TRIALS AND TRIBULATIONS OF WASTEWATER FLOW MONITORING

Wayne Henderson, Harrison Grierson Consultants Ltd
Nigel Tse, Harrison Grierson Consultants Ltd

ABSTRACT

Local Authorities today are relying more and more on hydraulic models to assist in the planning of infrastructure upgrades and assessing the performance of their existing networks. They are also continually faced with the challenges of providing the most cost effective solution for reticulated sewerage infrastructure and ensuring that the systems are also optimised for performance. The basis for any hydraulic model is the input data put into the model such as asset data, flow data and rainfall data. The asset data can be easily verified as with the rainfall data as this is obtained from the metrological service.

The flow data component for modeling is usually collected 'in-house' or by specialist flow monitoring contractors, typically both using engineering technicians or often staff with limited or no tertiary hydraulics or hydrographics training. Hydrographics training is usually for rainfall and open stormwater channels, therefore not always directly applicable to the unique world of piped and pumped wastewater networks. Engineering training provides theoretical training, but also lacks the hands on training required for installing, operating and calibrating specialist flow and rainfall gauge instrumentation.

This paper will outline the various different gauge types that can be utilized to capture flow data within wastewater systems along with the various different monitoring technologies and their relative strengths and weaknesses. It is well known that budgetary considerations are a significant driver for the amount of flow monitoring undertaken.

The paper will discuss how you can ensure suitably trained staff and appropriate equipment and gauging methods is provided to undertake accurate and comprehensive flow gauging studies for completing requirements of network model calibration and inflow / infiltration (I/I) assessment. Alternatively the information from this paper may allow you to assess perceived or real accuracy issues from former monitoring studies from an understanding of the issues associated with wastewater flow measurement.

This paper shall discuss these issues in more detail and provide Local Authorities with a comprehensive overview of current issues associated with flow monitoring in the 21st century.

KEYWORDS

wastewater flow monitoring, inflow infiltration analysis, in pipe flow meter, V notch weir, flume.

1 INTRODUCTION

The field of wastewater flow gauging methods and their associated calculation methodologies in gravity networks are often poorly understood. The issues contractors face in capturing accurate field data are also poorly understood by many in the industry. It is not as simple as installing a flow meter, measuring up all of the site parameters and then leaving the meter in place for 2 or 3 months to capture 5 or more varying size rainfall events to provide enough data to calibrate a hydraulic model from. Most people in the industry wish it was that easy, as descending into live sewers for monitoring purposes is dangerous and more often dirty work.

It is from a general lack of understanding that most of the trials and tribulations associated with flow gauging studies and use of the captured data can result.

In a "perfect world" all in-pipe type, open channel depth and velocity measuring flow meters should be sited in pipelines with good uniform hydraulics, with enough flow at all flow regimes to allow accurate manual depth and velocity gaugings. Accurate manual gaugings from a person trained in taking consistent manual gaugings then become the basis of any flow meter calibration. Flow meters must be installed well up the incoming pipe where manhole benching and invert falls have less or no effect on the gauging cross section. The flow meter installation should have as little effect on the flow within the pipe as possible.

Very accurate data starts with very accurate depth measurement of flow levels within the pipe. In a good flow gauge site the manual calibrations would confirm the monitor depth is within 2mm of the manual depths taken, for calibrations at all flow regimes [minimum, average, peak dry weather flows and at any wet weather flow regimes]. The monitor depth should be adjusted to the manual depth calibrations so the two correspond. Similarly very accurate velocity data also requires that the velocity sensor calibration is confirmed in a similar way against manual velocity gaugings to establish the correlation between the monitor reading and manual gaugings so the monitor readings are adjusted during data processing to provide accurate average velocity readings under all flow regimes.

Unfortunately in the "real world", flow gauging is undertaken in real sewers that do not always have perfect hydraulic conditions and the field equipment may or may not be suited to the site specific gauging conditions. Therefore designing flow gauging networks and managing flow gauging projects is all about compromise. The compromise involves selecting the best available flow gauge installation site, using the best type of installation type [discussed later], with a flow meter with preferred velocity and depth measurement attributes to work well in the selected location for the anticipated flow ranges. Different makes of in-pipe monitor types have different strengths and weaknesses. Each different make uses slightly different technology, and in particular velocity sensors can have widely varying accuracies depending on the time of day, the depth of flow and the turbidity or clarity of the flow. Similarly older pressure depth sensor type instruments can also be prone to minor or major depth reading drift over the course of a week, introducing further inaccuracies that must be manually adjusted for during any data processing activities.

2 MONITORING ISSUES AND EFFECT

This section of the paper will provide an overview of many of the issues faced when undertaking flow monitoring, and the effects that have been observed to result. Whilst it is not an exhaustive listing of issues, they are the more common issues that are being found to result in inaccuracies in final depth, velocity and flow quantity data sets.

2.1 EXPERIENCED WASTEWATER GAUGING STAFF

Formal training for wastewater flow monitoring is not readily available within New Zealand, and most senior people within the industry have either been trained by or worked for US, UK or Australian flow gauging companies, have some form of stormwater hydrographics training or are self taught. Many of the people undertaking the day to day field work for flow monitoring projects have no formal tertiary hydraulics or hydrographics training. Undertaking confined space entry of sewers on a day to day basis is undesirable work, and staff turnover can be high and experience from the industry is frequently lost as people move on to cleaner professions.

The office based data processing components of the work is often undertaken by 'in-house' trained staff who can have tertiary qualifications in engineering, hydraulics, hydrology, science, or other disciplines, but this is also not a mandatory requirement.

Hydrographics training is usually for rainfall and open stormwater channels, therefore not always directly applicable to the unique world of piped and pumped wastewater networks. Engineering training provides theoretical training, but also lacks the hands on training required for installing, operating and calibrating specialist flow and rainfall gauge instrumentation.

The effect of the above is that mistakes can be made, or hydraulic issues with the sites or data are not identified during the monitoring studies due to inexperience or the lack of technical understanding of the issues by the person analysing/reviewing the data. Therefore it would be unreasonable to expect gauging contractors to pick up issues occurring within existing wastewater networks from the data being captured. Experienced contractors may indicate something is unusual as part of their reporting, but it is not their responsibility to investigate the network operation issues if any are indicated.

2.2 NETWORK ISSUES

Network issues such as known blockage areas with tree root issues or siltation issues should be cleaned prior to any flow metering project. Similarly any known inflow points such as manholes within minor flood plains, overflow structures that can backflow with stormwater or other significant hydraulic choke or capacity issues should be repaired prior to gauging. It is also good practice to flush all siphons and test all pumps and check them for blockages prior to commencing works. In an "ideal world" the network should be in as good a condition as possible to capture flow data from a system in a well maintained state to enable the system to be simulated accurately in a hydraulic model.

Proposed flow gauging sites are not always ideal for gauging, and sometimes you can only achieve limited data capture or accuracy. Similarly good locations may be sited in private property or heavily trafficked areas, and poorer locations in easily accessed locations. Contractors will gravitate to the easier to access locations if given a choice, but the choice must be based on the accuracy of the data required balanced against the additional cost of traffic control and increased data accuracy.

