V0. 13

FLOW CALIBRATION GUIDELINES

DEVELOPED IN SUPPORT OF
CHAPTER 40E-63, F.A.C.

EVERGLADES BMP PERMIT PROGRAM

OCTOBER 1, 1996
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FOREWORD

All calibrations, re-calibrations and flow verifications submitted in compliance of the Everglades BMP Permit Program (Chapter 40E-63) shall include at a minimum:

(1) Which pre-approved Calibration Field Data Collection Methodology was utilized
  a. Instrumentation
  b. Procedure

(2) Which pre-approved calibration Data Evaluation Methodology was utilized
  a. Flow Equation Development
    - Parabolic
    - Cubic
    - Linear

  b. Alternative Mean Flow Rate Determination

  c. Theoretical Equation

  d. Flow Verification of previously accepted equation

(3) Operating ranges of speeds (if applicable) and head differentials

(4) Actual data collected

(5) Final Calculations to be applied to determine flow
  a. Flow Equation
  b. Mean Flow Rate
  c. Theoretical Equation
  d. Previously Accepted Equation

(6) Primary operational instrumentation in place (e.g. RPM sensor, RPM tachometer, water level sensor, staff gauge, data logger, log book) necessary to determine flow

(7) Back-up instrumentation in place (e.g. RPM tachometer, staff gauge, log book) necessary to determine flow in the event the primary equipment fails

(8) Certification or verification Statement

CALIBRATION GUIDELINES

TABLE OF CONTENTS

LIST OF TABLES

Version 10/01/96 (Page Amended 06/10/97)

CALIBRATION GUIDELINES

INTRODUCTION

Chapter 40E-63 (Everglades BMP Program), F.A.C., requires permittees to submit and implement an acceptable water quality monitoring plan which provides "reasonable assurance" that annual water discharge and phosphorus load are accurately documented. Permittees within the Everglades Agricultural Area (EAA) under the Everglades BMP Program are currently required to calibrate off-site discharges from 300+ locations. Calibration information is being compiled for two purposes:

1) provide guidelines to permittees prior to permit renewal (January 1, 1997) for consistent application of calibration requirements, and

2) implement a simplified alternative calibrated flow calculation method.

Flow rates are currently being calculated using a variety of discharge equations. In response to requests by permittees, a method is being investigated that would utilize a single flow rate thereby decreasing the type of field readings and simplifying the calculations. The SFWMD assembled a group of professionals with specialized expertise in flow calibrations to further discuss and develop the feasibility of these concepts. This Flow Calibration Work Group has been acting in a peer review fashion and consists of the following individuals:

Steve Dobbs, P.E., United States Sugar Corporation
James Endres, P.E. Moving Water Industries
Richard Hall, P.E., Farmers Manufacturing Co., Inc.
Mark Howell, United States Sugar Corporation
Dean Mades, P.E., HydroScience Water Resource Consultants, Ltd.
Art Schmidt, P.E., HydroScience Water Resource Consultants, Ltd.
Pamela Smith, P.E., SFWMD
Benita Whalen, P.E., SFWMD
Andrew Wiley, Farmers Manufacturing Co., Inc.

This calibration guideline document addresses issues such as standardized methodologies for field data collection and data evaluation to produce a flow equation, changes that necessitate a re-calibration, frequency of re-calibrations, etc. This document is not intended to be a how-to-manual and therefore is not a substitute for technical knowledge required by any individual conducting a flow calibration.

~~**NOTE:** The criteria contained in this flow calibration guideline document is effective on October 1, 1996. Therefore, all proposed flow calibration methods (including those discussed in this document) and entities performing these methods will require approval from the SFWMD prior to performing calibrations after October 1, 1996. The District's calibration confirmation process is discussed in more detail under Section VII.~~

1. FLOW CALIBRATION DATA COLLECTION METHODS

The following section identifies and describes the type of data collection methods which have been used to satisfy the flow calibration requirements of chapter 40E-63. Also listed are special concerns that need to be considered when selecting a data collection method for a particular location. It should be noted that with each data collection method strict field practices, quality workmanship, equipment maintenance, and accurate record keeping are needed to ensure data reliability.

PIPE VELOCITY

1. Pitot Tube/Manometer

The rate of flow in pipelines under pressure may be computed from the conduit cross-sectional area and velocity observations made by a pitot tube. The tube consists of a right-angle bend which, when partly immersed with the bent part under water and pointed directly into the flow, indicates the velocity head of flow by the distance that the water rises in the vertical stem. Common differential pressure measuring devices for the pitot tube are the pitot-static pressure probe and the inverted U-tube manometer. The pitot-static pressure probe consists of two separate, essentially parallel parts, one for indicating the sum of the pressure and velocity heads (total Head) and the other for indicating the pressure head. Similarly, the manometer is an instrument that consists of two vertical tubes, (each part a leg of the U), one for indicating total head and the other for indicating only the pressure head. The velocity head is obtained by subtracting the static head from the total head or by measuring the vertical difference between the two (manometer). For a constant rate of flow, the velocity varies from point to point across the pipe flow area hence the need to take readings across the pipe diameter. The mean velocity is obtained by dividing the cross-sectional area of the pipe into a number of concentric, equal area rings and a central circle, measuring/calculating the velocity of each section then averaging the values. A standard ten-point system (four equal area rings and central circle) is commonly used.

KEY POINTS FOR METHOD-CONSIDERATION:

(a) Flow should be uniform.
(b) High flow velocities make positioning and securing the instrument difficult. Dynamic instability may also occur, causing the tube to vibrate and produce erroneous readings.
(c) Partial pipe flow needs to be identified (measure air gap height) and flow area calculated appropriately. If the pipe is not flowing full, the change in velocity distribution must also be considered to accurately determine the average.
(d) Low flow velocities give small head differentials and reading errors may occur which greatly affect results.
(e) Sediment and trash may plug the small openings in the tubes.
(f) Pitot tube data are not valid when the magnitude of manometer fluctuations is greater than 25 percent of the differential pressure which translates into a velocity variability of 10 percent.
(g) The U.S. Geological Survey (USGS) standard 40-second minimum observation time shall be used.

(FLOW CALIBRATION DATA COLLECTION METHODS CONTINUED)

PIPE VELOCITY

2. Doppler

The Doppler Ultrasonic Flowmeter is a flow-monitoring device that utilizes the frequency shift (Doppler effect) of an ultrasonic signal to measure flow velocities. A generating crystal in the transducing sensor transmits a high frequency signal through the pipe wall into the water. This signal is reflected by suspended particles or gas bubbles in the moving fluid and is then detected by a receiving crystal located in the sensor. The difference between transmitted and detected frequencies is directly proportional to the flow velocity.

KEY POINTS FOR METHOD CONSIDERATION

(a) Flow should be uniform

(b) Transducers should be attached (1) at a location where the pipe is flowing full, (2) positioned near the end of a straight length of pipe that is at least 5 pipe diameters in length and (3) positioned at angles that are in accordance with the manufacturer's recommendations.

(c) Age and condition (rust) of pipe material must be considered so that readings are not adversely affected. Some models may not have adequate signal strength for older (corroded) pipe.

