Exhibit (how to measure flow)

Flow Measurement

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Introduction

The use of standard methods and devices for the measurement of flow and the study of hydraulics in general are areas where much investigation has been conducted and the science is well established. Within the agricultural, water supply and wastewater treatment industries, standardized approaches have been widely and successfully adopted. Conversely, the misapplications of flow measurement methods and equipment have the potential to result in highly inaccurate results, wasted resources and an inability for NMED to understand the volume and potential impact of wastewater discharges. Selecting, installing, calibrating and maintaining a flow measurement device to provide accurate and reliable measurements over a reasonable service life is rooted in an understanding of the basic science, the nature of the flow stream to be measured and the operating conditions to which the meter will be subjected.

I have gained experience in a variety of methods of flow measurement through my career as a water and wastewater operator, as a trainer/technical assistance provider working with facility operators throughout New Mexico and as the domestic waste team leader of the Pollution Prevention Section of the Ground Water Quality Bureau. What follows is a summary of my understanding of the approaches to flow measurement, their strengths and failings and the practical aspects of accomplishing accurate flow measurement in the harsh environment of water treatment/supply and domestic wastewater treatment facilities. The methods discussed are entirely applicable to the flow measurement of wastewater for dairy facilities operating in New Mexico.

One of the foremost authorities on flow measurement is the United States Department of the Interior Bureau of Reclamation (BOR). In particular, the BOR's *Water Measurement Manual* is an appropriate and widely used source for information on flow measurement. Some of the material for my testimony concerning flow measurement methods (20.6.2.3220.L), flow meter inspection (20.6.2.3220.P), and flow meter calibration (20.6.2.3224.E) is adapted from the BOR's *Water Measurement Manual*. Other material is drawn from the references cited and/or my experience.

Flow Measurement Units

Two types of units are used in measuring water: units of ***discharge*** and units of ***volume***. Discharge, or rate of flow, is defined as the volume of water that passes a particular reference section in a unit of time. Please note that this definition of discharge is applicable only in the context of my testimony, and should not to be confused with the regulatory meaning of the term. The units of discharge include cubic feet per second

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(cu.ft./sec), gallons per minute (gpm) and millions of gallons per day (MGD). The units of volume commonly employed are the acre-foot (ac.-ft.), gallons (gallons), and millions of gallons (MG).

Types of Flow Measurement Situations

There are two basic types of flow measurement situations: (1) gravity flow in an open channel and; (2) pumped flow in a closed-pipeline completely full of liquid. When classifying flow measurement situations, other factors, such as the solids content of liquid and steady state flow versus highly variable/intermittent flow, should also be considered.

Open Channel Flow Measurement

Open channel flow is defined as any channel in which the liquid flows with a free surface. Examples include rivers, gravity sewer lines and irrigation ditches. There are numerous methods for determining the flow in open channels, but the basic formula is:

$$Q = AV$$

Where: Q = *quantity of flow*
A = *the cross sectional area of the open channel, and;*
V = *the velocity of the liquid in the channel*

This equation assumes perfectly non-turbulent (i.e., laminar or low calculated Reynolds number) flow conditions within the open channel, which is difficult to approach in most settings. The development of open channel flow meters has largely been concerned with the construction of hydraulic structures that produce a flow that is characterized by a known relationship (usually nonlinear) between a liquid level measurement (head) and the flow rate of the channel. Hydraulic structures that achieve this aim are termed hydraulic structure **"primary measuring devices"**.

Head measurements of the liquid level in a hydraulic structure are taken on a standardized staff gauge which typically is graduated to read out in 1/100 of a foot and zeroed to the level that no flow exists through the structure. From the head measurement, the rate of discharge can be calculated using the appropriate equation for the specific device or from standardized tables for the specific device. The device specific equations include coefficients developed from mathematical and/or empirical models. Hydraulic structure primary measuring devices are unique in that once properly constructed; the actual rate of discharge moving through the device can be readily measured to a reasonable accuracy by anyone needing to do so, thus preventing attempts to obscure an accounting of the actual discharge. The most common hydraulic structure primary measuring devices for open channel flow measurement are weirs and flumes.