Backwater effects in the network near pumping stations, storage tanks and downstream of overflow locations can result in significantly decreased velocity readings. Some equipment will measure velocity down to 0.1m/s, but lower velocities than this means that many types of sensors do not work well in these slow conditions. Reverse flow due to backwater is very rare, and if it is known to occur and needs to be monitored it is often preferable to install a second flow meter in the reverse direction rather than hoping the flow meter can read negative velocities as claimed by some equipment manufacturers.

There is always an increased risk of blockage when a flow meter is installed into any system. When installed well and they are frequently maintained, any blockage and resulting overflow must be an accepted risk of undertaking the work. The smaller the pipe, the higher the risk of blockage, although blockages are quite rare and typically result from excessive hardfill or pipe bedding materials entering via defects in the system or spurious building materials such as lengths of wood entering the piped network.

Traditionally, the equipment is installed and calibrations throughout the monitoring period are undertaken, and all of the data processing is left until the completion of the flow monitoring period as it is easier and less costly for the contractor to do the project this way. Unfortunately if the data is not reviewed during the monitoring period, issues can be missed or be unresolved for some weeks or after the monitoring period has been completed, and the monitors may have been potentially removed.

2.3 EQUIPMENT ISSUES AND AGE OF EQUIPMENT

It is preferable that gauging contractors have a range of flow metering equipment with proprietary sensors less than 5 years old. The types of equipment brands used should be units that perform well in the flow conditions they will be used for. Very few units have velocity sensors that work well across very slow to very fast flow ranges. Velocity sensor performance also typically deteriorates with ongoing use, as the equipment will suffer wear and tear whilst in the pipe from debris strikes or from repeated reinstallation/storage during the life of the equipment.

Sites that use ultrasonic depth measurement [up-looking or down-looking] typically produce more accurate depth data compared to pressure depth type depth sensors as a monitor ages. Older pressure sensors, and in some cases brand new pressure sensors can drift. New sensors may only drift a few millimeters in a week. Older sensors may drift some 40 to 60mm in a one week period. Drift can be up, down or both. Drift has been such an ongoing accuracy issue that recent specifications now require bi-weekly calibrations for sites that use pressure depth level sensors if they drift by more than 4mm per week. Drifting depth data introduces unnecessary errors and uncertainty about the quality of the data. Data processing to "adjust" for any drift can introduce further unnecessary errors into a data set.

Some velocity sensors are known to require significant adjustment depending on the resulting depth at a site. Depth to velocity adjustment factors have varied from 1.3 x during minimum flows to 0.8 x during peak dry weather flow regimes. This excessive range of factoring calculated from a limited number of manual calibration visits would also introduce factoring errors into the data processing stage required for the final flow data calculation.

2.4 DATA AUDIT ISSUES

Data auditing is rarely undertaken and when it has been reviewed it has not been unusual to fail over 50% of locations during audit reviews of historical data. Many failed sites were for major issues associated with monitor performance due to depth drift, or poor attention to data editing procedures. Diminishing velocity sensor performance due to the use of aging velocity sensors was also often apparent. Typically a review of the site photos and depth and velocity ranges at many sites indicated that sensors should be working better than what was being observed, and many installations should have been installed further up the pipe to improve the hydraulic conditions at the gauging point. End users of the data would have possibly seen serious flow imbalances, unusual model calibration results between adjacent catchments, erratic dry weather flow patterns or erratic wet weather catchment responses that do not correlate between storms.

Some of the above issues can be catchment performance related or associated with the selected sites that were required to be monitored. Shifting silt levels or similar hydraulic shifts resulting from some form of downstream change or blockage can result in a change in both of the depth and velocity pattern, but the associated continuity based flow data should not shift if field measurements of the new silt levels are applied to the site and the data processing is done correctly. Experienced contractors should identify such potential issues during their routine data editing and quality assurance check procedures. This allows the end user to be advised, so the issue can be investigated during the monitoring period and reported on in the interim and final data reports and resolved well before the data is provided for modelling purposes.

Hydraulic modelers are frequently not expert in flow gauging practices and rely on the provided flow data being accurate and expect the contractor to indicate if there are errors or inconsistencies within the data.

Quality flow meters, operated and data processed by well trained suitably qualified and experienced people with good gauging methodologies is the key to removing or reducing data inaccuracies and uncertainties for future monitorng studies.

2.5 UNDERSTANDING FLOW DATA BALANCING BETWEEN MONITORS

When accurate data has been provided it should be possible to subtract upstream and downstream flow gauges and utilise the subtraction data, with a small amount of time averaging of often only a 1 hour period, to produce an indicative hydrograph of the subtraction catchment area. If pumping station influences are involved then periods of 4 hours or more may be required. If the hydrographs have periods of negative data this can indicate balancing issues are resulting.

A good area velocity type flow monitor data set can have an accuracy of +/- 20% in low flow minimum dry weather flow periods. The same monitor may have an accuracy of +/- 7% during peak dry weather flow periods. Therefore it is important to understand that two area velocity type sites in series may potentially add the discrepancy between them and have 40% at night, and 14% during the day. If there is a small contributing catchment between the two sites that does not contribute more than 40% of the flows being measured, then the inherent accuracy of the flow meters may produce the imbalance. Good calibration and data editing and processing to mitigate errors and bias in a flow meter calibration should mitigate this issue to a greater extent, although inaccurate flow meter calibration and data processing can also magnify any imbalance issue.

The figure below is an example of a time averaged balancing check on some preliminary flow gauge data [with minimum calibrations applied so far] that indicates the contractors early data still has some work to possibly resolve the minor imbalance during minimum flow periods, but the contributing catchment between these 3 gauge locations is less than 40%, and high and very clear base infiltration flows in the order of 4 l/s to 5 l/s may be affecting one or more of the sites velocity sensors. With 6 weeks of monitoring to complete there is ample time for investigation of this minor issue, and at the completion of the monitoring period the contractor and auditor will have agreed if this imbalance is an inherent accuracy issue that would need to be accepted.