(d) Interference from vibration or noise from the pump must be considered in selecting equipment.

(e) In general, data collected using the Doppler Ultrasonic Flowmeter become much less reliable when velocities decrease below 0.05 ft/s.

(f) Meter must be maintained and calibrated according to manufacturer's recommendations.

3. Dye Fluorometry – Tracer Dilution and Tracer Velocity

The two types of dye-fluorometry measurements, tracer dilution and tracer velocity, could be included within the APPROACH VELOCITY section but are included under PIPE VELOCITY for they would more likely be used to measure pipe velocities. Tracer dilution methods are used for higher-velocity sections (pump lines) where mixing can be assured. Tracer velocity methods are used in low velocity sections with known geometries (culverts).

Tracer Dilution

Tracer dilution methods are based on the principle of mass balance. A tracer is introduced into the upstream channel (or pump intake) at a measurable rate and concentration, tracer concentrations are continuously measured downstream (or in the pump outfall for a period of time, and the time series of concentrations are evaluated to determine discharge. Fluorescent tracers such as Rhodamine-WT are typically measured using a fluorometer. The amount that the added tracer solution is diluted by flowing water determined.

Dye Fluorometry – Tracer Dilution continued

KEY POINTS FOR METHOD CONSIDERATION:

(a) Determine whether slug or continuous injection of tracer should be used and develop appropriate tracer-measurement plan.
(b) Ensure that the tracer uniformly mixed within the sampling section. Injection manifolds may be needed to help achieve mixing.
(c) Instrumentation must be maintained and calibrated according to manufacturer's recommendations. Care must be taken to ensure that dye-water samples are within the linear range of a fluorometer and that background fluorescence is accounted for.

Dye Fluorometry – Tracer Velocity

Tracer velocity methods depend on measuring the time it takes a conservative tracer to pass through a channel (or pipe) having a uniform and measurable geometry. The tracer is introduced to the channel at some upstream location using the slug-injection method and continuously measured at a downstream location for a period of time. Discharge is determined by dividing the volume of water located between the injection and measurement sections by the lapsed time between the centroids of time-concentration curves for each section.

KEY POINTS FOR METHOD CONSIDERATION:

(a) A static volume of water located between the injection and measurement sections must be accurately known.
(b) Tracer sampling must continue for a long enough period of time to accurately determine the centroid of a time concentration curve.

APPROACH VELOCITY

4. Stream Gauging (current and electromagnetic meters)

Stream gauging is a method which measures velocities in the channel, upstream of the pump station. Two basic types of meters are generally used for stream gauging, (1) vertical-axis or vane-type current meter (Price AA) and (2) electromagnetic meter (Marsh-McBirney).

(1) A vertical axis meter consists of a wheel which rotates when immersed in flowing water and a device for determining the number of revolutions of the wheel. Water velocity is determined by counting the number of revolutions of the wheel over a given period of time. The relations between the velocity of the water and the number of revolutions of the wheel per unit of time for various velocities are determined for each instrument by U.S. Bureau of Standards and are supplied in the form of an equation from which a rating table is compiled.

(2) An electromagnetic meter operates on the principle that a voltage is induced in an electrical conductor moving through a magnetic field. For a given field strength, the magnitude of the induced voltage is proportional to the velocity of the conductor (flowing water). The sensor is equipped with an electromagnetic coil that produces the magnetic field and a pair of electrodes that measure the voltage produced by the velocity of the flowing water. The measured voltage is then processed by electronics and output as a linear measurement of velocity.

Three other types of current meters are also appropriate for measuring water velocity even though they have not yet been used to calibrate pumps for the Everglades BMP Program. These include the (1) acoustic Doppler current Profiler – ADCP, (2) Point acoustic Doppler Velocity Meter – PADVM and (3) Smart Acoustic Current Meter – SACM.

(1) & (2) The acoustic doppler current profiler (ADCP) and point acoustic doppler velocity meter (PADVM) operate on the principle of the doppler effect of sound in moving water. The meters emit a series of phase-encoded acoustic pulses at a fixed frequency along each of the narrow acoustic beams and measures the frequency shift (Doppler effect) of the return echo. The ADCP is suspended in a fixed position within the water column and continuously measures velocities at user prescribed intervals from near the channel bottom to near the water surface as the meter is moved across the channel. The PADVM measures a discrete velocity near the transducer heads and must be moved laterally and vertically within the measurement section (like a Price AA) to determine mean channel velocity. Velocities as low as 0.03 ft/s can be measured using ADCP and PADVM.

Stream Gauging (continued)

(3) The SACM is a vector-averaging current meter. The SACM is based on the time of travel of acoustic signals sent between two pairs of transducers oriented at ninety degrees from each other. A small reflector located about an inch below the acoustic transducers reflects an acoustic pulse from one transducer to the opposite transducer. Components of the velocity vector are resolved using the velocities measured along the two acoustic paths and an internal, magnetic compass. The SACM can measure point velocities as low as 0.03 ft/s.

Please note that in addition to the constraints listed below, stream gauging will only be accepted as a calibration data collection method in situations where 100% of the flow to the pump is through the single canal being measure. Low velocities, non-uniform channels, interference from side channels, fluctuating water levels during data collection are some of the conditions that exist at the majority of sites within the EAA which make this method more difficult to perform. Gauging at a downstream control section (e.g. culvert) will not be acceptable because the majority of pump stations have a much greater capacity than the control section and therefore an amount of storage is occurring in the forebay area. Stream gauging may be considered with the following constraints but only in situation where 100% of the flow to the pump is through the single canal being measured.

(a) Metering equipment must be used within the manufacturer's guidelines; In general, data collected using vane-type meters (such as Price AA) and the electromagnetic meters (such as Marsh-McBirney) become much less reliable when velocities decrease below 0.15 ft/s. Acoustic meters such as the ADCP, PADVM and SACM can be used to reliably measure velocities approaching 0.03 ft/s.

(b) Eighty percent (80%) of the point velocities measured must be above the manufacturer's minimum velocity.

(c) The two-point method and six-tenths-depth method of determining mean velocity in a vertical line shall be used. Meter measurements shall be taken at 2- and 8-tents depth if the depth of flow equals or exceeds 2 feet, otherwise at the 6-tenths depth.

(d) No velocity measurement section shall carry more than ten percent (10%) of the flow.

(e) The U.S. Geological Survey (U.S.G.S.) standard 40-second minimum observation time shall be used.

(f) Approach velocity measurement sections must be taken near the pump but no closer than a main canal width from the pump station and at least a main canal width downstream from side canals in a reach characterized by uniform flow and no turbulence. Artificial and/or temporary blocking of side or tributary canals are not representative of actual field conditions and therefore will not be allowed.

(g) Meter shall be formally calibrated according to manufacturer's criteria, annually at a minimum. Records should be kept to verify meter calibrations.