Weirs

A weir is essentially a dam located in an open channel which causes a head rise as water crests over the weir. Weirs are one of the oldest, simplest and most reliable structures for measuring flow. Where the weir's construction is held to standardized characteristics, the head rise over the weir crest is related to the flow through the structure, which can be determined using an equation specific to the weir type/size or from standardized tables for various weirs. A variety of weirs shapes and sizes exist, including; rectangular, triangular (V-Notch), trapezoidal (Cipolletti; see figure 1, below) and proportional (Sutro) as well as compounds of these types. Weirs can be constructed with, or without end contractions. Weirs without end contractions are also know as *suppressed* (i.e., the end contractions are suppressed). The weir crest can be either sharp or broad, although sharp crested weirs are far more common for wastewater applications and are generally more accurate. A stilling well is used to reduce the velocity of approach to a negligible rate, prior to water cresting the weir. The size, shape and depth of the stilling well must follow specific requirements to achieve standardized characteristics. Head measurements are taken on a staff gauge located at least four times the maximum head away from the weir to avoid the influence of drawdown.

Figure 1; *Cipolletti weir*

One of the chief advantages of the weir is its simplicity. Once a weir has been properly installed, any problems with its function are readily evident and can generally be easily corrected. Routine maintenance for weirs includes cleaning of the stilling well and of the crest to ensure settled/trapped debris does not detriment the accuracy of the structure. Weirs are generally applied to flow streams that do not have excessive settleable solids or trash, such as treated wastewater. They can be used effectively in less than ideal water quality conditions, but the maintenance requirements increase if accuracy is to be maintained. Due to the presence of high amounts of suspended and settleable solids in untreated dairy wastewater, weirs are unsuitable for measuring the flow at these facilities under most circumstances. The head loss required for the operation of a weir is one of its chief disadvantages.

Flumes

A flume is a section of an open channel with a contraction and/or change in channel slope which produces an increased velocity and/or a head rise in the liquid moving through the structure. Flumes typically consist of a converging approach channel, a narrowed middle section; know as the *throat*, and a diverging section that assures that the downstream level is lower than the level in the approach channel. In the preferred configuration of a flume, the flow can be accurately determined by measuring the head at a single location. The relationship between head and rate of flow can then be determined from standardized tables for the appropriate type and size of flume.

Flumes can be classified by the state of flow they induce; subcritical and critical. Subcritical flow is characterized by a low velocity, nearly flat surface and a tranquil or streamlined condition. Technically, it is a state where the force of gravity dominates over the force of inertia. Conversely, critical flow is characterized by a state where inertial forces dominate over gravity. Critical flow is induced in a channel by the insertion of a flume that uses a contraction and/or vertical drop to convert the subcritical channel flow to critical. Flumes used for most applications in public water supply, wastewater and agriculture are designed to operate in a critical state because this generally allows the use of a single head measurement to determine the rate of flow.