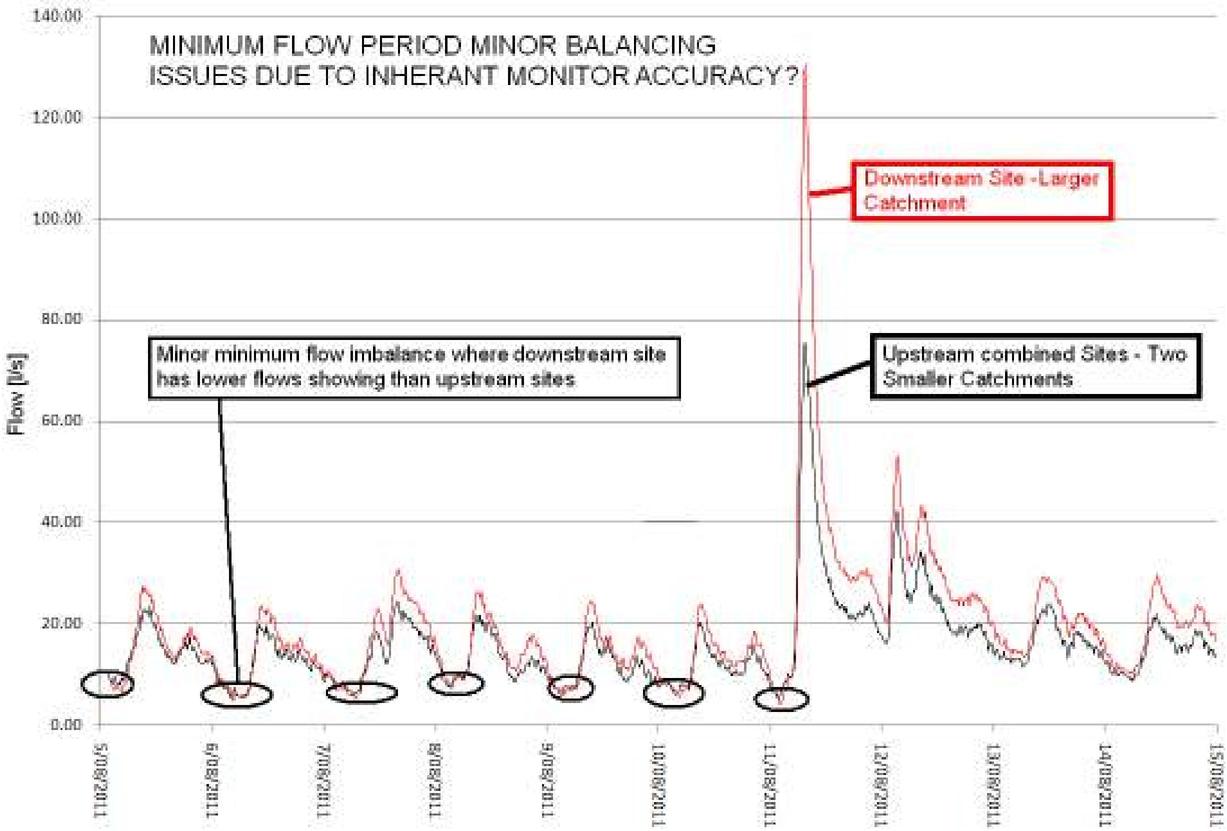

Figure 1: Example of a potential imbalance resulting from inherent monitor accuracy.

2.6 GOOD PRACTICE TO MITIGATE POTENTIAL ISSUES

The intent of the remainder of this paper is to provide an understanding of good practice methods and methodologies that could ultimately be used by modeler/engineer to understand flow monitor data processing and allow them to undertake a preliminary review of historical data sets to indicate if the data is from potentially good or bad field or data processing practices. It is often possible to undertake a formal audit or peer review process to attempt to salvage and re-process historical data or make an assessment of likely "good' or 'bad' data sets. The best way to avoid this situation is to ensure future monitoring projects are undertaken using best practices. Peer review and critical interrogation of flow monitoring data after the completion of monitoring project can be equated to the 'ambulance at the bottom of the cliff scenario', where the problems have already occurred and you cannot undo all of the data problems because the equipment has been removed and no further physical monitor checks or manual gaugings can be undertaken.

Independent auditing of flow gauging contract works from the beginning and throughout the duration of a monitoring contract has been found to be a constructive means of achieving agreed accuracy data where Clients can be assured the data is fit for purpose before the monitors are removed. The auditor is there to raise issues identified during the interim audit data reviews, and discuss potential causes and recommend to the contractor an agreed course of action to fix or mitigate any issues. The auditor should not be relied upon as the contractors quality assurance checking, and any specification must require to do full quality assurance checks before data is provided for review.

3 FLOW DATA REQUIREMENTS

This section of this paper will discuss elements of a flow monitoring program formation through to the undertaking flow metering works by various means. The intent is to provide an insight into the various stages and suggest actions that can be undertaken during each phase to improve the overall monitoring program, or to indicate relative accuracies that can be expected by various monitoring works to indicate how accurate the supplied data is likely to be.

3.1 DATA USERS AND THE NETWORK MODEL BUILD

Calibrated hydraulic models of network are undoubtedly the best means of analysing wastewater networks for capacity issues, network optimisation and infrastructure upgrades. Lid level and in-manhole surveys are well understood and the accuracy of the captured data of say +/- 20mm for both lid level and in-manhole inverts is easily achievable. Actual pipe diameters can be measured to well within 5mm for a circular pipe and overflow structures can also be accurately measured up and also be modelled to a high degree of accuracy. All of the above data inputs produce minor inaccuracies within the model build process that are understood and accepted.

3.2 PUMP STATION FLOW MONITORING

Magflow meter data from pump stations can also be recorded and provided from most scada systems nowadays, and a well installed magflow meter is typically within +/- 2% accuracy. It is recommended to undertake a volumetric test of any existing magflow meter to confirm its accuracy, and a visual inspection to confirm it is installed to manufacturers specification with clear straight lengths of pipe upstream and downstream, earthing and other technical issues is also recommended. Similarly any level data from a wet well level sensor is likely to be within +/- 20mm to 50mm when calibrated to the height datum used for the modelling. Depth sensor readings are most likely affected by scum buildup on the surface of the wet well and that is why a larger accuracy range has been shown above.

The ability to generate accurate calibrated flow data from telemetry stop / start data and any available alarm or level data is a complex process, where additional evaluations of field pump flow rate testing results should be cross checked against head/discharge system curves developed against the various pump station single and dual operating sequences. There are at least 5 different methods to calculate flows into or out of a pumping station, and selection of the most accurate and appropriate during wet weather operations is the most difficult task when undertaking this form of data processing.

3.3 IN PIPE GRAVITY NETWORK FLOW MONITORING

3.3.1 SITE SELECTION FROM THE OFFICE

The locations selected for flow monitors and the number of monitors required is dependent upon the type of investigation and the purpose of the investigation. Equipment selection is also frequently limited by budgetary considerations. The monitoring purpose can be one or a combination of the types of investigations bullet pointed below:

- Inflow / Infiltration investigation
- Network planning model calibration
- Overflow operation or quantification
- Issue investigation
- System optimisation
- Post Rehabilitation or augmentation

Typically a network map is produced from the GIS data or system plans, preferred locations and associated catchments are selected during this desktop evaluation, the number of monitors and locations on the plan are altered to fit the available budget and expected monitoring costs. The issue with desktop selection is that there is no certainty that the selected sites are accessible or are suitable for being flow gauged. If a flow monitoring contract is let upon this desktop evaluation only, there are often significant changes to locations required in the field, which can compromise some of the potential intentions of the monitoring study.

