`GUIDANCE FOR SELECTING AND CONDUCTING EVALUATIONS OF HYDROLOGIC INSTRUMENTS AND EQUIPMENT AT THE USGS HYDROLOGIC INSTRUMENTATION FACILITY

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PURPOSE AND SCOPE

The Hydrologic Instrumentation Facility (HIF) provides unbiased evaluation testing for Water Resources Discipline (WRD) developed and commercially available hydrologic instrumentation. The HIF conducts instrument evaluations to identify instrumentation and equipment that meet the requirements of the U.S. Geological Survey (USGS) to collect hydrologic data. The general requirements for USGS instruments and equipment are that the instruments be:

- cost effective, best value for a given performance;
- accurate, measures the parameter with the accuracy needed, and
- handles a wide range of environmental conditions in which the USGS collects data.

The order of the general requirements is not an indication of priority. All of the general requirements are of equal importance.

Finite resources at the HIF limit the number of evaluations that can be done during a given time period. Many groups outside of the USGS are also interested in the performance of hydrologic instrumentation. The HIF may partner with either outside federal or governmental agencies or other WSC to conduct equipment evaluations.

This document provides guidance for selecting and conducting evaluations of hydrologic instruments and equipment. The guidance herein applies to HIF evaluation testing of instruments.

EVALUATION PROCESS

The general steps for conducting evaluations of hydrologic instruments or equipment include:

- Proposing instrument or equipment for evaluation
- Selecting instrument or equipment and prioritizing evaluations
- Acquiring instrument or equipment
- Developing test plans
- Testing
- Analyzing and charting data
- Reporting evaluation results

The following sections have specific guidance for the steps of the evaluation process.

PROPOSING INSTRUMENT OR EQUIPMENT FOR EVALUATION

Equipment evaluations can be proposed by the technical offices of the Water Resources Discipline (WRD), Water Science Centers (WSC), and the HIF Field Service and Testing Sections. Vendors may bring new instruments for evaluation testing to the attention of the HIF by contacting the HIF Testing Chief. Other means, such as HIF user surveys and conference workshops conducted by the HIF, may be used as additional mechanisms to propose equipment for evaluation.

Proposed equipment evaluations are submitted to the HIF Testing Chief for initial review. Appendix A contains a form for proposing equipment for evaluation. Proposals received by the HIF Testing Chief will be summarized twice a year and presented to the HIF Chief.

SELECTING INSTRUMENT OR EQUIPMENT AND PRIORITIZING EVALUATIONS

The technical offices of the WRD, the Chief of the HIF, the HIF Field Service Chief and the three regional WRD data committees [Committee for Hydrologic Instrumentation and Data, Eastern Region (CHIDER) (*http://water.usgs.gov/usgs/orh/CHIDER/*), Central Region Advisory Committee on Data (CRACD)(*http://cr.water.usgs.gov/uo/tft/CRACD/*), and Western Region Technical Advisory Committee (WRTAC) (*http://hdtac.wr.usgs.gov/default.aspx*)] provide guidance and advice to the HIF Testing Chief on equipment selection and evaluation priorities. Additionally, the HIF Chief may periodically assemble a "panel of experts" to advise the HIF Testing Chief on specific instrument themes. The "panel of experts" may include experts from academia, instrumentation manufacturers, USGS cooperators, other federal agencies, and potential testing partners, as well as USGS experts.

The HIF Testing Chief maintains contacts with various USGS and non-USGS instrumentation groups and users to help determine evaluation needs and rank evaluation proposals. It is the responsibility of the HIF Testing Chief to make the initial selection of instruments (or equipment) for evaluation testing by the HIF Testing Section, based on the guidance and recommendations made by the Chief of the HIF, WRD technical offices and the WRD regional data committees.

The HIF Testing Chief maintains a list of planned equipment evaluations, sets priorities, and schedules the evaluations. The HIF Testing Chief will make available a list of instruments that have been selected and prioritized for evaluation. The list will be updated at least annually by the end of October. The instrument evaluation list will be distributed annually to the WRD technical offices and the three regional data committees along with a summary of evaluation requests and the status of ongoing evaluations.

