended on 30th August this year and the flows in the sewers returned to normal on this date.

This change in social behaviour has a significant impact on flows in the sewerage system and a specific wastewater profile would be required in verification to represent this behaviour.

Recommendations to Others

Early Consultation

Hold meetings with any relevant party even before planning flow survey locations. This includes Highway Authority, operational staff, trade waste and clean water departments, pollution and flooding teams. Ensure that all pertinent information is recorded effectively and used in consideration of flow monitor locations. Open up dialogue and engage with stakeholders to gain buy-in and understanding.

Comprehensive Planning & Pre Survey

Ensure all flow monitoring locations are pre-installed before installation begins. There should be no exceptions to this rule.

Data Redundancy

Detailed monitoring of assets will provide some redundancy in the event of monitor failure. This may serve to reduce the length of a survey and will improve model confidence.

A high resolution of rain gauges will allow rainfall variability to be accurately recorded and accounted for in verification. This is particularly applicable to large flow surveys.

Innovative Technology

The quality of the data recorded throughout this survey has proven the value of using new monitoring technology in many respects, though the increased complexity of using multiple sensors has led to challenges in data processing and handling, particularly in the early stages.

As there is not the luxury of weekly site checks by the contractor, due to the self-checking of the monitors, it is essential that monitor performance is checked thoroughly whenever a site is visited.

Communication

Establish a good line of communication between Consultant and Contractor before the survey starts. Devise a method of recording key dates and information on flow monitor locations. Responsibilities should be agreed and clearly defined before any work is completed.

Data Handling

Organised filing of pre-installation data, installation data, flow monitor location data and interim checks is essential and will help to keep track of the survey. This information is particularly valuable for reference in verification later.

Standardised Documentation

If possible, the processes described above should be recorded in a single, standardised document that serves the needs of the Contractor, Consultant and Client. This ensures that all information is available to all parties and should serve to remove any possible disputes and associated costs that may arise throughout the survey.

References

[1] Wikipedia – http://en.wikipedia.org/wiki/Ramadan

[2] http://www.ramadantimetable.co.uk/