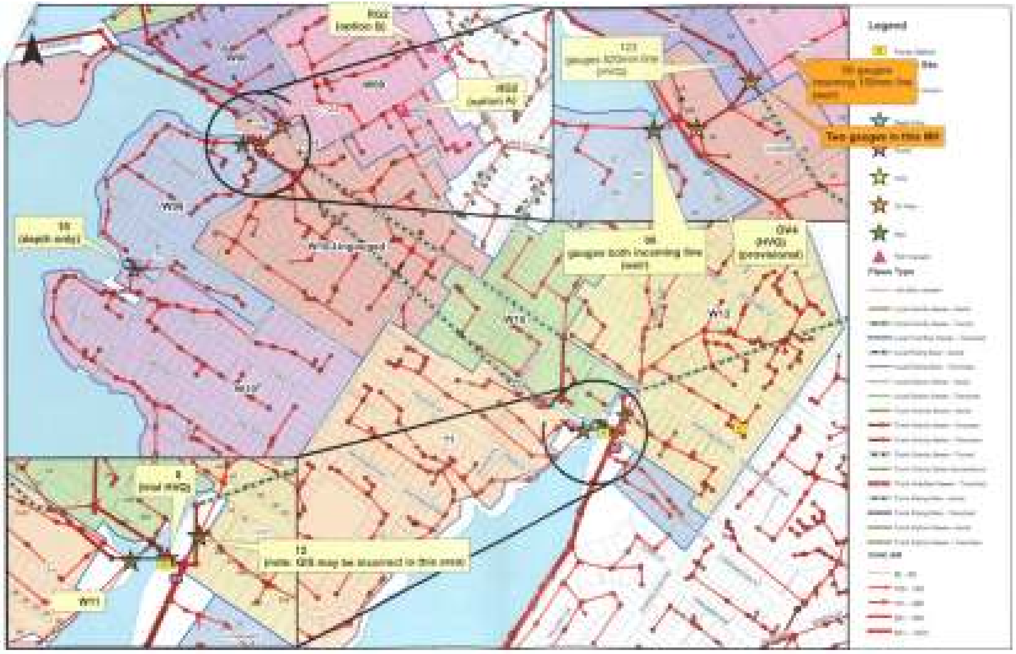

Figure 2: Example of a GIS schematic based on new and previously monitored locations.

Installing check gauges for 'Mass Balance' checking purposes is an important component of a flow monitoring network particularly if you do not already have level sensors and mag flow meters at pumping stations.

Site selection can be improved and the expected monitoring performance often better understood if there is already a model of the network prepared before the flow gauging study is undertaken. Use of existing telemetry data to generate flows at various catchment pumping stations can be used to indicate some regional runoff parameters for a 'first cut' wet weather flow assessment of the catchment.

During the asset surveys for the model build the network understanding and possible issues of silt and tree roots can often be identified and repaired, bifurcations and overflows can be surveyed, GIS pipe diameter data can be checked and an accurate network model created and run with indicative I/I rainfall response. This indicative model run is done to indicate if the theoretical I/I model run correlates with known problem areas within the catchment. Liaison with maintenance staff and review of maintenance call out records are also a useful source of identifying problem areas within a catchment. If maintenance staff indicate different wet weather capacity problems in other areas not indicated on the model then it may be prudent to undertake additional visual or CCTV investigations before commencing a monitoring project.

The more working knowledge of the catchment that is available, allows the proposed monitoring points to be selected with more certainty of better data capture to investigate issues from the proposed monitoring locations.

3.3.2 SITE SELECTION IN THE FIELD

Field inspection of the proposed manholes should occur prior to any tendering of works. The inspections should also include observation of the upstream and downstream manholes of the proposed manhole. Looking at all 3 points provides invaluable observations of the network with regards to potential in-manhole issues in the manholes such as tree root infestations and blockages affecting flows, hydraulic bottlenecks, surcharge level debris indication within the manholes, and sometimes evidence of lid overflows with debris covering the area surrounding the manhole. These inspections for the preferred site should be recorded on site specific sheets that detail as much information about the selected manhole that includes areas for making notes about the site regarding hydraulics, suitability for flow gauging and upstream and downstream observations. A second page should be included for making sketches of the manhole location, in-manhole layout including cross sections of the manhole and for providing any other useful information that can be evaluated from a 'topside investigation' whilst looking down the manhole.

One step further to ensure a proposed monitoring site is suitable, is to have an experienced person undertake the required confined space entry and descend the manhole and observe up the pipe in both the upstream and downstream directions to evaluate the hydraulics and pipe condition, undertake an accurate pipe measurement, photograph the proposed monitoring point and undertake a depth and velocity gauging to assess flow variances of the site for the time of day of the inspection. Experience should allow them to evaluate any further low flow or high flow regime affects the site may experience to include this form of commentary with a tender.

Field site selection before tendering any works allows certainty that the monitoring network proposed should not alter after commencement of the monitoring contract works. It also allows difficult sites to be identified, and preferred monitoring options to be considered whilst having alternative options to be available if 'trialing' of the preferred site does not produce satisfactory data. This allows the contract to allow for a Provisional Item for relocation costs in the schedule of prices for the works. The more certainty of location and overall project and specific manhole information provided to a flow monitoring contractor during the tendering period, the more certainty of the works and the more accurate the pricing. Poorly detailed project scopes that have only had desktop evaluation can increase tender prices due to the increased uncertainty of the scope of works. It can also lead to delays if proposed networks require altering, and additional claims for delays and variations for any works associated with relocations, etc.

3.3.3 UNDERTAKING A MONITORING STUDY – USING SPECIALIST GAUGING CONTRACTORS OR DOING IT IN-HOUSE?

Undertaking a flow monitoring study requires a substantial amount of investment to provide the monitoring equipment, health and safety equipment, laptop and desktop computers, software and staff training in the use of the various monitoring equipment used. Then there is the training in the necessary hydrographic gauging procedures for the various flow gauging installation types, and development of data handling and processing methodologies for instances that are not covered by the flow monitor software purchased for editing data and adjusting it to fit the calibrations. Some software does not produce the cross checking flow data entities [discussed later in this paper], and additional data processing spreadsheets may need to be developed.

Whilst it sounds like a daunting task, all of the requirements and robust process can be developed for undertaking monitoring studies. But this takes time. Any monitoring, by in-house staff or contractor, must allow the field gaugings and their application to the captured 'raw' monitor data, during any data processing phase, to be clearly documented. This allows the data to be reviewed and re-processed if an error or issue is identified. If the monitoring is for a small project then in-house monitoring may well be the preferred means of having the monitoring done [e.g. tradewaste monitoring]. If there is substantial monitoring required for major model calibration to determine the expenditure of millions of dollars, then it is suggested that the monitoring should be undertaken to very high standards with state of the art equipment.

3.3.4 IN PIPE METHODS AND METHODOLOGY FOR FLOW METERING

There are many methods available to capture flow data in gravity wastewater networks including Area-Velocity measurement, V-notch weirs and Flumes and many other variations on these themes. The following sections discuss the main type of in-pipe network flow meter installation used, and the benefits and disadvantages of each type of installation.

