DERIVING FLOWS IN A WASTE WATER SYSTEM FROM SCADA DATA

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ABSTRACT

Traditional extensive monitoring campaigns ensure collection of flow data but tend to be expensive and can be unreliable. Tauranga City Council and DHI have worked together on a novel methodology for deriving flow information from water levels recorded at waste water pump stations. This methodology produces consistent, comprehensive records at a reasonable cost in a short time.

Most urban utilities today collect large amounts of real time data that is captured by sensors and transmitted over a telemetry network. This data informs real time decisions in network operation, including alarm monitoring and emergency response to incidents and failures, yet these same utilities are often short of reliable flow data for model calibration and desktop analyses (I&I assessment or pump station performance analysis in particular).

Many SCADA systems have a built-in flow calculation routine, but often with severe limitations (e.g. unreliable in wet weather event or submerged inflows). The DHI flow derivation methodology overcomes these limitations by combining the information collected by SCADA with the network asset data, pump capacity curves, operational data and basic flow hydraulics. The methodology was verified against historical flow metering campaigns. Each derivation case was also “calibrated” against SCADA derived flows where these flows are known to be reliable.

The process allowed TCC to extract a comprehensive historical record of inflows into the pump stations. This has proven beneficial and cost effective to all involved in the waste water system operations, maintenance and planning.

KEYWORDS

SCADA data, modelling, pump station inflows, flow derivation

1 INTRODUCTION

Using SCADA (Supervisory Control and Data Acquisition) as a tool in operations of waste water networks is widespread in NZ, especially where significant pumping is present. While the main objective of the SCADA is to support daily and emergency operations of the network by operators, an alternative use of the collected data has been investigated and trialed frequently. This was especially evident with the onset of modelling as a standard investigation tool.

The usefulness of a model is very tightly related to the confidence in its ability to represent the real network and therefore can predict how network will respond to various scenarios. In order to ensure models are fit for a purpose, calibration and validation processes are carried out. The processes rely on high quality observed data being readily available. This is often not the case and lack of reliable flow data is very common.

It is widely recognized and accepted that direct flow monitoring is the most reliable method for collecting flow information in the system, when done correctly. The measuring accuracy is constantly improving and limitation on meter placement locations is reducing. The major obstacle for taking this path is often the high cost, especially because it is not a given that a monitoring campaign will deliver good quality results. Another potential problem is that there is always a possibility that the campaign will fail to capture high flows associated with lower return storm events.

When Tauranga City Council (TCC) embarked on executing their waste water modelling strategy in 2009, a small number of flow measuring devices were already deployed in their collection system. Magflows were installed on some trunk rising mains and a limited number of flow meters were used internally for short metering campaigns across the network. While the installed permanent measuring devices such as magflow can certainly be utilized, detailed model calibration does require more spatially accurate flow information it the model is to be used for local investigations. This is especially the case in catchments with diverse waste water loading (e.g. mixed residential, commercial and industrial catchments).

Tauranga City Council maintains high quality asset information, which provided excellent base for a model build process. It was however identified at early stage that a lack of flow information could be a crucial weakness as models could not be sufficiently verified and could result in lack of confidence. Models with low confidence are models not used.

2 OVERVIEW OF COMONLY USED FLOW DERIVATION TECHNIQUES

Since SCADA systems have become widely used for monitoring waste water networks, possibilities to use the collected data for flow calculations have been a topic of numerous discussions and papers. The appeal of a low-cost alternative to physical flow measuring is understandable given the high cost of properly executed monitoring campaign. In order to be suitable for flow calculation, SCADA system need to be able to log data with sufficient frequency (e.g. every minute) and off sufficient accuracy, ensuring the sensors are calibrated and maintained regularly.

Many SCADA systems have some ability for flow calculation either built in or available through scripting. Automated simple techniques present in most cases have severe drawbacks that limit their use, especially for modelling. The two main approaches to calculating flows utilize, either separately or in conjunction, changes in the volume of water in the wet well and volume of water pumped out (estimated or measured if a magflow is installed).

It is generally accepted that simple volume based techniques do not produce satisfactory outputs in cases of submerged inflow pipes unless a level to volume relationship is determined first, which is not an easy task. The same applies to all cases in which a prolonged high water level occurs, like during a rain event. Coincidently, the accurate information during the high flows is often the most valuable in various analysis of a system performance.

3 TAURANGA CITY COUNCIL SCADA AND FLOW CALCULATION

TCC uses HYDSYS, a software technology for SCADA, and large amount of data from the network is continually being logged. A simple algorithm within the TCC HYDSYS is routinely used for calculating inflow to pump stations, based on wet well water levels and pump operation status. The inflow calculation in HYDSYS is carried out during the period when wet well is filling and pumps are not pumping. The volume of water in the wet well between STOP and START levels is divided by the time passed between two consecutive starts of pumping cycle. The calculated inflow is therefore an average value during the wet well cycle that begins with emptying and ends with filling. The calculated flows suffer from severe inaccuracies and limitations and TCC staff was aware of this.

Before embarking on a high cost flow monitoring campaign, TCC wanted to investigate a potential to develop more advance technique that would generate reliable flows from SCADA information to be used for model calibration.

Analyses of the historical SCADA logs and HYDSYS calculated inflow data has relieved that derived flows using the existing algorithm are generally useable in cases of a simple pump station setup with identical duty and assist pumps and regular observed pumping cycles of less than 15min. In this case, conditional to the logged data being of a good quality, assumption of a gradually changing inflow makes the averaging technique acceptable. An example of a reliable HYDSYS flow calculation is given in Figure 1and a case where the calculation fails, for the same pump station, in Figure 2.

Figure 1: During regular pump operation and with good quality logged data, HYDSYS inflow calculation can be sufficiently reliable for most practical purposes including modelling. The data shown is for the PS52 in Matua catchment. The IL of the inflow pipe is at 1600mm therefore ensuring no backflow effect is observed in normal operation.