(FLOW CALIBRATION DATA COLLECTION METHODS CONTINUED)

THEORETICAL EQUATIONS

5. The use of theoretical equations to estimate gravity control structure flow does not in its self constitute a data collection method. However, some type of data collection, i.e. a field investigation and data history search of the range of water surface elevations, must be conducted to assist in the determination of which type of flow conditions (e.g. submerged weir flow, partial culvert tranquil flow throughout, etc.) exist so the appropriate theoretical equations are selected. Geometric configurations and measurements must also be know such as culvert invert elevation, length, material, diameter, gate opening, and flash board elevation if applicable.
   Weir equations and the U.S.G.S. source for culvert flow equations can be found within Section III. DATA EVALUATION METHODS AND FLOW EQUATION DEVELOPMENT CRITERIA.

OTHER

6. The use of any other data collection method not identified within this document will require prior approval from the SFWMD. The District's calibration confirmation process is discussed in more detail under Section VII.

II. FIELD DATA COLLECTION CRITERIA

A. Types of Flow Configurations

The various configurations of pumping stations or water control cross-sections can be classified into four different types.

Type 1 Well defined pump and pipe configuration. Well-defined pipe configurations are accessible and have a straight length of pipe at least ten times its diameter. The straight length of pipe can be on either side of the pump. Refer to **Figure 1** for a sketch of this situation. Type 1 configurations require measurement of headwater stage, tall water stage, pump speed, and average flow velocity.

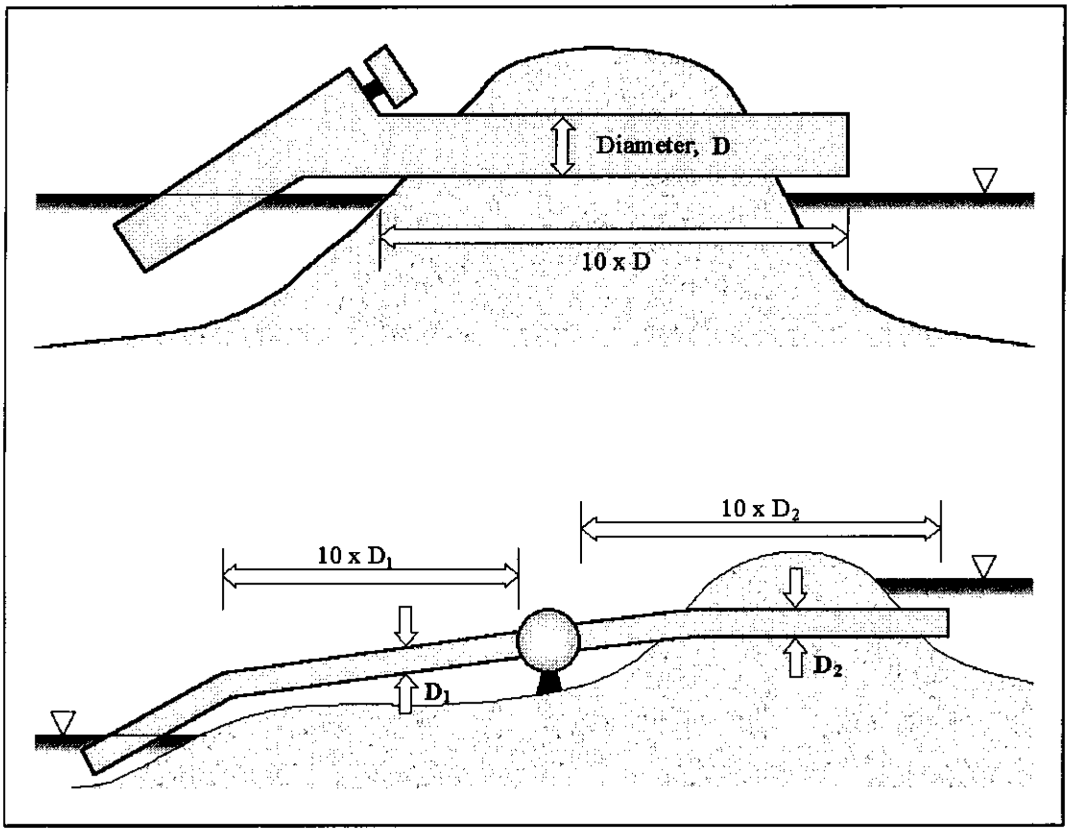


Figure 1. Examples of Type 1

(Types of Flow Configurations continued)

The two recommended methods for data point collection under Type 1 conditions are measuring pipe flow velocities and performing a mass balance by tracer-dilution methods. Stream gauging is listed as a method but note that its use is conditional (only in situations where 100% of the flow to the pump is through the single canal being measured).

(a) Pipe Velocity. Three ways to determine the pipe flow velocity are suggested as follows. 1. Measure pipe water velocity head or static and total head (pitot tube/manometer). 2. Use an acoustic (Doppler) pipe flow velocity-measuring device. 3. Use tracer-dilution method to perform a mass balance.

(b) Stream Gauging (current or electromagnetic meter) **CONDITIONAL** Only if 100% of the flow to the pump through the single canal being measured.

The measurements for Type 1 configurations are headwater stage, tail water stage, and pump speed at the start and end of each flow period and any other parameters necessary to calculate flow.

Type 2 Poorly defined pump This type consists of pump configurations that do not meet Type 1 criteria (not accessible and do not have a straight length of pipe at least ten times its diameter). Figure 2 shows examples of this configuration.

A recommended method for data point collection under Type 2 conditions is performing a mass balance by tracer-dilution. Other pipe velocity measurement methods such as the pitot tube or acoustic device may be used for this type of pump configuration if proper insertion of the pitot tube or attachment of the acoustic device is possible and an appropriate number of velocity measurements are made to accurately define the entire velocity profile. Stream gauging is listed as a method but note that its use is conditional (only in situations where 100% of the flow to the pump is through the single canal being measured).

(a) Dye Fluorometry use tracer-dilution method to perform a mass balance.

(b) Other Pipe Velocity Methods measure pipe water velocity head or static and total head (pitot tube/manometer) or use an acoustic (Doppler) pipe flow velocity-measuring device. Note that these methods are appropriate if proper insertion or attachment of the instrumentation can be accomplished and sufficient data is collected to accurately define the entire velocity profile.

(c) Stream Gauging (current or electromagnetic meter) **CONDITIONAL** Only in situations where 100% of the flow to the pump is through the single canal being.

(Types of Flow Configurations continued)

The measurements for Type 2 configurations are headwater stage, tail water stage, and pump speed at the start and end of each flow period and any other parameters necessary to calculate flow.