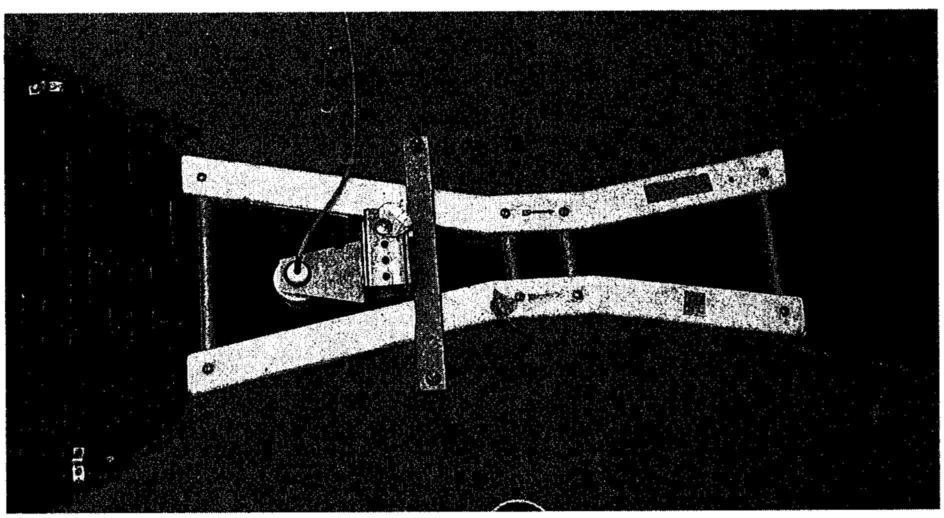

Figure 2; *Parshall flume*

There are a variety of flume types, including; cutthroat, trapezoidal, H-type, Palmer-Bowlus, Parshall flumes and the modern long-throated flume. Of the types, the Parshall flume (see figure 2, above) is the most widely employed for the measurement of water supply, wastewater and agricultural flows owing to its advantages (simplicity, wide availability, reasonable accuracy). Flumes can accurately measure a wide range of flows, require less head loss than weirs, are relatively insensitive to the approach velocity in the channel, can accurately measure flows under conditions of no downstream submergence, partial submergence and considerable submergence, and are self scouring. The self scouring aspect of flumes means that they operate well with discharges containing significant suspended solids. For this reason, flumes are particularly suited to the measurement of raw domestic wastewater, stormwater and untreated dairy wastewater.

The design, construction, maintenance and use of flumes must follow specific requirements in order for accurate flow measurements to be achieved. If standard head/discharge equations or tables are to be used for determining flow, the dimensions of the flume must be reproduced accurately and the installation must meet a number of criteria, depending on the flume type and size. In particular, attention must be paid to the approach channel leading up to a flume. Turbulence, eddies and surging conditions are to be avoided. Flumes should never be placed directly following a right angle in a channel and efforts should be made to smooth the flow prior to entering the flume. Additionally, the condition of downstream submergence must be understood for a given flume type and size because head readings from dual locations are often necessary for accurate flow measurement under conditions of submergence. For this reason, flumes should be sized and installed in a manner that ensures "free flow" (i.e., critical) conditions to ensure there is insufficient submergence at the flume outlet to reduce the discharge rate. Flumes can be constructed using a variety of materials, but should be resistant to corrosion. Prefabricated fiberglass, metal and plastic flumes are widely available.

Head Sensing and Recording Equipment

Primary measuring devices allow the determination of the rate of discharge for flow in an open channel. However, if the volume discharged over a period of time is to be determined, some method of constantly measuring the head in the device and totalizing the volume that has passed through the device over a given time period is needed. Head sensing, readout and recording instruments fill this roll and are collectively known as "**secondary devices**".

Head sensors are instruments that measure the operating head in a primary measuring device and transmit a signal that is proportional to the measured head to readout and recording instruments. In the past, mechanical head sensing systems, consisting of floats, cables and pulleys were common. Modern devices utilize a number of electro-mechanical based methods, including; ultrasonic transducers, capacitance probes and bubblers to sense head.

Equipment designed to receive and record the signal from a head sensing instrument and then produce a totalized record of flow for a set time-frame are universally referred to as flow *totalizers*. Totalizers from the past consisted of weight or spring driven drums with mechanical signal inputs driving pen on paper. Modern devices consist of electro-mechanical chart recorders, odometer style totalizing readouts and computer based data loggers. Direct readouts of the instantaneous rate of flow are generally incorporated into totalizers.