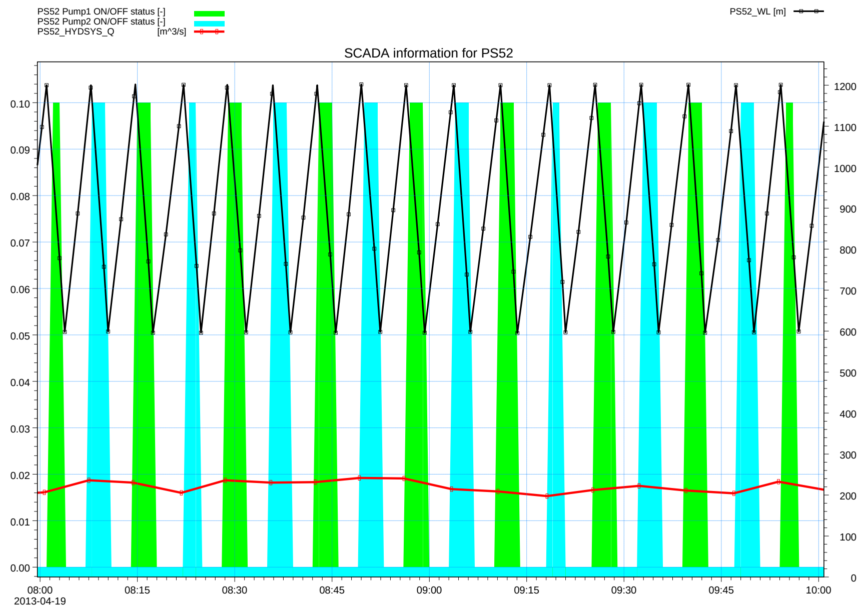
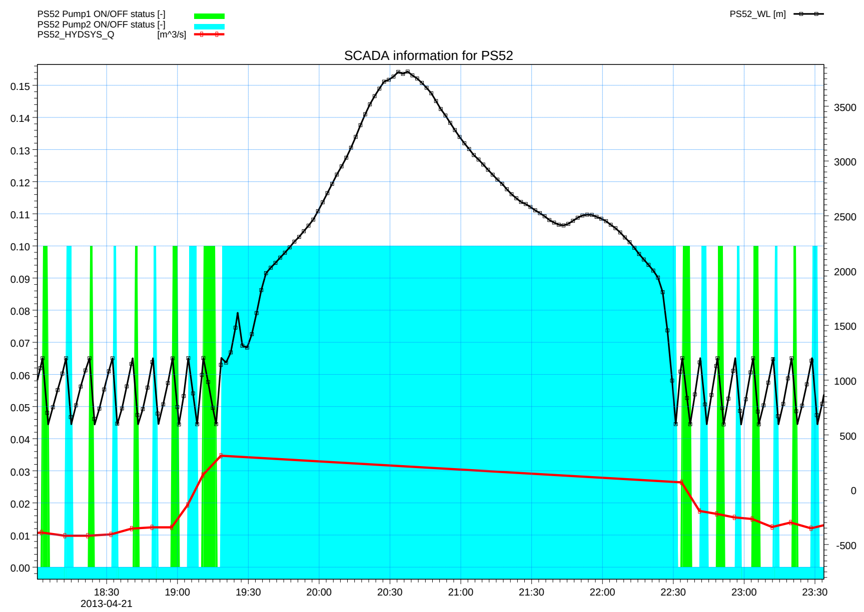


Figure 2: During a 3 hour rain event one day later at the same location, the HYDSYS calculation relying on regular pump start/stop cycle obviously can't reproduce the peak inflow and the total event volume is grossly underestimated.



In general, the TCC HYDSYS calculated inflows are considered unsuitable for use in the following cases present in the waste water network:

- Prolonged pumping cycle in wet weather situation where pumps are not turning off and averaging the inflow can't reproduce the peak;
- Pump stations with submerged inflow pipes (there are several significant trunk pump stations where the pump START is higher than the lowest inflow invert level);
- Proximity of upstream rising main (common occurrence in Tauranga);

- Irregular pumping cycles due to reduced pumping efficiency against dynamic head (pump injection systems present in Papamoa)

DHI and Tauranga City Council worked together in developing a methodology which would overcome at least some of the above limitations.

4 ADVANCED FLOW DERIVATION TECHNIQUE

For a pilot scenario, it was decided to focus on developing a method that would enable flow derivation during a high flow event that resulted in significantly prolonged pumping cycle.

For the operational purposes, SCADA data were logged in regular 2 min intervals. The first change towards improving the usability of SCADA data in the inflow calculation was to additionally log the water level at the pump change of state points (ON/OFF). This is not only required for the calculation but is also a confirmation of the actual start-stop levels and assessment of potential drifts. While more frequent logging would be preferable, the two minutes resolution is a practical compromise between logging frequency and the number of parameters being observed.

In order to better capture the peak flows, the calculation frequency needed to be much higher than once per filling cycle as it was in HYDSYS. It was decided to initially calculate inflow every 2 min, matching the data logging frequency. The intention was to start simple and make use of all available information including the wet well volume change, theoretical pump discharge curves, drawdown tests, asset and operational data (set points, alarms etc.) and even the HYDSYS calculated flows.

In simple terms, we can state that, between any two discrete points in time, the inflow into a pump station can be calculated from the change in the wet well water volume adjusted for outflow from the station.