Many old technology flow meters use pressure depth measurement as their primary depth measurement sensor. Many pressure depth sensors are prone to drift, and drifting depth and constant and ongoing estimation and depth adjustments is one of the two main issues at the core of monitor data calibration issues when using old technology monitoring equipment. When depth is measured accurately using non-drifting ultrasonic depth measurements, the accuracy of any captured data is immediately improved. It is likely that in the future the use of ultrasonic depth measurement [up-looking or down-looking] could be the preferred primary depth measurement device, with a surcharge pressure sensor also installed in the site as an emergency backup and also for system surcharge depth measurement. Where contractors propose to use pressure depth as the primary depth measurements, specifications should require proprietary flow meter pressure sensors to be used, and require the contractor to confirm that the sensor does not drift, or if it does drift then the drift is less than 4mm per week, and the contractor should also provide 'raw' flow data from the flow meters last site installation to confirm the quality of each flow meters depth and velocity performance.

2.2.4.1 AREA VELOCITY MEASUREMENT [HVQ INSTALLATIONS]

Most flow meters are designed to measure depth and velocity of flows in a pipeline. These sort of meters measure Height, Velocity and generate Quantity, and are often referred to as HVQ type installations. They generally work best in larger pipelines > 225mm diameter with good laminar hydraulic conditions with flow depths greater than 50mm to 100mm at all times, and velocities greater than 0.2 to 0.3 metres per second. Reasonable amounts of suspended solids in the flow at all times allows the velocity sensor to record the particle velocities and work out either a 'peak' or 'average' velocity. A good location with excellent hydraulic conditions should be able to reliably read depth to within +/- 2 to 3 mm, and average velocities to within +/- 0.03 to 0.05m/s. These are the sort of supplier claims with regards to the resolution of the sensors, and in a perfect site or a test rig in a laboratory they can be achieved.

Unfortunately sewerage systems are not designed to create perfect flow monitoring conditions, and the actual hydraulic conditions can vary from good to un-monitorable with area velocity type equipment. Even for good sites it is accepted practice to adjust the monitor readings to the manual gaugings measurements as the basis for calibrating and processing the captured data.

With old technology equipment it is more difficult to rely on the monitor velocity readings being entirely accurate, and often adjusting the location of the velocity sensor within the pipe will alter the daily velocity pattern readings for a given depth of flow. Therefore you must have enough depth and velocity of flow to be able to undertake accurate manual gauging's to adjust and calibrate the monitor to. When flows are shallow and less than 50mm in depth, with either fast or slow velocity, is not possible to accurately take calibrations at the site using a traditional hand held pygmy propeller velocity meter.

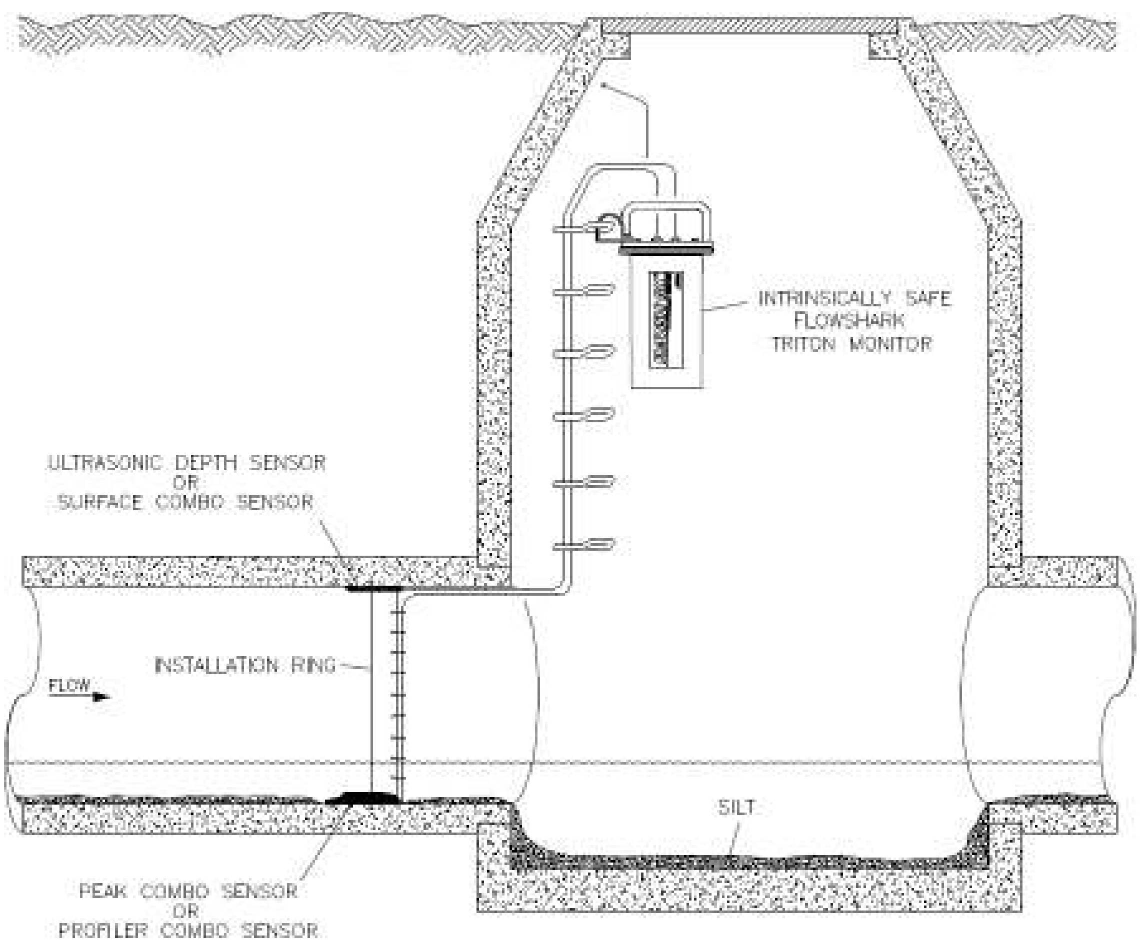

Figure 2: Typical HVQ Installation

Good flow monitoring practice is to undertake a series of very consistent manual gaugings at different flow regimes and adjust the data to the trusted manual gaugings. The gauging point is immediately in front of the sensors some 50 to 100mm in front of the installation ring depending on the type of flow meter. The sensors must be installed well up the pipe to mitigate any potential hydraulic influences of the benching with the manhole [constriction, draw down, turbulence from other incoming lines, etc] from affecting the gauging point selected. Installing sensors at the outlet of any pipe as it enters the manhole to make calibrations easier to undertake is considered bad practice and should not be accepted.

Good practice also requires processing the gauging calibrations from an area velocity monitor against a form of Fitted Mannings primarily as a quality assurance and calibration check on any HVQ site. Use of a Mannings generated flow quantity as the primary final quantity data series should require approval, and should have a sound reason based upon hydraulic principles to justify its use over continuity data. It is suggested replacement of the monitor with a monitor type [potentially an alternative brand or monitor] that can produce good velocity data should always be the first course of action to resolve sites with velocity issues. We provide the following three steps that are used in various flow gauging specifications that the gauging contractors are required to undertake for area velocity type flow metering sites to calculate a Fitted Mannings quantity as part of the quality assurance processes undertaken during a monitoring study data processing procedures.

