THE USE OF ACOUSTIC DOPPLER PROFILING IN WASTEWATER NETWORKS

Peter Stephens – AWT New Zealand

ABSTRACT

Acoustic Doppler Profiling (ADP) has had widespread use in stream gauging since 2000. Typically the use of ADP technology has involved using portable instruments that have relatively quick deployment times, highly repeatable results with low measurement uncertainty. The use of ADP's has in many instances as made velocity profiling of stream flows a redundant methodology. Over the past 3 years ADP's has been developed as fixed installations for the measurement of stormwater and irrigation flows. However, their use in gravity wastewater systems is relatively unreported. In this article we report on our use of ADP's in large gravity wastewater pipes in New Zealand with particular emphasis on ADP site installation, calibration and maintenance. Our findings indicate that although further development of ADP wastewater monitoring systems is required, the enhanced flow data accuracy means that this technology is the future of flow monitoring.

KEYWORDS

Wastewater, Monitoring, Acoustic Doppler

1 INTRODUCTION

Wastewater flow monitoring has been undertaken using area-velocity (HVQ) monitors for over 20 years. The principle of HVQ velocity measurement is continuous wave Doppler. The instrument obtains the water velocity by transmitting sound of known frequency into the water and measuring the Doppler shift of reflections from particles in the wastewater, which are assumed to be passively moving with the water.

Experience has demonstrated that HVQ monitors provide flow data to within ±7-15% measurement uncertainty under good conditions. The measurement uncertainty increases in shallow flows (<60mm), slow flows (<0.2m/s) and under complex hydraulic conditions (backwater, non-uniform velocity distribution).

Contradictory to the exaggerated claims of equipment manufacturers, there is not a continuous wave Doppler velocity system that records an accurate mean velocity. The reasons vary but include:

- The principle of operation is to measure the peak velocity through a narrow band of flow with calculation of average velocity based on a theoretical algorithm.
- A single velocity beam can only sample through a small percentage of the total flow. Particularly in large pipes the slower velocities to the sides of the pipe are ignored as are the faster velocities at the surface in deep flows.

Therefore the only way to accurately calculate mean velocity is to undertake in-situ calibrations (typically velocity profiling using current meters) over the full range of anticipated flow conditions. A depth-dependent relationship between sewer depth and velocity adjustment factor (velocity index) is generated and applied to the raw velocity data captured by the flow monitor. This calibration procedure is technical and time consuming and significantly adds to the cost of flow monitoring projects.

2 ACOUSTIC DOPPLER PROFILING

The principle of operation of an acoustic Doppler instrument differs from continuous wave Doppler in that the Doppler signal is pulse-gated. Rather than receiving a continuous signal, the received signal is gated so that the time elapsed between the transmission of the pulse and the opening of the gate determines the depth of the velocity measurement, i.e., the position of the sample volume. What this effectively means is that the flow can be divided up into small depth segments (bins), through the water column, in multiple directions. By repetitive sampling of the return echo, and by “gating” the return data in time, the ADCP can produce a "profile" of water currents over a range of depths.

Reliable operation is observed in relatively clear flows (>50ppb particles), slow flows (0.03 m/s), negative or reverse flows and high velocity (up to 5.0 m/s). Minimum depth limitations apply (see later discussion) but under typical conditions a ±2-4% measurement uncertainty range is regularly achieved.

There are several pulse-gated acoustic Doppler velocity profiling systems on the market that are available for fixed installations. They vary from a single beam to four beam systems. Manufacturer claims vary from never needing calibration to velocity indexing is essential. This paper investigates the use of multi-beam pulse-gated acoustic Doppler velocity sensors in wastewater systems.

3 WHEN CAN I INSTALL AN ADP?

There are two types of multi-beam instruments on the market that AWT has tested – Sontek Argonaut SW and ISCO ADFM (AccQmin – shallow water applications & PRO20).

The ISCO AccQmin can be installed in pipes up to 1200mm diameter provided that the minimum depth exceeds 75mm. In practice, the size of the sensor and nature of urban wastewater flows in New Zealand means that a 375mm diameter is about the smallest pipe diameter. Although velocity profiling is functional in 75mm depth, velocity data quality is typically poor until a depth of 150mm is reached.

The Sontek Argonaut-SW and ISCO PRO20 systems can be installed in pipes up to 6000mm diameter provided that the minimum depth exceeds 300mm. In practice, the size of the sensor and nature of urban wastewater flows in New Zealand means that a 900mm diameter is about the smallest pipe diameter. Surprisingly, velocity profiling is functional in 200mm depth with good data quality.

The presence of silt in the invert of the pipe is problematic (discussed later). Generally large amounts of silt (50mm or greater) preclude the use of ADP systems.

4 INSTALLATION OF AN ADP

Both SonTek and ISCO have upward looking ultrasonic sensors for both depth measurement as well as dynamic boundary adjustment of the velocity beams. Dynamic boundary adjustment is a function of the monitors that ensures that the flow velocities are profiled to the surface of the flow.

Therefore it is essential that the sensors are installed in the centre of the pipe invert for correct operation. This requirement creates two immediate problems:

1. If silt is present in the invert the ADP sensor can’t be rotated up the pipe out of the silt. ISCO makes a mount to increase the height of the sensor above the silt. In practice this system doesn’t work well as silt tends to accumulate around the raised sensor creating debris accumulation (sensor ragging) problems. The washing of silt over the sensor also leads to intermittent loss of depth and velocity data.