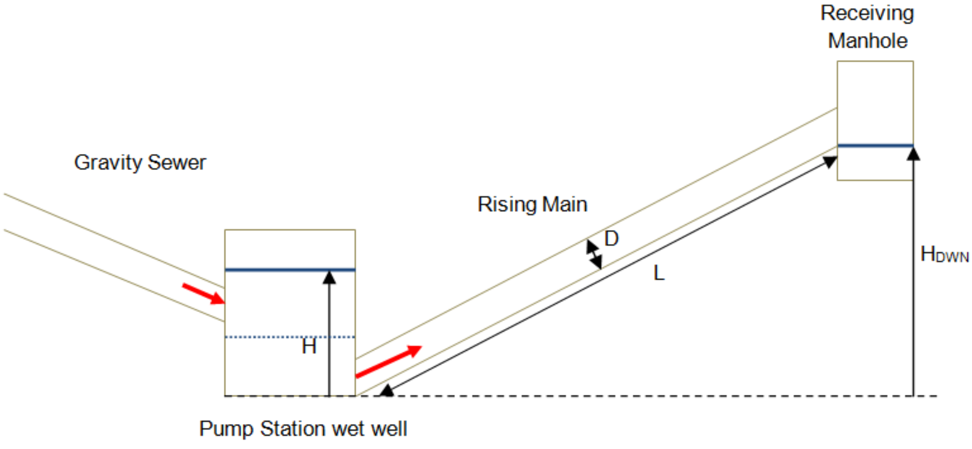
$Q_{In} = Q_{Net} + Q_{Out}$

The first step was to calculate the Q_{Net} from the change in the recorded water level and wet well geometry. As we are looking at the discrete volume of a wet well and the flow getting into the wet well, the assumption was adopted that the volume backed up in the upstream sewer can be ignored. This assumption is elaborated further in the validation section.

The second step was to determine the actual pump station output as closely as possible. As only few rising mains in Tauranga network have magflows installed, the PS output needs to be calculated from the theoretical pump curves and estimated total pumping head. The rising main losses were estimated using Manning's equation assuming the level in the receiving manhole is static.

Figure 3 shows a schema of a typical pump station setup and information used in calculation.

Figure 3: Schema of a typical pump station and information used in calculation



Having calculated the theoretical pump station output, the next step is to determine what is the real output. We refer to the process as “calibration” of the Q_{out} to the HYDSYS calculated flows before and after an event (as demonstrated in Figure 1, in many situations the HYDSYS flows are sufficiently accurate).

The automated flow calculation process generates, in addition to theoretical flow, a range of reduced flows by scaling the manufacturer’s capacity curve in increments of 10% (the increment can be customized). The calibration process essentially requires overlaying the calculated flows and choosing the one that provides the closest match for instantaneous, hourly and daily accumulated HYDSYS flows. The chosen reduction accounts for wear and tear and any other factor that influences pump efficiency. It also incorporates all other losses not already taken into account. Once the reduction in pumping capacity is determined, it is applied through a high flow event.

There may be many reasons why the derived flows will not align perfectly with HYDSYS flows and will appear fluctuating. The most commonly fluctuations are due to alternating pumps behaving differently, kinks in the water level data or inaccurate wet well geometry information. The objective of the “calibration” is not to reproduce accurate instantaneous flows, but to ascertain the actual pumping efficiency in cases where magflow data is not available or not reliable. The reduction factors for pump stations processed so far for TCC is mostly between 20% and 50%, but can be up to 70%. The additional benefit of the flow derivation is informing TCC asset management and operations on potential errors in the asset records (wrong pump type) or serious problem with pump performance.

A typical example of the derivation of inflows was shown in Figure 4 and Figure 5. Flow derivation into the PS52 in Matua waste water catchment was carried out for April 2013 rain event. Looking at the flows just before and after the event, a reduction of 40% was adopted.

Figure 4: Deriving flow including calibration of the reduction factor by close inspection of the instantaneous data. The black lines show observed water level and the HYDSYS calculated flows; red is the inflow as per theoretical pump curve and the pink is the adopted derived flows used in the I&I study.

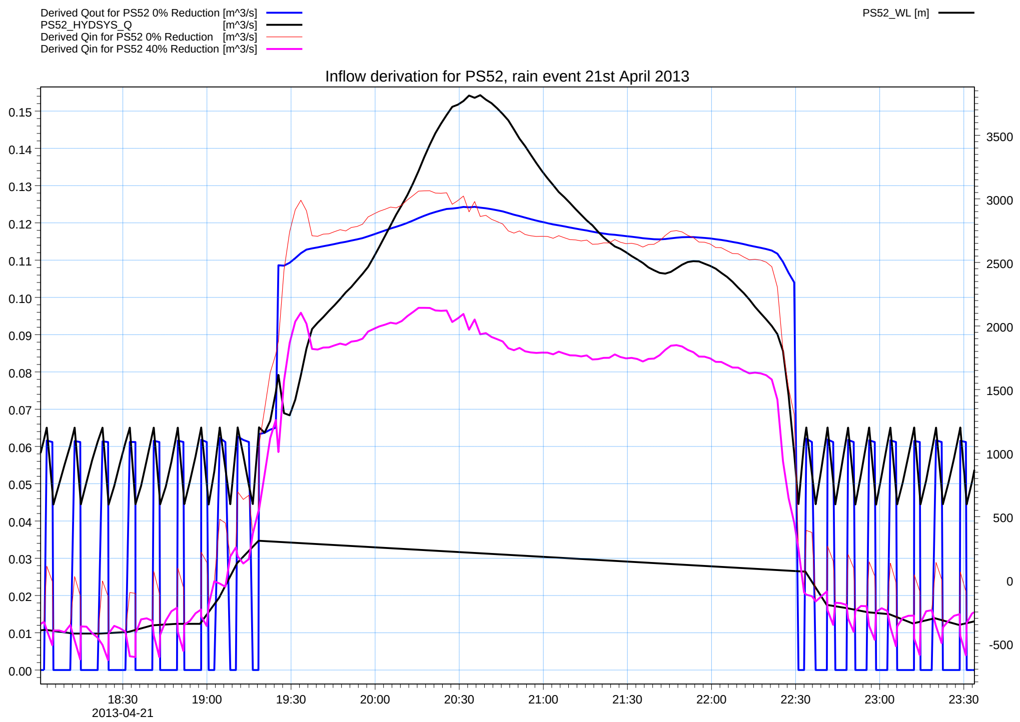
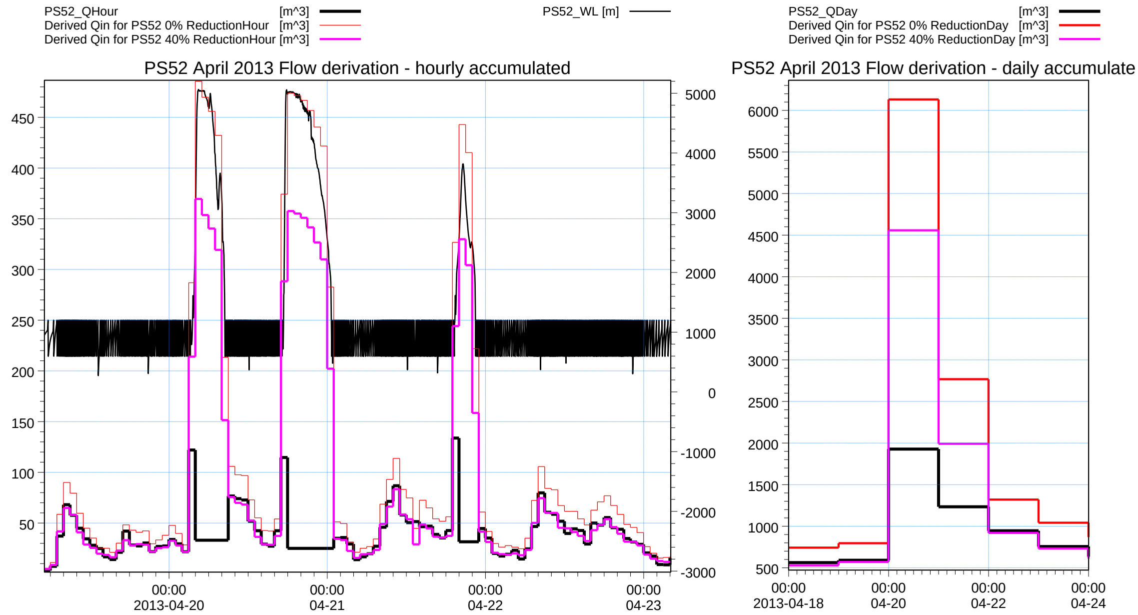