1) Fitted Manning's quantity data must be generated from the provided depth data and must be used as an independent means of confirming the Continuity data during "free flow" conditions. It shall be calculated for all Area Velocity sites, and its analysis across different flow regimes is an indicator of sites where uniform flow conditions occur, or variable backwater effects are resulting, as well as being a good indicator of the consistency of the contractors gaugings. The contractor shall advise the Engineer immediately if a site is determined as having no suitable Fitted Mannings relationship due to variable downstream backwater levels [e.g. site within backwater influence from a trunk sewer that is frequently rising main influenced].
2) The Fitted Manning's data shall be calibrated using a "lumped" pipe gradient and friction factor that is calculated from the field gauging calibrations undertaken. For the purposes of this specification this "lumped" coefficient will be called a Hydraulic Coefficient (abbreviated as HC). Quite often the HC is depth dependent, hence the depth to HC relationship must also be calculated and presented as part of the calibration presentation process for the Interim and Final Reports.
3) Use of the Manning's Equation and the fitted HC component does not require knowledge of the pipe slope (S_0) or estimates of the pipe friction factor (Manning's 'n'). The HC also takes into account any 'manhole benching' effects that may be resulting.

Fitted Manning's Equation : $Q_m = HC \times AR_h^{2/3}$

Where: HC = Hydraulic Coefficient = $(1/n) \times S_0^{1/2}$

Q_m = Manning's Flow rate

A = Cross-sectional area

R_h = Hydraulic Radius

S_0 = pipe gradient

n = pipe roughness coefficient (Manning's 'n' value)

During field calibrations the depth and average velocity are measured and the gauged Quantity is calculated for the gauging cross-section. The measured depth and quantity are substituted into the Manning's equation and the only "unknowns" are the "lumped" slope and friction components of the Manning's equation, which is known as the "HC". Therefore for the given depth of each calibration undertaken the HC is to be calculated.

The 'HC' Equation : $HC = Q_{gauged} / AR_h^{2/3}$

Where: Q_{gauged} = Gauged Flow rate

A = Calculated from Gauged Depth

R_h = Calculated from Gauged Depth

Whilst a Fitted Mannings type equation will not provide accurate data during backwater or surcharge type periods, it is a useful cross check on the captured flow data for area velocity sites that are in a free flow condition. It is found to work at about 70% of most HVQ type sites for flow ranges from minimum to peak dry weather flows. If a site suffers partial backwater at higher flows, then at least a significant portion of the minimum and average dry weather flow periods of the day may work for a Fitted Mannings flow. We suggest that some cross checking ability between Continuity and Mannings is better than no cross checking at all for quality assurance purposes.

For sites that require velocity sensor adjustment that varies with depth, it has been found through experience that it is best to generate the 'velocity to depth' adjustment factoring using an assessment of the 'un-factored Continuity data against the Fitted Mannings data. The Continuity data adjustment is the same as the required velocity adjustment as

Continuity Quantity = 'velocity adjustment factor' x Velocity x Area

A depth to velocity factor can also be generated from a comparison of the manual gaugings to the monitor data recorded about the time of the gaugings. The problem with this approach is that there is a substantially higher risk that the monitor data at that time has been corrupted by the gauging velocity probe or depth measurement ruler being in the flow at the time of sensor firing. It has also been found that data adjusted by direct gauging comparisons is more likely to have a significantly poorer Continuity and Mannings data correlation. When Continuity and Mannings data does not match for a site that has a consistent depth to HC to depth relationship, then this raises the likelihood that the data processing methodology may be introducing errors into the data being processed for use.

The above discussion has been based upon requirements for 'old technology equipment, whether it is ultrasonic or pressure depth measurement, or whether it be doppler velocity or magnetic velocity sensor measurement.

There are also what are known as Acoustic Doppler Profiling [ADP] velocity sensors available that use gated and targeted multiple velocity sensor readings across the flow cross sectional area to attempt to record a better average flow velocity from the particles within the wastewater flow. They are part of what may be considered the 'new technology' of flow meters, and they have been shown to have increased velocity measurement accuracy. The better performing ADP sensors are significantly larger than most old technology sensors, and they must be very accurately sited in the invert of the pipe or centre of a box type channel. Whilst they are more suited to stormwater gauging applications at this time, they have been used in wastewater monitoring projects. Reported results have advised that they can produce an installed 'un-calibrated' velocity accuracy often within +/- 10%, and a calibrated [depth to velocity factor from gaugings] to within +/-5% or even greater tested accuracies approaching +/- 2% in very good locations.

Some flow meter brands are starting to miniaturise these forms of ADP velocity reading technology for temporary flow meter use, or have vastly improved the velocity sensor and reading processing algorithms and ultrasonic depth measurement sensors of the old technology to a point where recent monitors released to the market are deserving of a 'new generation' description.

As a result of new generation flow gauging equipment, contractors will be doing less data processing, less adjustments and therefore less manipulation of the data. This is providing less chance to make human errors with the processing, whilst also providing some cost savings due to decreased data handling. At the same time there is significantly increased confidence in the provided data as long as the data is being processed by sound methods that can be audited as discussed above. The new generation monitors are also demonstrating that they are able to capture more data from marginal flow gauging sites.

Old technology flow gauges that were well installed and correctly calibrated generally had an accepted accuracy range in a site with good hydraulics typically between +/- 8% during peak and wet weather flows, reducing to 15% to 25% or beyond during minimum night time flow periods depending on how shallow the flows get and the size of pipe. Poorly installed sites near the outlet pipe into the manhole, or in a site with poor hydraulic conditions can have significantly lower accuracies beyond +/- 30% at all times. Poorly edited sites identified in audit evaluations have been found to have peak wet weather flow rates that were up to 30% below the originally provided data due to poor velocity to depth factoring analysis and application. It is recommended that each HVQ type site has a realistic site specific uncertainty statement prepared to indicate the expected accuracy at all flow depths from minimum depth to maximum surcharge depth so that modelers and data users can clearly understand the nominated accuracy of the data set and make clear assessments of the suitability of using the data. The depth and velocity relationships at each site can be determined by preparing scattergraphs from a period of dry and wet weather and the depth and associated typical velocity used to prepare the flow data uncertainty for each 5mm increment from low flow depth to full pipe, then at 100mm increments when the pipe network is surcharging. The uncertainty statements are used to advise modelers of the accuracy of the provided flow data, and can be used to quality code the flow data into accuracy bands for upload into hydrographic database software.