Estimated Hydraulic Structure Primary Measuring Device Equipment Cost

The equipment and engineering cost for a typical primary measuring device for the measurement of discharge volumes on the order of 0.1 – 1.0 MGD, including head sensing and totalizing equipment and engineering fees are estimated to be as follows:

Pre-fabricated Parshall flume (6")[1]	$3,000.00
Head sensor and totalizer[2]	$2,000.00
Engineering services (10% typical)	$500.00
Total cost	**$5,500.00**

The installation costs are site specific and therefore difficult to estimate. Installation fees could include the cost of bringing 110V electrical service to the site, excavation, concrete work and other costs. Additional design work will incur additional engineering costs. The cost for the installation of open channel devices generally exceeds the cost for close-pipe devices, but once the hydraulic structure is installed, there is generally no ongoing or replacement cost other than for head sensing and totalizing equipment.

Closed-Pipe Flow Measurement

A wide variety of approaches to flow measurement in closed-pipe situations exist and the selection of a method requires a good understanding of the nature of the liquid to be measured. These methods include; venturi meters, flow nozzles, orifice meters, Pitot tubes, trajectory methods, current meter method and commercial meters. The basic formula for flow remains $Q = AV$, as previously discussed in the open channel flow measurement section, but in a closed-pipe setting, the cross sectional area is generally fixed and the measurement method centers around some way of determining the velocity of the fluid in the pipe. It is generally recognized that the physical element of the meter that is acted upon by water in the pipe constitutes the primary measurement device in a closed-pipe flow measurement situation. Instantaneous readout and/or totalizing mechanisms constitute secondary devices in this context.

For practical purposes, the only closed-pipe flow measurement method widely used for water supply, wastewater treatment and agricultural purposes is the commercial flow meter. For this reason, only this method is discussed further.

Commercial Meters

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[1] USA Bluebook part # 18214 available at: http://www.usabluebook.com/
[2] USA Bluebook part # 26483 available at: http://www.usabluebook.com/

Commercial meters used for flow measurement in closed-pipes can be classified in three general categories: (1) the displacement type, (2) the velocity sensing type and; (3) the by-pass type or proportional type (which often employs velocity sensing). Displacement and by-pass type meters have few applications in the measurement of wastewater flow streams, due to inherit limitations of their designs. No further discussion of these types of meters will occur here and NMED is recommending against the use of all types of flow measurement devices other than commercial meters that rely upon some form of velocity sensing for closed-pipe situations.

Velocity Sensing Meters

There is a wide array of commercially available velocity sensing flow meters. The types include; the turbine meter, the propeller meter, the magnetic meter, the Doppler Effect meter and the transit-time meter. The function of each is described briefly as follows:

- Turbine meters use a multi-bladed propeller rotating a shaft parallel to the pipe-line axis to measure the velocity of the liquid. The cross sectional area of the meter is fixed, therefore; the discharge can be determined according to Q = AV. These meters mechanically (or electromechanically) transmit the velocity information to readout and totalizing equipment. They are commonly recognized as a standard "water meter". Traditional models were entirely mechanical and required no electricity; however, modern meters often use datalogger devices and therefore require an electrical power supply.
- Propeller meters operate similarly to turbine meters with the exception that a propeller (paddle wheel) rotating perpendicularly to the direction of flow in the pipe is used to measure the velocity of the liquid. The cross sectional area of the meter is fixed, therefore; the discharge can be determined according to Q = AV. The velocity measurement is transmitted to readout and recording instruments, similar to turbine meters.
- Magnetic meters (known as mag-meters) rely on the fact that voltage is induced in a conductor moving though a magnetic field. In this case, an electromagnetic field is created in a pipe section and the water flowing through the pipe acts as a conductor and induces voltage. For a given field strength, the induced voltage is proportional to the velocity of the liquid. The cross sectional area of the meter is fixed, therefore; the discharge can be determined according to Q = AV. The measured voltage is electronically conveyed to readout and recording instruments. A source of electrical power is required.
- Doppler Effect meters use ultrasonic pulses reflecting off of bubbles and suspended solids in the liquid. The velocity of the liquid in the pipeline is determined by discerning the frequency shift (Doppler shift) that results when the sound pulses bounce off of the moving bubbles or particulates. The cross sectional area of the meter is fixed, therefore; the discharge can be determined according to Q = AV. The measured velocity is conveyed to readout and recording instruments as an electronic signal. A source of electrical power is required.