Figure 5: The derived flows are cross-checked by looking at the hourly and daily accumulated volumes.



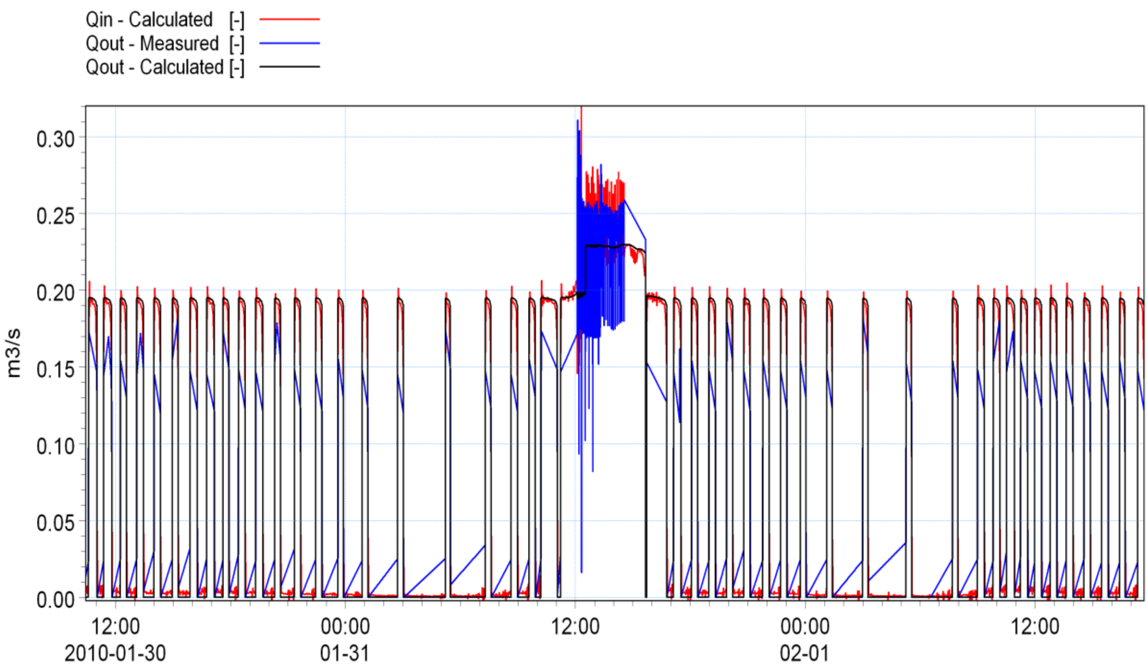
4.1 VALIDATION

Three pump stations in Mt Maunganui waste water catchment were selected for the inflow validation. The first one, the McDonald Street PS is the largest trunk pump station in the catchment. The pump station inflow pipe is submerged during the standard operation and TCC staff was interested to see if the improved flow derivation technique can overcome the problem evident with the HYDSYS derived flows.

McDonald St PS is equipped with a magflow and the derived flows using the DHI algorithm were compared for March 2010. DHI derived flows, without any reduction factor, were in average 8% higher than the measured flow (the HYDSYS flows were 20 times lower than the magflow due to inability to cope with submerged sewer).

Note that in this case it is not possible to determine pumping reduction factor by looking at the HYDSYS flows as they are highly inaccurate for the submerged inflow situation. The reduction could be determined from magflow comparison but there have been some concerns about accuracy of the recorded flows.