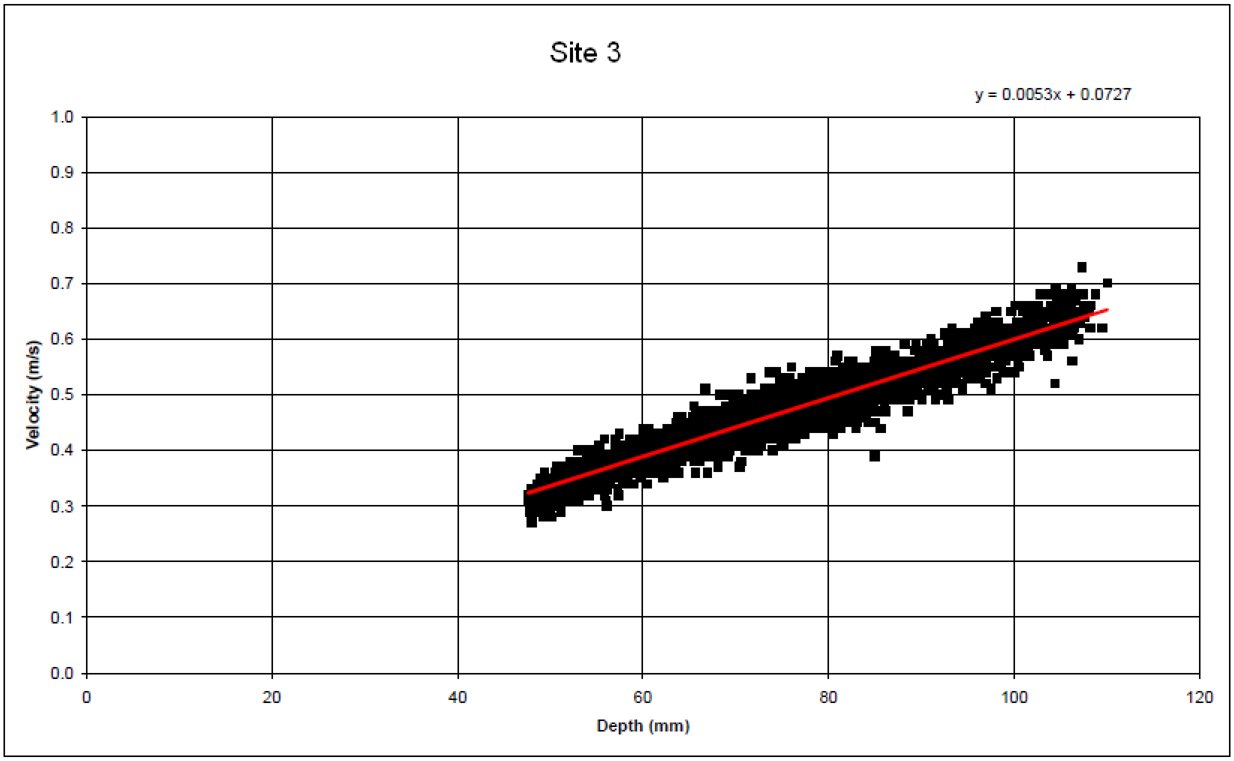

Figure 3: HVQ : Depth to Velocity Scattergraph

Another advantage of the new technology gauges is that there is improved velocity data capture at marginal sites with poorer hydraulic conditions or significant clear [infiltration] flows at night. A current site with a new technology monitor is currently recording over 98% velocity data availability after editing. The same manhole was previously monitored with a good brand of 'old technology' equipment could only record 67% percent of velocity at the site. The latest results of 98% are clear indication that the new technology velocity sensor and reading processing technology has made significant improvements over the old technology sensors. General observation of all except one site in the current project is that all sites are providing more than 98.7% velocity data availability, with exceptionally good manual to monitor calibration accuracy using fixed velocity adjustment factors that are applicable over all flow regimes, ultimately simplifying the data processing and minimising the adjustments to the velocity data. This leads to more accurate flow data being produced.

2.2.4.2 WEIR AND FLUME MEASUREMENT [HQ INSTALLATIONS]

Generally small pipes in the range of 150mm to 225mm diameter have the highest inaccuracies due to small flow quantities if a HVQ type installation is used. There is often not enough flow to undertake manual gaugings. The preferred way to improve low flow monitoring accuracy is to install a 90 degree angle V-notch weir structure across the manhole. This angle is the preferred angle by most companies after many years of use of weirs. Smaller notch angles would give higher flow quantification accuracy, but they are more prone to debris blockages catching in the notch. Angles larger than 90 degrees are suitable for use if there are higher flow rates at a particular site to justify their use. Quantity from a weir is derived using ISO Standard weir tables or approved formulas that are depth dependent. Weirs concentrate low flows through the weir notch, and the level is measured in the typically calm weir pool behind the weir board. Therefore good level measurement of 1 to 2mm results and better flow quantification accuracies result for the smaller pipes with lower flows. Accuracy is still expected to be within the 8% to 15% range. A HVQ type monitor in a smaller site, even with a hump or other flow bunding device behind it would be likely to be half the accuracy of a weir gauge. Whilst weir gauges are preferred to measure smaller flows on branch sewers for intensive Inflow / Infiltration monitoring type purposes, weirs can have a localised hydraulic 'loss' effect that must be considered when selecting them as a gauge type. Cut down weirs partially within 300mm diameter trunk sewers can sometimes be used with great success if there are small dry weather flows in the trunk sewer that would be too low to use a HVQ type monitor configuration. Weirs should not be used immediately downstream of overflow locations, gully traps that overflow or in areas where the increased loss could result in manhole lid overflow.