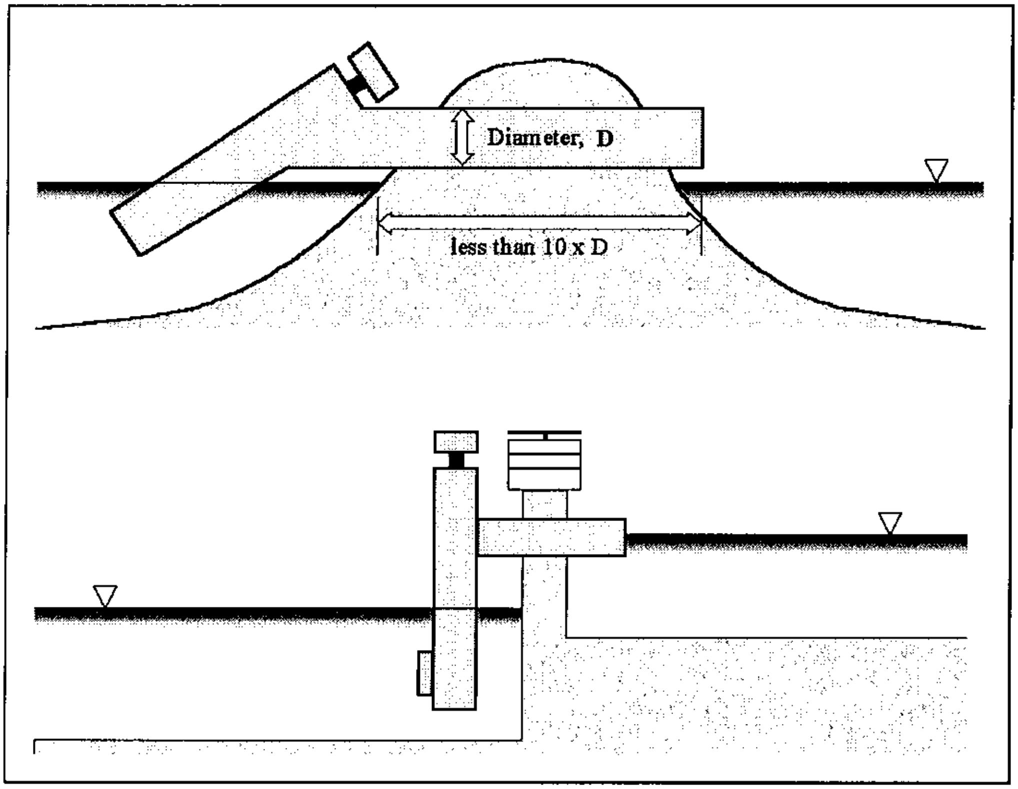


Figure 2. Examples of Type 2 – Poorly defined Pumps 9pipe length less than 10 x pipe diameter)

Type 3 Vertical lift box pump

The two recommended methods for data point collection for vertical lift box pumps are performing a mass balance by tracer-dilution methods and not collecting data points but instead using a theoretical weir discharge formula. Stream gauging is listed as a method but note that its use is conditional (only in situations where 100% of the flow to the pump is through the single canal being measured).

(a) Dye Fluorometry Use tracer-dilution method to perform a mass balance.

(b) Theoretical Equation Use applicable weir equations.

(c) **Stream Gauging** (current or electromagnetic meter) **CONDITIONAL** Only in situations where 100% of the flow to the pump is through the single canal being measured.

The measurements for Type 3 configurations using the methods described in section (a) and (c) above are head water stage, tail water stage, and pump speed at the start and end of each flow period and any other parameters necessary to calculate flow.

Type 4

Gravity control sections. This type includes gravity flow through structures such as gates, weirs, and culverts. **Figure 3** displays some examples. The U.S.G.S. is an authority of streamflow measurement. Theoretical equations outlined by U.S.G.S. in their technical document titled "Measurement of Peak Discharge at Culverts by Indirect Methods" by G. L. Bodhaine (1968) are acceptable for flow computations for culvert structures. Theoretical equations for weir flow and submerged weir flow are also acceptable as outlined on Page C-IV-24 of the SFWMD's Permit Information Manual Volume IV, Part C surface Water Management System Design Aids.

The permittee also has the option of conducting field measurements to calibrate these theoretical equation. The key points and criteria previously identified under the appropriate data collection method shall be followed when taking flow measurements to calibrate theoretical equations.

(a) Theoretical Equations For culverts: U.S.G.S. "Measurement of Peak Discharge at Culverts by Indirect Methods" by G. L. Bodhaine (1968). For weirs: Page C-IV-24 of the SFWMD's Permit Information Manual Volume IV, Part C surface Water Management System Design Aids.

(b) Use tracer velocity method to calibrate the theoretical equation.

(c) Stream Gauging (PADVM or SACM) to calibrate the theoretical equation.

Some geometric configurations and measurements must be known for use of theoretical equations such as culvert invert elevation, diameter, length, material, gate opening, and flash board elevation if applicable.

If the theoretical flow equation is calibrated, recorded measurements for Type 3 configurations are head and tail water stages across the control cross-section for each flow period. The length of each culvert must be at least ten times the diameter when measuring culvert flow. To use a culvert of less than ten pipe diameters in length for discharge calculation there should be sufficient justification and assurance of uniform flow.

(Types of Flow configurations Continued)

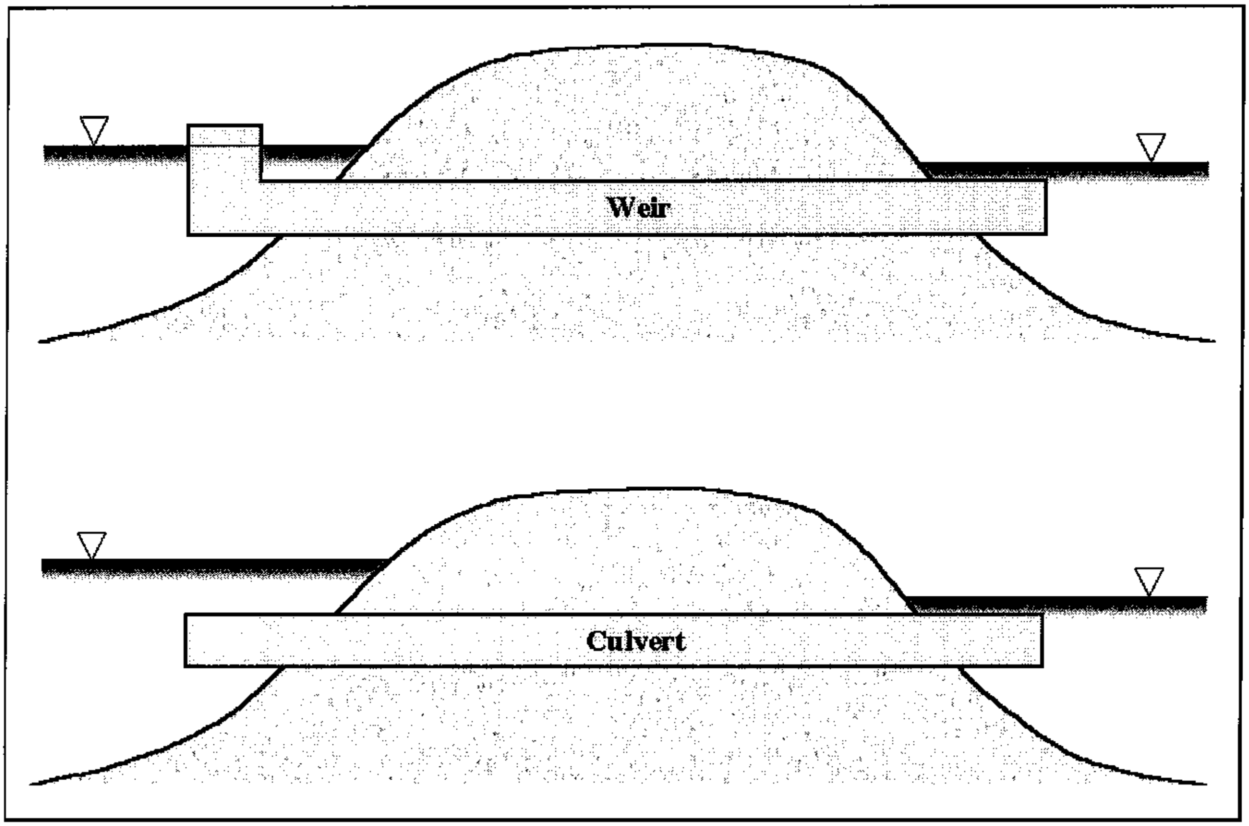


Figure 3. Examples of type 4 – Gravity Control Structures

A decision matrix worksheet is presented as Table 1. This worksheet will be used as the guide to determine if a flow calibration method is appropriate for given flow configurations.