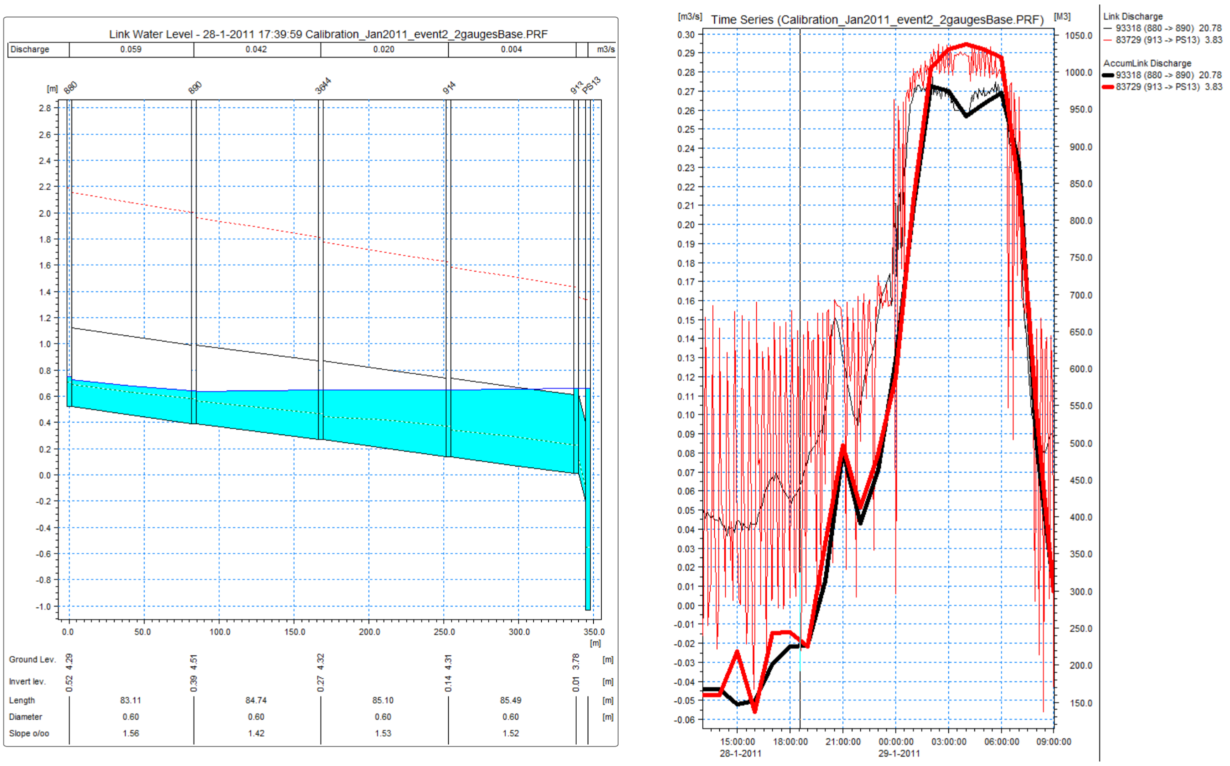
Figure 6 "Spiky" calculated inflow for submerged sewers



Although the daily accumulated volumes compared well with the measured (and can be further improved by applying a reduction factor), the attention was drawn to spiky appearance of instantaneous inflow values shown in Figure 6. The effect was discussed with TCC and the results are accepted as correct in terms of the flow entering the wet well (as opposed to a catchment flow approaching the pump station). As visible in Figure 7, the same fluctuation of the inflow into the pump station is reproduced by the model. Some smoothing (e.g. moving averages) or accumulation of both modelled and derived flows may be necessary in order to quantify the alignment during model calibration.

The outcome of this validation case was satisfactory, although the flow calculation would be improved if the number of pumping cycles is increased from less than two per hour to at least 4. This could be achieved by slightly lowering the duty start level.

Figure 7: The flow approaching the PS13, results from the calibrated model. The inflow pipe profile (left) is taken just before the pump starts. The right panel shows the instantaneous (at 5min interval) values in the first pipe (black line) and the pipe entering the wet well (red spikey line). The thick lines show accumulated values respectively



The second validation case was PS3 located on Carysfort Street. This pump station was selected for the flow derivation to try to resolve apparent anomaly in DWF in the catchment (the HYDSYS flows were too low for the estimated population and the standard waste water pattern).

The initial flow derivation for a day with no rain showed good alignment with the HYDSYS when 50% reduction factor was applied and no apparent anomaly with the HYDSYS flows were uncovered. The pump station configuration was checked and no backing up of wastewater upstream of the PS3 was detected in normal DWF conditions. This is also visible from the recorded water levels as the rise in the water level during the wet well filling is uniform.

In order to confirm the findings, a two months inflow metering campaign was then carried out for two contributing inflow sewer lines. The data obtained from the flow meters showed unexplainable anomalies (highly non-uniform flows with frequent negative flows, shown in Figure 8). In agreement with TCC the measured data was deemed inaccurate and was not used for validation purposes.

The flow derivation was then carried out for a wet weather event on the 31st January 2010 (Figure 9). This derivation confirmed that the initially determined 50% reduction factor was also applicable for this event, increasing the confidence that the reduction is realistic.

