United States Department of the Interior
U.S. GEOLOGICAL SURVEY
Reston, Virginia 20192

In Reply Refer To: January 15, 2016
Mail Stop 415

Memorandum

OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM 2016.02

SUBJECT: Quality Assurance Practices for the Mitigation of Systematic Discharge Measurement Errors

The purpose of this memo is to document Office of Surface Water (OSW) policy for mitigating systematic (bias) errors in discharge measurements made by USGS personnel. Although some of these policies have been articulated in training and other less formal guidance, there is a need to clearly define OSW's policy on mitigating systematic errors in discharge measurements. This memorandum (1) describes the two main types of measurement errors, (2) specifies required quality assurance (QA) practices, and (3) provides OSW policy regarding adjustments to faulty or biased discharge measurements and the resulting discharge records.

Types of Errors

There are two types of error in discharge measurements; random errors and systematic errors. **Random errors** are measurement uncertainties that can be either positive or negative and are randomly distributed throughout the measurement (Sauer and Meyer, 1992). Random errors are inherently unpredictable, and are scattered equally about the true value such that the mean value is generally accepted to be unbiased with respect to the true values. Random errors tend to have a null arithmetic mean when that measurement is repeated many times with the same instrument. Further, uncertainty associated with random errors can be determined by observing the deviations between repeated measurements. All measurements are prone to random error and while random errors can be minimized, such errors cannot be completely eliminated from the data we collect. Random errors can be reduced by increasing the number of observations. For example, random error in mechanical meter velocity measurements due to pulsation in flow is reduced substantially by measuring point velocities for 40 seconds instead of 10 seconds (Carter and Andersen, 1963; Sauer and Meyer, 1992). Random errors are reduced by the square root of the number of samples (ISO, 2007), and if measurements are averaged long enough, the random error due to velocity fluctuations should approach zero. An example of how USGS minimizes random errors in ADCP discharge measurements is the use of the proper exposure time for steady-flow measurements.

Systematic errors are biases in our measurements which cannot be eliminated by repeated measurements. Systematic errors lead to the situation where the mean of many separate measurements differs consistently from the true value of the measured attribute. Sources of systematic error may be improperly calibrated equipment or improper use of equipment. In the USGS, systematic errors (even small ones) are undesirable and considerable effort is expended to minimize them. Systematic error may be predictable in some situations, such as when an instrument tested under rigorous laboratory conditions is found to under-register velocity. However, not all systematic errors can be easily detected or quantified, and the onset (timing) of the problem cannot always be determined. Quality assurance programs and measurement techniques have been developed to identify and eliminate systematic errors. When best practices are used, systematic errors are generally assumed to be negligible in the discharge data we collect.

Unfortunately, systematic errors can and do present themselves in the discharge measurements we make. Measuring instruments that are found to be out of calibration will cause a systematic bias in measured discharge. As previously stated, such biases may also be evident in any streamflow records computed using any affected measurements. OSW Technical Memorandum 99.05 (USGS, 1999) documents an example of a systematic error found in standard ratings for Price AA current meters equipped with certain bucket wheels. It is necessary therefore to follow required QA and quality control (QC) practices that significantly limit the effects of systematic error in discharge measurements and, by extension, computed streamflow records. At present (2015) the USGS has several QA/QC programs and (or) procedures for evaluating measuring instruments for systematic errors. They include the acoustic Doppler velocimeters (ADV) Quality Assurance Program, as outlined in OSW Technical Memorandum 10.02 (USGS, 2010), the ADCP Quality Assurance program, as outlined in OSW Technical Memorandum 14.04 (USGS, 2014), ADCP beam alignment tests as specified in Mueller and others (2014), and the recently announced Mechanical Meter Quality-Assurance Program.

Quality Assurance Practices

1. The potential for biases in published discharge records will be reduced when the following quality assurance (QA) practices are used by USGS personnel engaged in the measurement of streamflow. <u>Discharge Measurements by More than One Person</u>. For any given station, discharge measurements are made by more than one person during each year. This reduces the amount of any systematic error for any one station record that may be associated with an individual’s measurement techniques.

2. <u>Field Trip Rotation</u>. Field trips are rotated within Water Science Centers at least every three years. Similar to the previous practice (1 above), this limits longer term systematic errors associated with individual hydrographers in all aspects of data collection, computation, and analysis. In addition, consider rotating assigned measurement

equipment at some interval, similar to field trip rotation, so that the same meter is not used for all measurements at a site.