2. In large (>2000mm) wastewater pipes (inlet flows to Mangere WWTP & Christchurch WWTP), the minDWF depths range from 450 – 850mm deep. The sensor is attached to a stainless steel band that must be bolted securely to the invert of the pipe. Working in such depths may require compressor-driven drills / tools that can survive immersion in wastewater, dry-suits or commercial divers.

Orientation of the sensor so that is perpendicular to the flow is also critical. The diagnostic functions of the sensors (velocity vectors & beam correlations) will indicate poor alignment. Poor alignment will result in reduced data accuracy. Aligning a sensor in a fast flowing, 800mm deep flow is not easy.

The sensor band must be flush with the invert, securely bolted with the sensor cable neatly tied to the back of the sensor band. If debris can catch it will! If debris catches close to the sensor it may cause velocity signal deterioration.

5 IS THE NUMBER OF VELOCITY BEAMS ON A SENSOR SIGNIFICANT?

Short answer is yes but there are more significant factors such as:

1. Beam Direction: how many sensors facing upstream / downstream? Are the beams perpendicular to the flow or angled towards the pipe walls?

2. Beam Angle: Are the sensor eyes are flat on the surface of the sensor or at a 30^o or 45^o degree angle? What is the beam width through the flow?

3. Frequency of the acoustic signal: The higher the frequency (MHz) the shorter the profiling range of the instrument. However low frequency instruments have a greater dead-band (distance from the face of the instrument that the transmitted signal and return signal can't effectively be separated) – this is observed in practice as the minimum depth required for operation.

6 IS VELOCITY INDEXING REQUIRED?

Yes, velocity indexing is required. The degree of velocity indexing required is instrument and site specific. As a guide:

- Always undertake in-situ velocity profiling using current meter or moving ADP technology to assure that both the level and discharge data being captured is within specified measurement uncertainty.

- The more complex the pipe geometry (ovoid pipes, dome-shaped, rectangular & trapezoidal) the greater the requirement for indexing as it is unlikely that the velocity beams will be able to measure all areas of the flow.

- The more complex the hydraulic conditions (backwater, pumped flow, variable hydraulic conditions created by pipe conditions [roughness, offset joints] or flow approach [bends]) the greater the requirement for indexing.

- The more velocity beams and the better their flow coverage, the closer the correlation between the recorded and in-situ profiled velocity.

- The ratio of flow depth to flow width is critical. Keep this ratio under 4:1 (width to depth) under good hydraulic conditions then indexing is usually close to 1. Once a ratio of 12:1 is exceeded, significant indexing is required.

For example, circular pipe of 1200mm diameter: two-beam Sontek Argonaut-SW system provided raw velocity data to within ±8%. Three-beam ISCO AccQmin system provided raw velocity data to within ±3%. After indexing both systems provided discharge data to ±2-4% over a full range of flow conditions.

A two-beam ADP installed in a rectangular pipe with dimensions of 2600mm x 2400mm could only provide raw velocity data to within ±16%. After velocity indexing, discharge data was provided to ±4% over a flow range of 0.8 – $9m^3$/sec.

7 THE AWT EXPERIENCE

AWT has trialed acoustic Doppler velocity technology in wastewater pipes ranging in size from 375mm – 2400mm. Our experience is:

1. Don't use shallow water ADFM instruments in depths <150mm.

2. Keep the Sontek Argonaut-SW system under at least 300mm flow always for best velocity profiling.

3. Always be mindful of the width to depth ratio. Try and keep the ratio below a maximum of 4:1.

4. Set the units up to sample continuously and provide an average value every 5 or 15 minutes. The internal quality auditing of the instrument tends to filter out spurious readings using proprietary diagnostic checks. The more readings the more likely the quality control is correct.

5. Understand and use the diagnostic functions: beam check & correlation & signal to noise ratio. These diagnostic functions will indicate when service / maintenance are required as well as data quality issues.

6. The acoustic properties of wastewater are not well known. This equipment was primarily designed for stream monitoring where high levels of hydrocarbons, fats & greases are abnormal. Signal strength may deteriorate although the flow has a lot of particulate and the sensor is clean.

7. Data accuracy, particularly in slow flows (<0.2 m/s velocity) and under complex hydraulic conditions, is a magnitude better than traditional HVQ monitors. The velocity data just doesn't have drop-outs, spikes and sags. Data analysis, once the velocity index is established, is minimal making it ideal for SCADA systems.

8. Emphasis on manufacturers to further miniaturize the sensor head and streamline the sensor profile to ensure good debris shedding. Current instruments are too high and have too many sharp angles for maintenance free operation.

9. Manufacturers need to further refine beam numbers & geometry to increase the flow coverage during velocity profiling.

8 CONCLUSION

The use of acoustic Doppler technology for wastewater flow monitoring is still in its infancy. Manufacturers still have a challenge to refine the sensor profile, number of beams and beam geometry for optimal operation and to ensure that the instrumentation can be used in a wider range of wastewater monitoring applications. The significantly greater expense of acoustic Doppler systems and narrow range of applications mean that its use will be limited to applications where traditional HVQ monitoring yields poor results or when high accuracy flow monitoring is required (consenting & process control).

Velocity indexing (in-situ calibration) is still essential but the initial 18-months trial undertaken by AWT would indicate that once calibrated the data from instrument remains very consistent – significantly reduced calibration required compared with HVQ monitors. The data accuracy from an acoustic Doppler profiler is typically 5-10% more accurate in good hydraulic conditions and much more under non-ideal conditions. It is hard to envisage this technology not being standard for most wastewater flow monitoring applications in the next 2-3 years.