TABLE 1 **DECISION MATRIX OF APPROPRIATE DATA COLLECTION METHODS BASED ON FLOW CONFIGURATIONS**

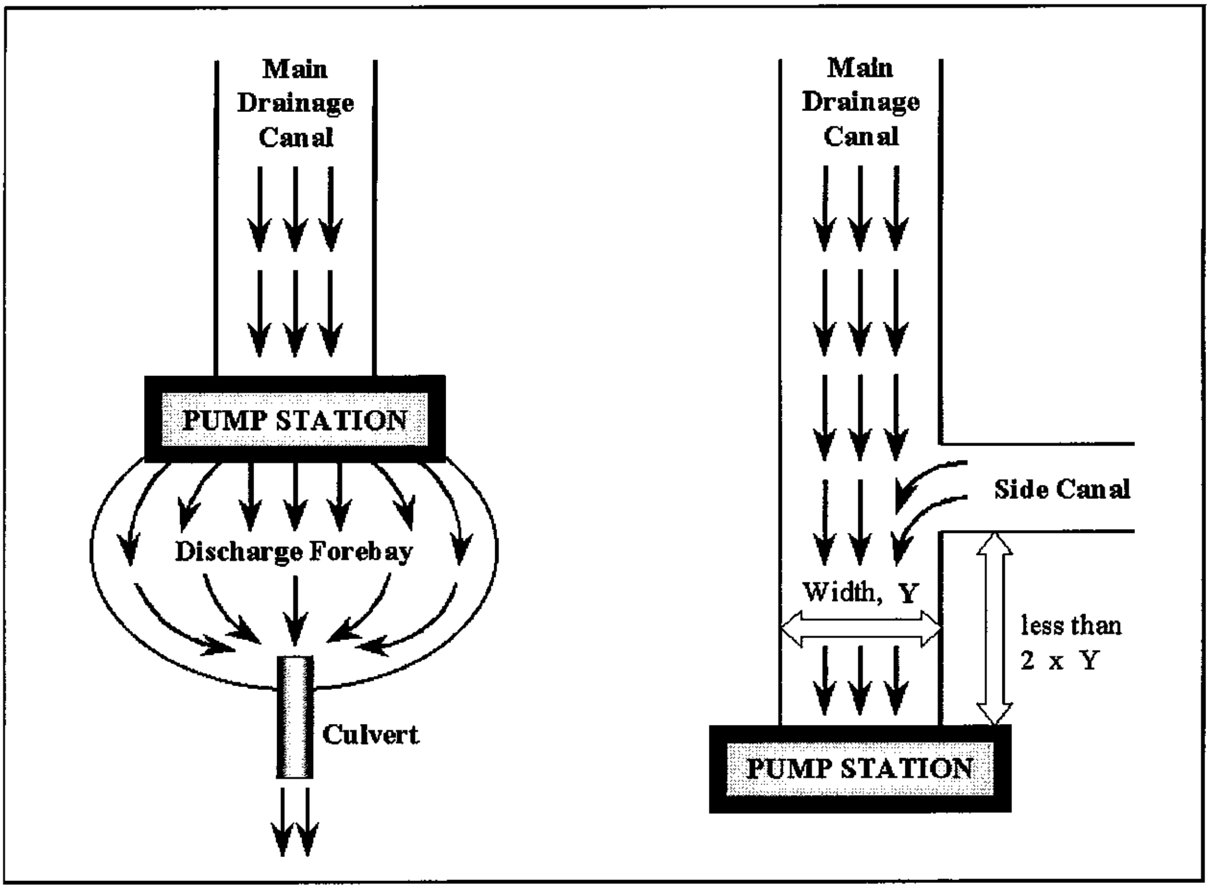
FLOW CONFIGURATIONS	PITOT	DOPPLER	TRACER-DILUTION	TRACER-VELOCITY	STREAM GAUGING	THEORETICAL EQUATION
TYPE 1 WELL DEFINED PUMP				n/a	conditional on Section 1.4 and Table 2	n/a
TYPE 2 POOR DEFINED PUMP	refer to type 2 page 9	refer to type 2 page 9		n/a	conditional on Section 1.4 and Table 2	n/a
TYPE 3 VERTICAL LIFT BOX PUMP	n/a	n/a		n/a	conditional on Section 1.4 and Table 2	
TYPE 4 GRAVITY CONTROL CROSS-SECTION	n/a	n/a	n/a		conditional on Section 1.4 and Table 2 and limited to PADVM or SACM	

Shading indicates method is not appropriate (n/a) or use of method is conditional on other criteria.

B. Types of Canal Configurations

The various configurations of canals can be classified into four different types. Breakdown of canal configurations is for the stream gauging data collection method only. All other methods used are located at the pump or control structure. Approach velocity measurement sections should be located far enough upstream (typically a main canal width) from the pump to avoid turbulence effects, at least a main canal width downstream from side canals, and close enough to the pump so that the lag time to achieve equal pump and canal discharges when pumping conditions (lift and/or speed) change are minimal.

Type 1	Uniform main canal cross-section and no side canals within two main canal widths of pump station.
Type 2	Non-uniform main canal cross-section (varying depth or width) and no side canals within two main canal widths of pump station. Note that stream gauging may be performed at a non-uniform section but greater care must be taken when measuring depths and subdividing the measurement section.
Type 3	side or tributary canals within two main canal widths of pump station (refer to Figure 4).
Type 4	Pump discharge forebay with increasing stages/storage occurring (refer to Figure).



TYPE 4 TYPE 3

Figure 4. Examples of Canal Configurations which are <u>NOT</u> appropriate for stream gauging

A decision matrix worksheet is presented as Table 2. this worksheet will be used as the guide to determine if stream gauging is appropriate for given canal configurations.