3. Check Measurements. When check measurements are made a different instrument is used (if at all possible), and a different measurement section should be chosen. Changing the instrument helps to eliminate instrument bias (systematic error) as the cause for an unexplained departure from the stage-discharge relation. A back-up instrument strategy, whether it is a second ADCP or a mechanical meter and required deployment equipment, should be devised for all gaging stations and be explicitly outlined in the station description. In some cases it may not be possible to use a different instrument; for example a moving boat ADCP measurement using a manned boat on a river that has no available bridge from which to make a mechanical meter measurement.

   Using a different measuring section helps to eliminate random and / or systematic errors that might be associated with the local hydraulics of the original measurement section. However, there may be no option for using a different measuring section – such as when there is no other hydraulically acceptable section for making a wading measurement, or when a bridge is the only safe location for making a non-wading measurement.

   When limitations associated with instrumentation or measuring section present themselves, the hydrographer changes as much as possible about the measurement. For further guidance, see the ADCP Check Measurements section of OSW Technical Memorandum 12.01 (USGS, 2012). Finally, all check measurements that are made at gaging stations must be indicated as such in NWIS. In SVMobile there is a check box to indicate that the measurement is a “check measurement.” Text indicating that a measurement is a check measurement must be added to the top comment level in SVMobile, which will then be present in NWIS.

4. Instrument Identification Number. All discharge measurements stored in NWIS include an instrument identification (serial) number. This information can be used identify discharge measurements that may contain a systematic bias as a result of instrument error when that bias is detected at a later date. It will allow USGS personnel to assess the number of measurements affected and the conditions under which these measurements were made.

5. Meter QA Program. Meters used to collect streamflow data in the WMA are registered in any existing USGS meter quality-assurance program. As of the release date of this memo there are two such programs; the ADV Quality Assurance Program, and the ADCP Quality Assurance Program. When new instruments are obtained, the WSCs are responsible for ensuring that the new instrument is included in the respective meter QA databases. WSCs and hydrographers to whom the instruments are assigned are responsible to review the results of these testing programs periodically and determine if any follow up actions are required.

6. Periodic Comparison Discharge Measurements. Periodic field comparison measurements are an essential part of any QA/QC program. All actively used or backup instruments, including hydroacoustic and mechanical meters, should have field comparison measurements made and documented at least once every three years in addition to any tests performed as part of a formal USGS instrument QA program. A field comparison measurement is made at a site where the measured discharge can be compared with a known discharge obtained from some other source, such as an independent instrument or the rated discharge from a site with a stable stage-discharge rating. Comparing many instruments used by a Center at one time is also encouraged as it provides an opportunity for assessing instruments and measuring techniques and is an excellent venue for informal training. When an instrument is purchased or returned from repair, a comparison measurement is conducted with that instrument and the results documented in an instrument log. Table 5 in Mueller and others (p. 11, 2013) contains a helpful description of QA requirements for ADCPs.

Adjustment for Systematic Errors

Despite our best efforts, systematic errors will occur; instruments will be found out of calibration, thermistors will fail, and so forth. The magnitude of most systematic errors are not large enough to warrant the adjustments of computed discharge records as outlined in current revision criteria policy (OSW TM 06.05). Further, it may not be possible to determine when the instrument bias began. OSW policy is that systematic errors in discharge measurements are minimized by the quality assurance practices and programs outlined above. Therefore, past data believed to be affected by small biases (less than three percent) need not be corrected.

Effective as of the date of this memorandum, if a meter is found to have a systematic error greater than three percent, the following steps must be followed:

1. A comment must be added to the top level comment field in SVMobile, which will then be present in NWIS, to the potentially affected discharge measurement(s) that describes, with as much information that is available, the error found, the effect of the error, the magnitude of the error, and when it was identified. For example: "An error in measured velocity of positive 3.4 percent was found for the FlowTracker used to make this discharge measurement, serial number P066, when tested at the HIF on May 2, 2014." Here is an example for a beam matrix error identified for an ADCP: "A beam matrix error was found on June 25, 2015, for the ADCP used to make this discharge measurement, TRDI Workhorse serial number 2002, which causes a 3.8 percent error in bottom-track velocities, this will affect the measured stream velocity."

2. A WSC may determine that for some site-specific reason that the records for a station need to be recomputed or adjusted. If this is done, the change must be made following the current best practices for making and documenting revisions, discussed in associated station analyses, and noted, where possible, in NWIS.

3. If an instrument bias is believed to have a large enough effect on computed records such that it meets the current revision criteria policy (OSW TM 06.05, as of the release date of this memo), records must be recomputed. Again, the change must be made

following the current best practices for making and documenting revisions, discussed in associated station analyses, and noted, where possible, in NWIS.

This memo summarizes important policies regarding mitigating the effects of systematic errors in streamflow measurements and associated streamflow records. Questions concerning the policies outlined in this memo may be addressed to Jim Kolva (jrkolva@usgs.gov).

/signed/

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Chief, Office of Surface Water

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