Figure 8: Measured inflows into the PS3

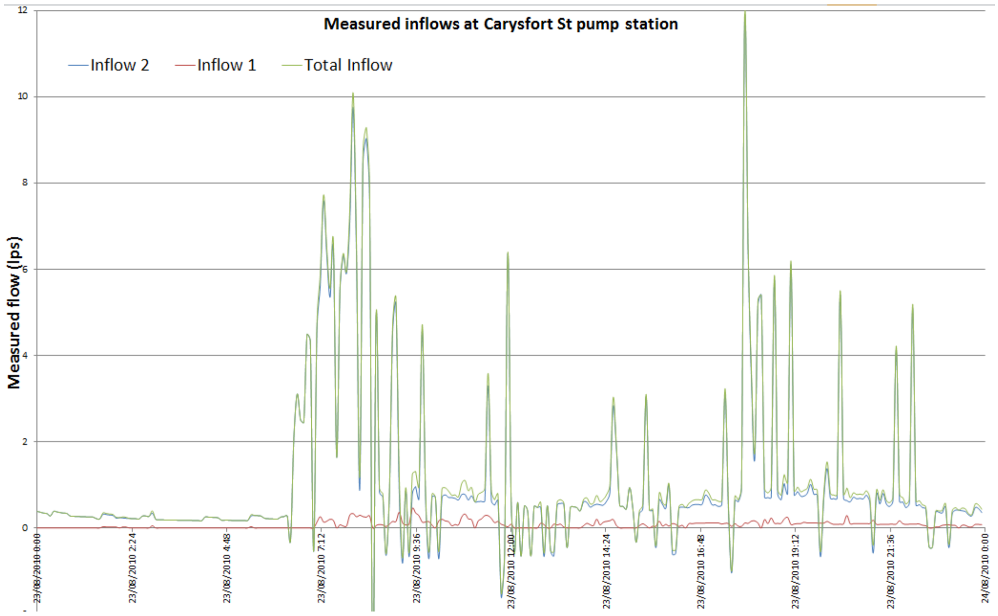
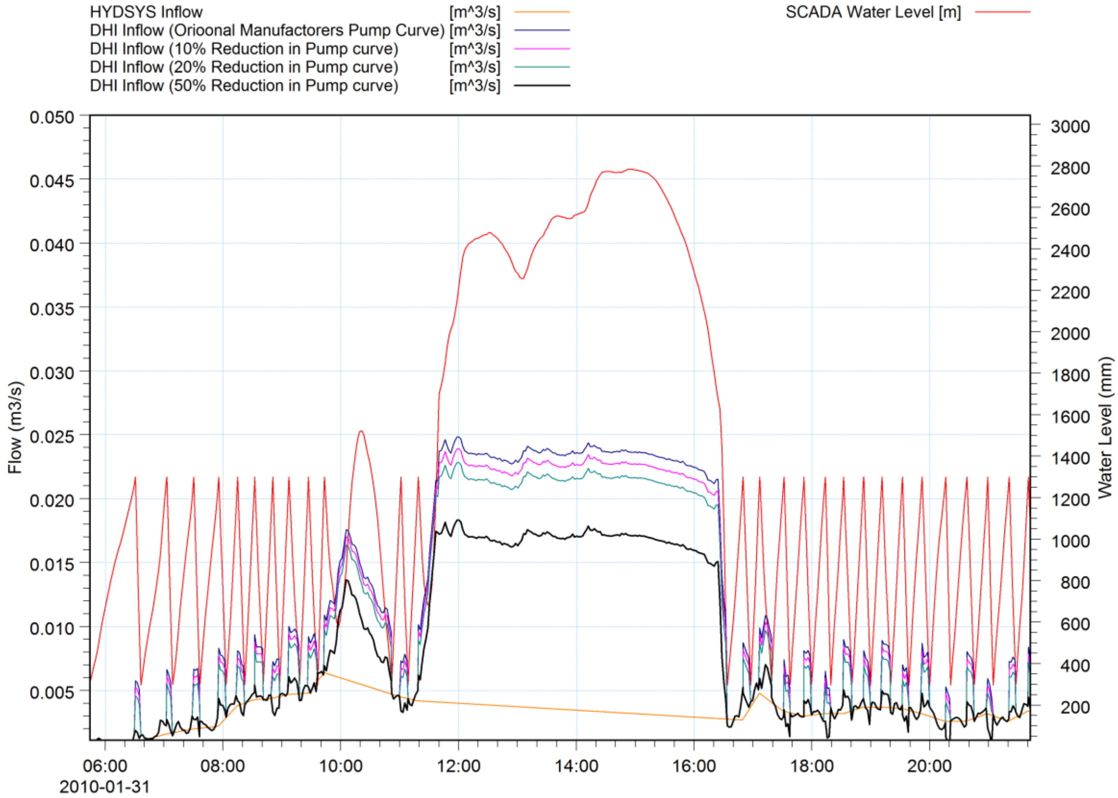
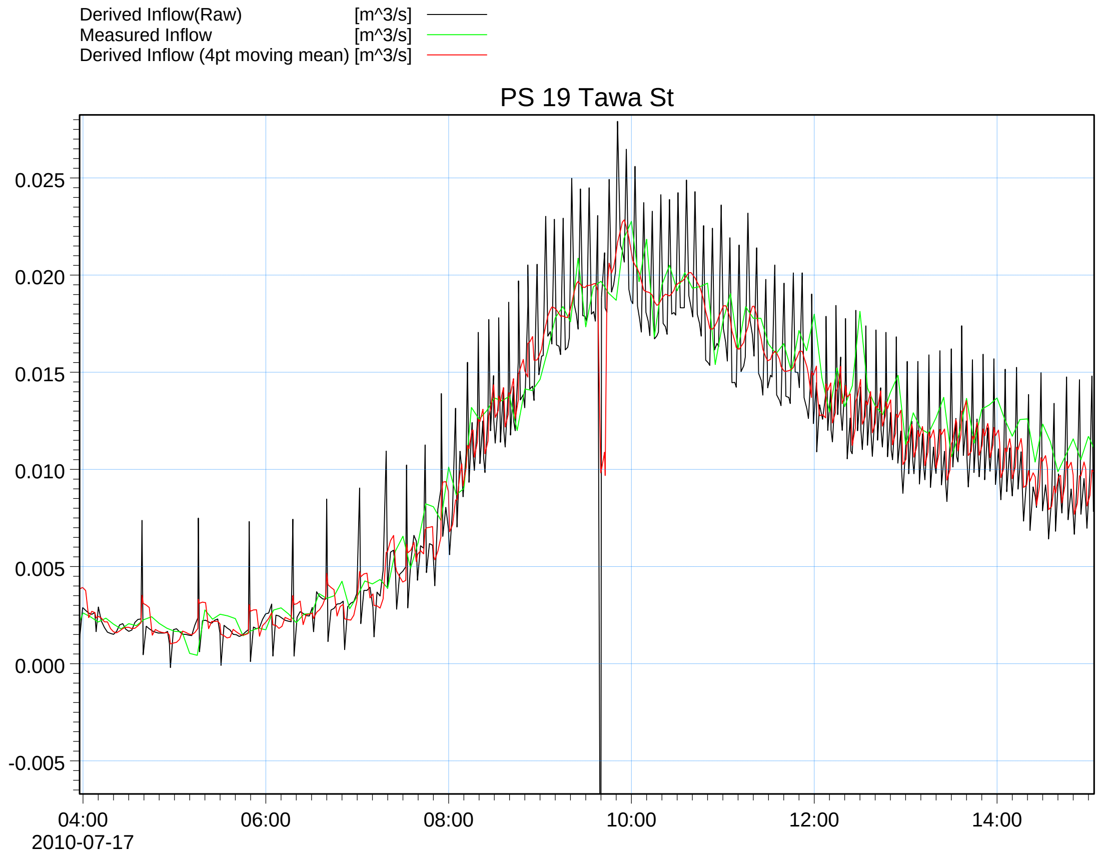


Figure 9: Flow derivation validation for the PS3.