- Transit time meters use ultrasonic pulses from two sources aimed diagonally through a pipeline at each other. By detecting the change in transit time between a pulse traveling with the flow and one traveling against it, the velocity of the fluid in the pipe can be determined. The cross sectional area of the meter is fixed, therefore; the discharge can be determined according to Q = AV. The measured velocity is conveyed to readout and recording instruments as an electronic signal. A source of electrical power is required.

Advantages and Disadvantages of Commercial Meters

Commercial meters are generally recognized as cost effective, accurate flow measurement devices. Compared with the demands of open channel devices, the installation of commercial meters in a closed-pipe setting generally require less space and is easier to accomplish in most respects. Because the velocity of liquid in a closed pipe-line is not uniform throughout the entire cross sectional area of the pipe, commercial meters have been developed which average the velocities, thus producing a highly accurate measurement (often within +/- 2% of actual flow in laboratory settings). Commercial meters are constantly under development and new approaches are being introduced on an ongoing basis, thus improving upon the performance of this group of devices.

Under ideal situations, commercial meters are capable of very accurate flow measurement. However, achieving the ideal operating conditions is generally not possible, due to limitations on piping configurations and variations in the flow stream being measured. In fact, many factors can contribute to significant inaccuracies for these types of devices under real world conditions. Confounding matters, unlike an open channel primary measuring device, there is no easy method for assessing the overall operating condition and accuracy of in-pipe commercial meters.

Each commercial flow meter type has its strengths and weaknesses, which should be understood during the selection process. Without exception, these devices are designed to operate in pipelines flowing full with liquid that is moving within a minimum and maximum velocity. When operating without a full pipe-line or outside of the velocity range for which they are designed, significant inaccuracies are to be expected. For instance, since their inception, it has been widely understood that mag-meters are most accurate when the velocity in the pipeline is in the upper half of their design range and in excess of 1 meter per second. Yet, I have seen this type of meter applied to situations where the velocity is in the lower half of the meter's range and/or below 1 meter per second, with inaccurate measurements and dissatisfaction with the meter being the result. Turbine meters can provide an accurate measurement of flow when properly applied; however, this type of meter is subject to significant error from anything that causes increased resistance in the turbine or bearing it spins upon. For this reason, these meters are not well suited to measuring water with suspended solids or water that will spur the growth of bio-fouling. This makes them impractical for most wastewater flow measuring applications, yet attempts at using them in the wrong application continue, with poor results.

Estimated Velocity Sensing Commercial Meter Equipment Cost

The cost for a typical velocity sensing flow meter for the measurement of discharge volumes on the order of 0.1 MGD, including readout and totalizing equipment and engineering fees are estimated to be as follows:

Mag-Meter[3]	$3,500.00
Engineering services (10% typical)	$350.00
Total cost	**$3,850.00**

The cost for a typical velocity sensing flow meter for the measurement of discharge volumes on the order of 1.0 MGD, including readout and totalizing equipment and engineering fees are estimated to be as follows:

Mag-Meter[4]	$4,200.00
Engineering services (10% typical)	$420.00
Total cost	**$4,420.00**

The installation costs are site specific and therefore difficult to estimate. Installation fees could include the cost of bringing 110V electrical service to the site, excavation, piping changes and other costs. Additional design work will incur additional engineering costs.

References

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Open Channel Flow Measurement Handbook, Second Edition, ISCO Inc., P.O. Box 5347, Lincoln Nebraska 68505

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[3] USA Bluebook part #47038 available at: http://www.usabluebook.com/

[4] USA Bluebook part #47040 available at: http://www.usabluebook.com/

Hydraulic Handbook, Twelfth Edition, Fairbanks Morse Pump Corporation, 3601
Fairbanks Avenue, Kansas City, Kansas 66110