TABLE 2 DECISION MATRIX FOR ACCEPTABLE CANAL CONFIGURATIONS TO STREAM GAUGE

CANAL CONFIGURATIONS	**ALLOWABLE (conditional on Section 1.4)**
TYPE 1 UNIFORM CROSS-SECTION AND NO SIDE CANALS WITHIN TWO MAIN CANAL WIDTHS OF PUMP STATION	
TYPE 2 NON-UNIFORM CROSS-SECTION	
TYPE 3 SIDE CANALS WITHIN TWO MAIN CANAL WIDTHS OF PUMP STATION	n/a
TYPE 4 PUMP DISCHARGE FOREBAY WITH CONTROL SECTION	n/a

Shading indicates method is not appropriate (n/a)

(DATA COLLECTION CRITERIA CONTINUED)

C. Minimum Data Collection Criteria

For all types of data collection methods, the head water stage, tail water stage (centerline of pipe if outlet is unsubmerged), pump speed, and elapsed speeds remain the same during the measurement. Water surface elevations at a minimum must be recorded at the start and the end of each measurement (measurements should verify that flow is stable). the rotational speed of the pump may be measured by a tachometer mounted on the pump or engine. If a tachometer is mounted on the engine, the ratio of the engine speed to the pump speed must be known. The engine speed will typically be greater than the pump speed. All structures should be rated for the range of water stages and pump speeds expected during operation.

1. Operation Range
   If the structure is existing, data history research shall be done to determine actual operating conditions (head differentials and pump speeds) for the structure.

2. Minimum number of data points required for calibration.

   FOR PUMPS:

   Minimum of 5 data points which cover 2' of change in head differential or 25% of operating head differential range. Test speeds shall fully cover the operating speeds expected based upon documented observation.

   Note that greater than 2' of head differential or greater than 25% of the operating head differential range may be necessary in situations where there is less certainty of pump performance. In order to obtain 25% or more of the operating head differential range, a discharge valve or other mechanism may need to be installed to artificially create the necessary head conditions in the field for collection of data points.

   FOR GRAVITY CONTROL STRUCTURES:

   If a permittee elects to calibrate a theoretical equation, at a minimum, two data points are required with a minimum head differential equal to or exceeding 0.1 foot of head differential.

3. At a minimum, water stages shall be collected at the beginning and end of each measurement.

III. DATA EVALUATION METHODS AND FLOW EQUATIONS DEVELOPMENT CRITERIA

Once the calibration field data points have been obtained, an analysis is performed to develop a flow equation. In the case of gravity control structures using uncalibrated theoretical equations to calculate flow, a field investigation is conducted to determine which type of flow conditions exist so the appropriate theoretical equations are selected.

PUMP FLOW EQUATIONS

Static head and pump speed (if a variable speed power unit is used) are the variables in the flow equation. Various types of flow equations which were previously submitted are graphically presented in **Figure 5** and discussed in more detail below. These equation forms have been used in the past to adequately describe the data points collected and will be the only types accepted in the future unless approval can be obtained from the SFWMD.

A. Types of Flow Equations

1. Parabolic (equation type that describes a typical axial flow pump curve)
   $Q = [A^*(\text{FIELD RPM}/\text{RPM}) - B^*HD^{C}(\text{RPM}/\text{FIELD RPM})^{2C-1}] * 1000$
2. Cubic (equation type that describes an axial flow pump operated at speed less than 75% of design)
   $Q=B^*(\text{FIELD RPM}/\text{RPM})[A-((\text{RPM}/\text{FIELD RPM})^{2}*HD-C)/|((\text{RPM}/\text{FIELD RPM})^{2}*HD-C)|(|(\text{RPM}/\text{FIELD RPM})^{2}*HD-C|)^{.333}]$
3. Linear (slope from the manufacturer's curve, transposed over the calibration data points)
   $Q = ((A^*(\text{FIELD RPM}/\text{RPM})^{2}-HD)/C)+(B^*\text{FIELD RPM}/\text{RPM})$

where A,B,C are coefficients

Q = flow, gpm

HD = static head differential

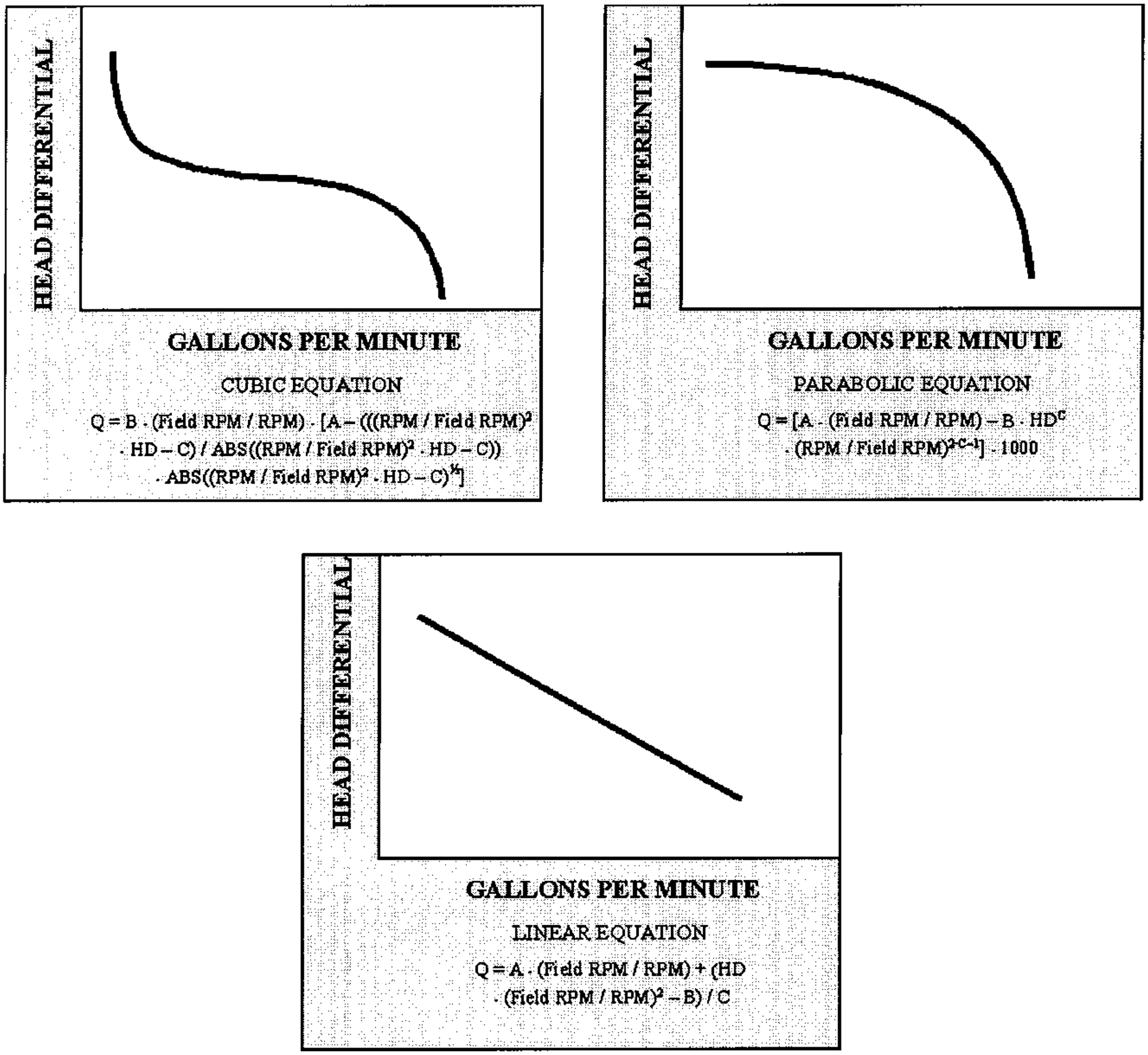
FIELD RPM = actual pump or engine speed

RPM = calibration pump or engine speed

B. Minimum Equation Development Criteria

All developed pump flow equations must meet the following criteria and all calibration submittals shall provide documentation which indicate this criteria has been met.