The third validation case was Tawa St pump station. As with the PS3, a measuring campaign was carried in 2010 and the verification data was available. The close-up of the derived and measured flows is shown in Figure 10. The accumulated daily volume difference was between 9% and 20%. Close inspection of the water level data has shown slight irregularities which adversely affected the derived flows. An option to clean up the water level data prior to flow derivation was discussed with TCC but it was decided to leave the data as is, mainly for transparency.

Figure 10: Comparison of measured and derived inflows for Tawa Street pump station (Validation case 3)



Based on the validation cases, TCC was satisfied that the methodology is capable of deriving inflows into pump stations from collected SCADA data. It was decided that the methodology will be refined further if required.

5 IMPROVEMENTS OF THE METHODOLOGY

The initial methodology was further improved as more complex cases were encountered. This includes:

- Reduction of pumping capacities when multiple pumps are operating in conjunction. Drawdown test data are utilized in the process if available. The algorithm works out, from the set points and water level, if one, two or more pumps are working together. Based on the drawdown test the theoretical capacity is determined for each case. The combined capacity is then subject to further adjustment through the reduction factor calibration process presented earlier.

- Allowance for dynamic head against which pumps operate has been the toughest challenge yet. Tauranga's wastewater network features several injection systems where multiple pump stations pump into a common rising main. Papamoa network, for which a detailed model build and calibration has just been completed, comprises two such systems. Figure 11 shows Opal Drive pressure system. When a dynamic head is suspected, the initial approach was to determine the likely pressure range for each location and then use the average value. The process was iterated several times before satisfactory results are achieved.

Figure 11: Opal Drive pressure system, a complex injection system in Papamoa network

Trials with iterations for a range of total head values have proven to be beyond the capabilities of the method designed for a single pump station setup. The main problem was that the methodology deals with each pump station in isolation and is not "aware" of what other pumps are doing at the same time.

We are currently testing a new approach to be used especially for complex systems such as the Opal Drive. The approach will use the actual MIKE URBAN model of the complete injection system and the observed water level data will be applied as model forcing at all contributing pump stations. The initial results of this approach are very promising although further refinements will be required.

The Figure 12 and Figure 13 show the comparison of the derived flows using the original method (pink line) and the derived flows using model (blue line). It is clear from the plots that the original method is over predicting the flows during rain event as it assumes certain pumping rates if the pumps are running. This is not always the case if the pumps are competing against stronger pump stations sharing the same rising main.

Figure 12: Wet weather calibration plot for PS88 - flows

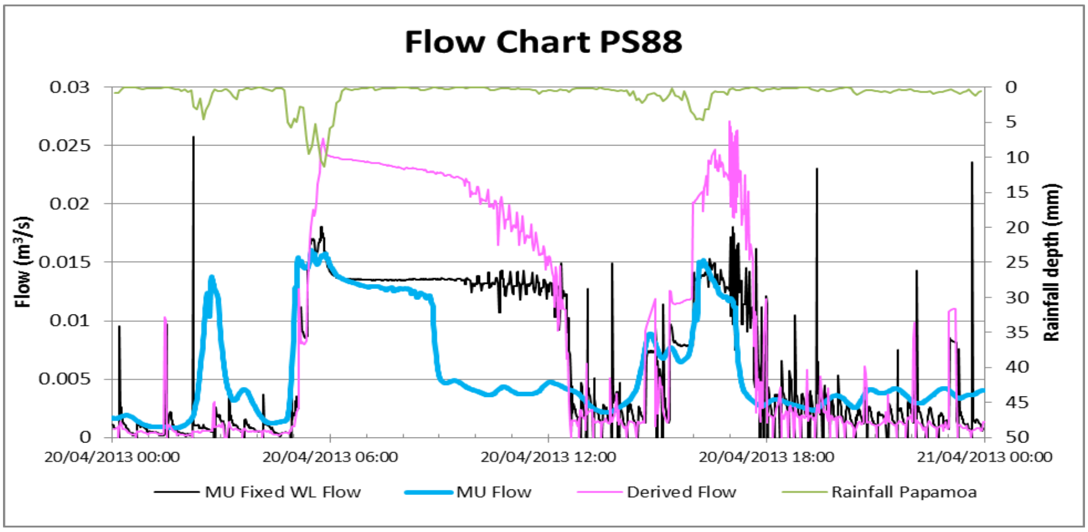
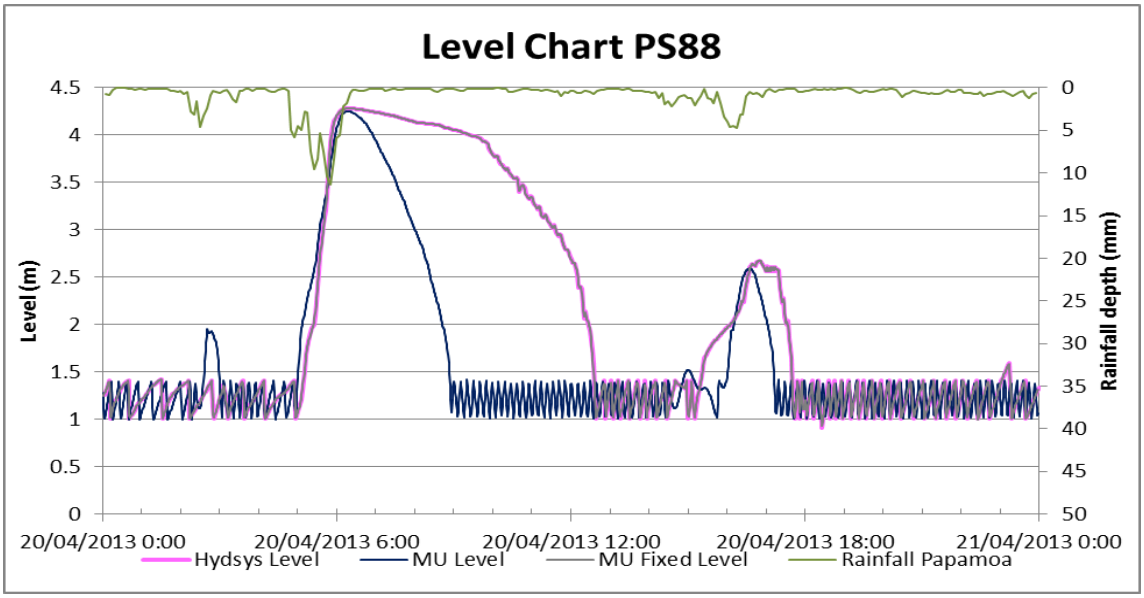