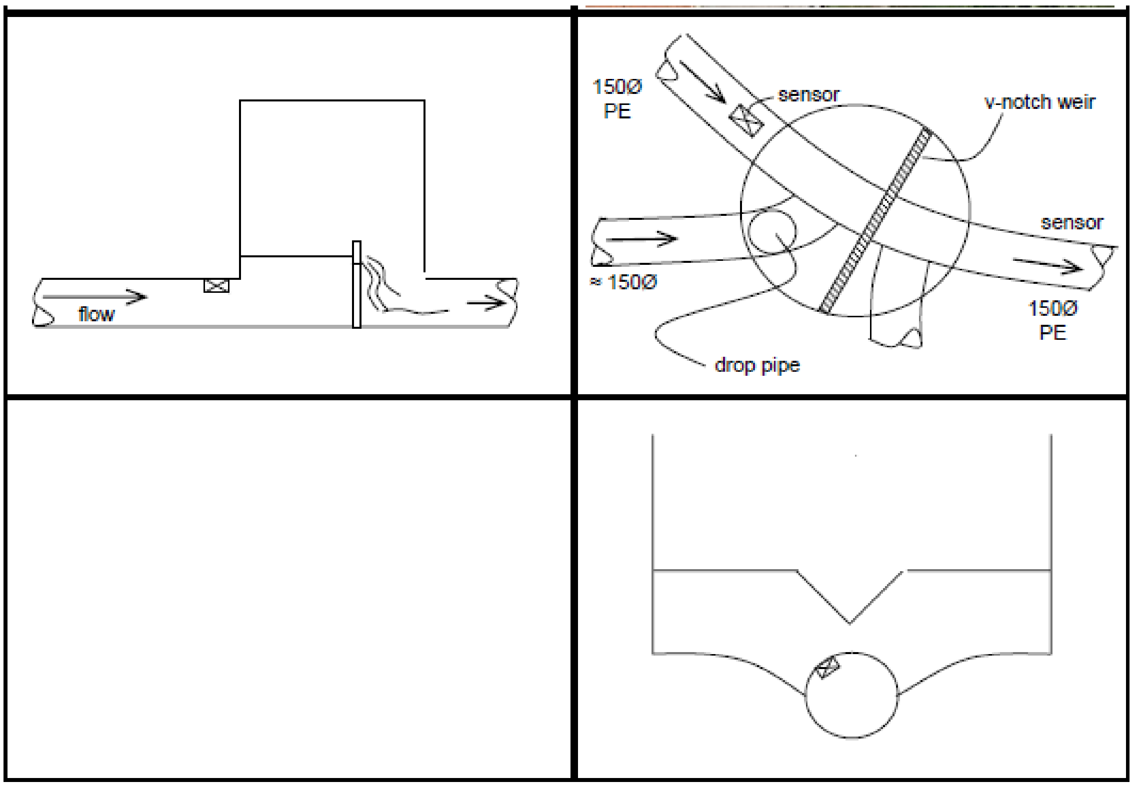

Figure 4: Typical Weir Installation Schematic

Flume structures are less accurate than weirs as there is a larger cross sectional flume area that results in less resolution of the depth changes for various flow rates. They are still more accurate than HVQ gauges in low flow sites, and they still promote a minor weir pool upstream of the flume that promotes more accurate level sensor readings than a HVQ type gauge. Flumes are generally limited to pipeline gradients less than 2 percent fall. Flumes are also suitable for use upstream of overflows and other areas with surcharge issues

The common misconception with Weirs and Flumes is that they are not suitable for use during surcharge periods. The reality is that they are well suited when a good velocity sensor is installed up the incoming pipe(s), and the velocity sensor is well maintained. Preference for a weir or flume site is to install it in a manhole with only one major incoming pipe, requiring only one velocity sensor. During increased wet weather flows there should be sufficient velocity for the velocity sensors of a weir or depth and velocity recordings from upstream of a flume to generate continuity data from before, during and after any surcharge periods. There is typically some continuity data during adwf and pdwf flow periods each day that allows the weir or flume to have an independent cross checking continuity entity to be generated and available for quality assurance checking of the weir or fume flows. Similar to area velocity type sites, this cross checking second flow data ability provides confidence that the sites remain calibrated whilst the two quantities match.

For a weir site the velocity sensor is installed in a full pipe, therefore continuity data [from Pipe Area x Velocity] can be calculated and typically a single velocity adjustment factor can be determined by using the calibrated weir quantity data. Weirs can suffer deposition and they need to be thoroughly cleaned at least once per week, as deposition materials can fill the incoming pipe and take up area.

For a flume site a depth and velocity sensor is located in the incoming pipe, and the depth is used to calculate the flume depth and hence flow from the flume's depth to discharge rating table. During calibrations the manually taken depth is recorded at the flume pool area just before the table section of the flume, but it is also measured at the sensor location up the pipe. Therefore it is possible to back calculate a HVQ continuity flow from the depth and velocity sensors up the pipe at the flume site. Flume devices can be difficult to install, and they must remain tightly wedged into the manhole benching so flow does not seep under the flume. The photograph below shows a flume tightly packed into a manhole benching and firmly held in position using timber wedges and props.

Photograph 1: Typical Flume Installation

It is always preferable to use a weir or flume to measure low flow sites rather than install a small lump of epoxy, padded steel band or wood behind a HVQ site to force flows to always be greater than 50mm. This sort of flow obstruction usually induce poor general hydraulics and can induce swirling during minimum flow conditions.

3.3.5 EXPECT THE UNEXPECTED

The trials and tribulations of flow metering has time and time again taught the lesson that you should 'expect the unexpected'. A few lessons learnt and reinforced over the years are :-

a) Check your overflow structures before and during any monitoring period. Network blockages have been found to result in long term overflows during previous studies. Having pre-analysis of a theoretical mini-catchment average dry weather flow rates from property counts led to one long term overflow being discovered when the flow data captured was one third of the expected amount. This prompted a catchment walk over which found the blockage at an overflow site resulting from a large Coke bottle jammed in outlet pipe of the manhole. Another recent overflow was easily found during a flow meter data collect at an overflow site, as the site was found to be overflowing during a dry weather period due to a downstream system root blockage.

b) Don't believe everything you are told. A client once insisted that a very large overflow tank never overflowed as no overflow had been recorded by the telemetry system. Below is the photograph of the overflow float switch positioned above the overflow sill level that was found to be the reality.

Photograph 2: Overflow Float Alarm Switch Above Overflow Sill Level

c) Check to make sure your system is flood proof. If manhole lids are located at the bottom of stormwater detention basins, or can backflow stormwater from streams if their lids frequently come off during heavy rain, do the necessary repairs / relocations <u>before</u> any flow metering project to prevent massive inflows into the network.

d) Review overflow structures and ensure that they cannot backflow into the wastewater network and act as sources of massive inflow. Make sure your overflow flap gates in streams and coastal reserves are free to open and operate when required. It is amazing how many get covered in mud or wedged open by debris.

e) Make sure all of your pumps and control start / stop systems at pump stations are working well. Don't program major maintenance events at pump stations during the monitoring period.

f) Ensure operations staff program annual line cleaning works to be done <u>before</u> the monitoring project, not during it.

g) If early data indications find a problem catchments with excessive I/I ingress, undertake further wet weather walkover or flow isolation investigations or install additional monitors to isolate problem areas to assist in determining the nature of the excessive flow source(s) during the monitoring period if possible.

h) Make sure your water treatment plant isn't flushing backwash water into the gravity sewer system at significant flow rates. Also check to see if the water treatment plant has an alarm on any bypasses that discharge raw water flows to the sanitary sewer before the dam is nearly empty.

4 CONCLUSIONS -

The conclusions that can be drawn from our observations of the flow monitoring industry over the past 10 years are as follows:-

- Auditing data during the data collection process should produce data at the end of the monitoring periods with no anomalies, and provide certainty and agreement about all of the work provided. Auditing after a flow monitoring study is far less successful with regards to salvaging problematic data, but can be undertaken to provide a form of Peer Review of historical data sets.

- When considering equipment purchases or engaging flow monitoring contractors for gauging works, part of the tender assessment should review, and weight accordingly, the supply of new technology flow meters that have a proven track record. Seek many opinions from independent users of various flow metering data before selecting a contractor.

- New generation monitoring equipment is demonstrating significantly improved monitor accuracy and greatly improved velocity data capture, meaning that previous sites considered to provide marginal data capture are now showing vastly improved levels of data capture.

- Historically the old adage "you get what you pay for" is applicable to the flow monitoring industry. The good news is that modern equipment is now available within the industry and there are Clients willing to pay for superior accuracy flow data. The unfortunate news is that it is likely to cost more than previous studies to do monitoring to a higher standard, but as more projects are undertaken, costs will reduce and an acceptable level of accuracy for data that is fit for purpose will be the result.