1. Flow equations should exhibit standard axial flow pump principles (e.g. increasing head differential – decreasing flow rate; increasing pump speed – increasing flow rate).
2. Application of Affinity Laws: Head differentials must also be converted when using the Affinity Laws to convert multiple speed data points to a single speed.
3. Predicted flow from discharge equation shall be within ± 10% of tested flows.
4. R^2 should be > 0.85
5. For linear equations, slope from the portion of the manufacturer's curve through normal head differential range can be used only if it is the actual pump curve (not similar pump curve) and no alterations have been made to the pump.
6. For parabolic equations, "A" coefficient (zero head differential must be positive); "B" coefficient must be positive so as head differential increases, flow decreases and "C" coefficient for axial flow pumps should be between 1.5 and 3.0.



CUBIC EQUATION

$$Q = B \cdot (\text{Field RPM} / \text{RPM}) \cdot [A - (((\text{RPM} / \text{Field RPM})^2 \cdot HD - C) / ABS((\text{RPM} / \text{Field RPM})^2 \cdot HD - C)) \cdot ABS((\text{RPM} / \text{Field RPM})^2 \cdot HD - C)^{1/3}]$$

PARABOLIC EQUATION

$$Q = [A \cdot (\text{Field RPM} / \text{RPM}) - B \cdot HD^C \cdot (\text{RPM} / \text{Field RPM})^{2 \cdot C - 1}] \cdot 1000$$

LINEAR EQUATION

$$Q = A \cdot (\text{Field RPM} / \text{RPM}) + (HD \cdot (\text{Field RPM} / \text{RPM})^2 - B) / C$$

Figure 5. Types of Flow Equations

(DATA EVALUATION METHODS AND FLOW EQUATIONS DEVELOPMENT CRITERIA)

GRAVITY FLOW THEORETICAL EQUATIONS

Selection of the appropriate theoretical equations for uncalibrated flow estimation relies on accurate data collection. Peak upstream and downstream water surface elevations, structure geometry and canal geometry are some of the information obtained in the field survey. Weir equations that may be appropriate are listed below. Appropriate culvert flow equations can be found in the USGS document identified below.

Weir Flow (submerged & unsubmerged)

(a) For Vertical lift box pumps and flashboard risers, a rectangular sharp-created weir discharge equation (Page C-IV-24 of the SFWMD's Permit Information Manual Volume IV, Part C Surface Water Management System Design Aids) may be appropriate.

$Q_F = 3.13LH_1^{1.5}$

Rectangular sharp-crested weir – unsubmerged
Q_F = free flow, cfs
L = weir length, feet
H_1 = upstream head above crest, feet

$Q_S = Q_F[1 - (H_2/H_1)^{1.5}]^{0.385}$

Rectangular sharp-crested weir – submerged
Q_S = submerged flow, cfs
H_2 = downstream head above crest, feet

(b) The head H_1 should be measured at least $2.5H_1$

Culvert Flow (full & partial)

(a) The U.S. Geological Survey (U.S.G.S.) an authority of steamflow measurement. empirical equations outlined by U.S.G.S. in their technical document titled "Measurement of Peak Discharge at Culverts by Indirect Methods" by G.L. Bodhaine (1968) shall be used for culvert flow. Culvert flow has been classified into six types on the basis of the location of the control section and the relative height of the headwater and tailwater elevations. Justification of which type(s) of flow regime exist is required.

GRAVITY FLOW CALIBRATED THEORETICAL EQUATIONS

(a) If the permittee elects to obtain field measurements to calibrate the theoretical discharge equation (flow data will be collected to determine a coefficient of discharge for the culvert structure), the tested flows shall be within ± 10% of the flows predicted by using the appropriate theoretical discharge equation.

IV. FIELD INSTRUMENTATION AND RECORD KEEPING

The minimum field instrumentation required for both pump and gravity control structures is identified below. the environmental conditions existing in the EAA coupled with the use of electronic water level sensors necessitates that a strong maintenance program be implemented to ensure that accurate head differentials are being measured. Therefore, a sensor maintenance and calibration program is required to be included with any flow calibration using electronic water level sensors. the maintenance and calibration program for the sensors will document that the sensors will be formally calibrated quarterly (minimum) and informally checked and verified bi-weekly on the regularly scheduled sampling trip.

A. Pumps

Continuous stage and speed recording devices or manual readings of staff gages and pump speed recorded in a logbook is required. Manual readings are required at a minimum of twice per day during discharge.

B. Gravity Connections

Gravity connections with multiple control structures (culverts, weir, etc.) and culverts greater than 36 inches in diameter shall have continuous stage recording devices with readings taken at least every 15 minutes (readings may be averaged over a period of one hour). Backup instrumentation shall consist of additional continuous stage recording device or manual readings taken at least twice daily.

Gravity connections with a single control structure (culvert, weir, etc.) and culvert diameter less than or equal to 36 inches are required, at a minimum, to record manual readings twice per day during discharge.

V. RE-CALIBRATION OR FLOW VERIFICATION

It is acknowledged that discharge from the pumps located in the Everglades Agricultural Area will normally decrease over time. the amount of change in discharge will vary with pump type, size, normal maintenance and frequency of operation. Because Chapter 40E-63 requires that discharge be accurately measured, pumps will be required to periodically verify flow measurement accuracy or be re-calibrated. In an effort to recognize that the change in discharge is correlated with frequency of operation, the period for flow verification or re-calibration will be based upon days of structure operation (days of structure operation versus pump operation since discharge values are submitted to the District by structure). Re-calibrations or flow verifications will be required after approximately one and one-half years of pump operation/use (550 days of pump operation). Re-calibrations have the opportunity to be somewhat simplified if the new data collected indicates that previously certified flow equation or flow value is still valid (flow verification).

Calibrations of new pumps and re-calibrations of repaired or relocated pumps shall be performed by Florida registered Professional Engineers. Flow verifications of pumps that one and one-half years of pump operation since the last calibration may be performed by a registered Professional Engineer or other qualified entity that have received District confirmation (described in Section VII). Re-calibrations shall follow the calibration criteria previously outlined. Flow verification shall follow the data collection criteria previously outlined. If the data collected for a flow verification is not within ± 10% of the predicted flow from the previously accepted discharge equation, a re-calibration to develop a new discharge equation is required.

A. Required Frequency – After approximately one and one-half years of pump operation (550 days of pump operation) ~~not to exceed eight (8) nine (9) calendar years~~, based on data submitted to the District.