Figure 13: Wet weather calibration plot for PS88 - levels



6 EXAMPLES OF USE AND LESSONS LEARNT

The flow derivation initial (and main) purpose was to provide calibration results for waste water models being built in Tauranga. The fact that this method can be applied for recorded historical events makes it particularly attractive for model calibration as it allows large selection of events to be processed and used if necessary.

The flow derivation was mainly used for deriving wet weather flows, but also to determine dry weather flows where:

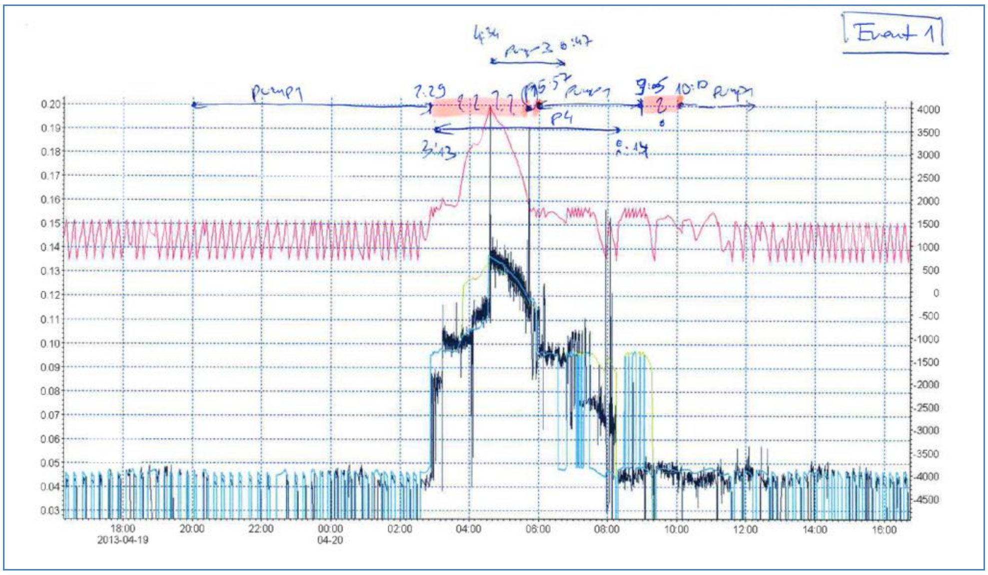
- The inflow sewer backs up during normal dry weather loading operation.
- Discrepancy exists between measured data (e.g. accumulated daily magflow data for the upstream PS higher than the accumulated daily magflow data further down the trunk).
- Proximity of the upstream rising main results in highly variable inflows in bursts that makes the averaging assumption invalid.

In addition to being utilized in model calibration, the flow derivation was used in separate desktop studies investigating I&I issues in catchments where wet weather calibrated models have not yet been developed. As the algorithm is scripted in VBA and does not require a model to run, it is easily applied wherever asset and SCADA data is available.

Even though many of the derivation steps are automated, the process still requires some manual processing and is best done in collaboration between network operators and a skilled engineer performing the derivation. This is especially important in complex cases where the active network operation, pump failures and blockages during the event are evident (example given in Figure 14).

In addition to improving the methodology and in an effort to further reduce the cost of flow derivation to TCC, we are also investigating opportunities for further automation of the derivation workflow and data pre and post processing.

Figure 14: Example of a complex flow derivation where the actual manual operation of the pumps was required as an input in interpreting the SCADA data



7 CONCLUSIONS

SCADA data is widely available in NZ utilities. While the main use of this data is to support network operations, it can also be utilized for deriving flows in the network. Many SCADA systems have some ability for flow calculation, either built in or available through scripting. However, the approaches are often too simplistic and have severe drawbacks that limit their use, especially for modelling.

Tauranga City Council and DHI have initiated a pilot study with aim to develop an advanced method that would produce better results and have fewer limitations. The main driver for flow derivation was to provide calibration data for detailed waste water modelling in a cost effective way.

The flow derivation methodology developed calculates the inflows into pump stations based on basic flow equations and utilizing recorded water levels, calculated HYDSYS flows, asset data, operation statuses and engineering judgment. The methodology was verified against magflow and flow meter data at two locations in Mt Maunganui waste water catchment and is accepted by TCC as suitable for deriving flows to be used in model calibration.

The methodology can derive flows in many scenarios where simple techniques fail: through a wet weather event, in case of submerged inflows and proximity of an upstream rising main. An alternative method is currently being tested to deal with complex injection pressure systems.

In addition to being used for modelling, the methodology was used to provide data for several desktop studies investigating problems linked to high I&I in Tauranga.

Although the methodology is partially automated using VBA scripts with Excel interface, it is still critically important that the data is manually checked and the results are interpreted by a competent engineer.

As is the case with all other methods, including direct measuring using monitoring equipment, the methodology is not free of errors. The assumptions need to be understood and the results used with caution. The main appeal of the methodology is the ability to use the historical data already available and extract the flows in a cost effective way.

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