B. Circumstances Warranting More Frequent Calibration

1. If the bowl area and/or impeller of the pump is modified, a re-calibration is required.
2. If a pump is relocated, a re-calibration is required.
3. A replacement pump for the primary pump under repair will require calibration if it is at that location for a period greater than 4 weeks.

VI. ALTERNATIVE DETERMINATION

A. Introduction

Various permittees requested that the District investigate alternative calibration methods based on their observations that there was very little change in flow rate over normal operating conditions. In response to requests by permittees, an alternative flow determination method has been investigated that would utilize a single mean flow rate.

A brief description of the SFWMD's investigation of the feasibility or appropriateness of a mean flow rate calibration follows. Data from several pumps were reviewed. For a comprehensive analysis, the pumps chosen currently use either a linear, cubic or parabolic discharge equation. Median head differentials were calculated from all of the actual historical field data for that particular pump. Days of discharge were randomly chosen and flows were calculated using the median head condition. The total flow using the median head condition was compared to the total flow calculated using the actual head conditions for the same event. Of the pumps chosen, the pumps currently using a linear or parabolic equation showed the best correlation for using a median flow rate (< 7% difference in total flow). The pumps currently using the cubic equation resulted in greater than 25% difference in total flow.

Based on the correlations noted above, it appears that the use of a mean flow rate may be suitable for some pumps but each pump will have to be reviewed for its appropriateness of using this method. Therefore it has been determined that the mean flow rate calibration will be an option to the permittees.

B. Description of Procedure and Criteria

The following procedures and criteria must be followed and met for the Alternative Flow Determination Method to be accepted.

1. Criteria for selection of data collection method still apply.
2. Calibration entity and pump operator evaluate previous flow calculations to determine if structure currently exhibits small changes in flow rates over normal operating head differentials.
3. Calibration entity and pump operator evaluates median head differential from previous head differential conditions experienced.
4. Pump operator indicates the high and low operation speed (if diesel engine, single speed if electric) that will only be used.
5. Entity obtains two data points at the median head condition for each speed (high and low).
    - If the 2 data points are within 10% of each other, then an average of the data points is calculated.
    - If the 2 data points are not within 10% of each other, then a check measurement shall be taken to confirm the 10% criteria has not been met. If the 10% criteria can not be met, this alternative method will not be accepted.
6. Flow rate(s) are certified as the mean flow rates(s) for the pump.

(ALTERNATIVE FLOW DETERMINATION CONTINUED)

C. Benefits

- No stage readings are required for flow calculations therefore less instrumentation is needed.
- Daily flow calculations are simplified by using a flow rate and time of operation 9no equation).
- Fewer field data points are required and only at normal conditions.
- Verifying flow for BMP field inspections would be simplified.
- Obtaining results of calibrations should take less time (no equation to be developed).

Note: One potential drawback of the use of a median flow rate is the overestimation of discharge if the actual static head differentials encountered during operation are consistently greater than the calculated median head differential.

VII. ADVANCE CALIBRATION OR FLOW VERIFICATION METHODOLOGY CONFIRMATION/APPROVAL

Any entity ~~after October 1, 1996~~, proposing to perform a calibration, re-calibration or flow verification for the requirements of Chapter 40E-63, F.A.C., is required to receive advance District Confirmation/Approval. Confirmation will consist of two processes; (1) submittal of a detailed proposed calibration or flow verification methodology for District staff's review and approval and (2) field observation of the entities data collection procedures and data manipulation. The District will provide a conceptual review within 7 business days of receipt of a calibration, re-calibration or flow verification submittal.

VIII. CERTIFICATION

All calibrations or re-calibrations performed by a Florida registered Professional engineer shall contain the following **Pump Calibration Certification Statement**:

Assuming that no alterations are made to the system and the system is operated within the normal range identified, in my professional judgment, the calibration methodology, instrumentation, procedure, data collection and interpretation, and final flow equation or flow value will be sufficient to quantify the discharge as described in Chapter 40E-63, Florida Administrative Code (F.A.C.).

All flow verifications shall contain the following **Flow Verification Statement**:

Assuming that no alterations are made to the system and the system is operated within the normal range identified, in my technical opinion, the data collected verifies that discharges are continuing to be sufficiently quantified by the previously developed flow equation as described in Chapter 40E-63, Florida Administrative Code (F.A.C.).

Appendix A

Implementation of the 550 Day Pump Re-Calibration Tracking Process

Background

The intent was to develop a method to track the amount of pump operation that would not require permit individuals to invest more time, effort, and money to track and record this information. Data is currently submitted to the district which provides the million of gallons pumped per day. Days with no pumping are reported as zero.

Tracking the hours of pump operation would be too costly and require:

- purchase, installation, and maintenance of hours meters installed on each pump (meters on each pump not on each engine – it is common to move and remove engines)
- additional record keeping by the permittee;
- additional submittal of information to the SFWMD.

SFWMD staff did not select the 550-day time period lightly or in a vacuum. the SFWMD has the unique benefit of having a database containing over 278,000 daily flow records from all the 40E-63 permit structures within the EAA. Given the approach of minimizing the impact to permittees as described above, the SFWMD discussed with a group of technical professionals who have advanced knowledge on pump calibrations, flow measurements, and flow conditions in the EAA, the appropriate frequency for re-calibration. As an advance to these discussions, District staff discussed "normal" operating conditions, times, and years with several growers as well as pump manufacture and repair specialists. The result of these discussions was that pumps operating under the conditions in the EAA would decline 10-15% from their calibration after less than 4 to 5 years of normal operation (recommended ranges included 1 to 8 years for calibration). District staff conducted a frequency analysis of EAA submitted pump data. The District opted to error on the side of the growers and examined the re-calibration return frequency of 5 to 6 years based upon normal operating conditions. The frequency analysis revealed that approximately 500 days of pump operation (based upon daily records submitted to the District) indicated that 75% of the single pump discharge stations in the EAA would fall into the 5 to 6 year pump re-calibration frequency. Again, in an interest to error on the side of the permittee, the return frequency of 550 days was selected. The 550-day counter DOES NOT represent 13,200 hours of pumping (550 days x 24 hours/day)

As of April 1997, the 40E-63 program has been operating for over 4 calendar years. Only four out of over 300 structures have reached the 550-day count. Keep in mind that this includes two extremely wet years with pumping well above normal frequency and duration.

Implementation

The SFWMD will conduct a simple count each month based upon the daily flow data submitted by the permittees. the owners/operators of any structure which are identified as approaching the 550 days of operation will be notified. If the discharge structure has multiple pumps, only the pump(s) which have reached the 550-day count would be required for re-calibration. Below are two examples.

Example 1. A four-pump station is identified as reaching the 550-day count. The owner identifies the station as operating as follows:

Pump A	Pump B	Pump C	Pump D
567 days	320 days	200 days	2 days

Only Pump A would be required to be re-calibrated. The District would reset the counter to begin counting from 320 days since that was the next highest level of operation.

Example 2. A four-pump station is identified as reaching the 550-day count. the owner identifies the station as operating as follows:

Pump A	Pump B	Pump C	Pump D
200 days	220 days	150 days	0 days

No pumps would require re-calibration at that time. the District would reset the counter to begin counting from 220 days since that was the next highest level of operation.