Evaluations are prioritized using criteria similar to that used for selection. Equipment for which there is a broad demand by USGS offices, and offers a possible solution to a measurement problem will have a higher priority than equipment that duplicates existing equipment measurement capabilities. Equipment that is a possible replacement for obsolete or discontinued equipment will also have a higher priority than equipment that duplicates existing measurement capabilities. In general, equipment that offers the best potential return for USGS offices, by improving measurement capabilities, enhancing safety or decreasing purchasing costs or servicing costs, will have higher a priority than equipment that duplicates existing measurement capabilities.

The HIF Testing Section has a finite capacity to do instrumentation evaluations. HIF Testing Section provides new product acceptance testing for equipment purchased for the sales and rental program as well as equipment evaluations. Depending on available funding, work force, test equipment, staffing levels, staff expertise, and routine acceptance testing demands, the capacity to evaluate equipment will vary over time. Partnerships within the USGS and other governmental agencies will also be used as appropriate to improve evaluation capacity.

Equipment Selection Criteria

Equipment is selected for evaluation testing based on the desirable characteristics that it offers. Equipment must meet a set of minimum requirements prior to being considered for evaluation testing by the HIF.

Minimum requirements

Unless the equipment meets an unmet measurement need, such as measuring an important water parameter that previously could not be measured, all equipment or instruments selected for evaluation will:

- Have stated manufacturer accuracy and resolution that meets USGS requirements as stated in the appropriate policy memos, field manuals or USGS reports. For surface-water instrumentation, see Water Supply Paper 2175 and Office of Surface Water memo No. 96.05. For ground water instrumentation, see Techniques of Water Resources Investigations (TWRI) Chapter A, Book 8. For water-quality instrumentation, see TWRI Book 9 and Water Resources Investigation Report, WRIR-00-4252 (Wagner and others, 2000)
- Have a minimum temperature compensated operating temperature range in air of -40 to 60 ^{o}C and/or in water of 0 to 40 ^{o}C. Depending on justifiable operational needs, the operating temperature range for some classes of sensors may be narrowed.
- Support the USGS standard instrument protocol, currently Serial Device Interface 12 (SDI-12) for outputs (or inputs if a data recorder) if the instrument/equipment operates in an unattended mode in conjunction with auxiliary data recorders. Documentation for SDI-12 is available at www.sdi-12.org.
- Use 12 VDC if the instrument or sensor can be powered through the SDI-12 cable.

For the purpose of the USGS HIF instrumentation testing the following definitions of accuracy and resolution apply. Instrument accuracy is defined as the range within which the closeness of agreement between the instrument measurement and the “true” value of the measurand will lie with a 95% confidence interval. Instrument resolution is defined as the smallest change in value that an instrument can display.

Most instruments selected for evaluation will work in an unattended mode. Other limiting criteria may apply for specific types of sensors and instruments and may be described by other USGS reports. Additional minimum criteria for data loggers, water level, water velocity and some water-quality sensors are in appendix B.

Desirable characteristics

Hydrologic equipment that meets the minimum criteria is selected for evaluation based on the following desirable characteristics. Any equipment selected for evaluation must meet at least one of the following:

- Unmet measurement need
- Reduces ownership costs
- Replaces discontinued/obsolete equipment
- Increases equipment choice and types
- Reduces initial equipment cost
- Improves safety

Equipment that meets a previously unmet measurement need is important to evaluate because it may increase the USGS's ability to provide reliable information on national water resources. Equipment or instrumentation that can provide a measurement of an important water parameter that available equipment is unable to measure in a real-time, unattended or attended mode in the field may facilitate water resource investigations and improve water management. Water parameters that are an immediate USGS program need are prioritized ahead of water parameters that do not have an immediate program need. Depending on the level of need, some or all of the minimum requirements for evaluation may be waived for promising instrumentation that meets an unmet need.

Evaluation of equipment that reduces ownership costs by providing a reduction in installation, maintenance, and operating expense compared to existing equipment (reduced life cycle costs) is important because it maximizes the return on public funding. Equipment that requires fewer field trips, and/or less expense to install, maintain and is easier to use can help reduce costs for collecting water data. Extension of maintenance cycles over the typical maintenance cycle of surface-water instruments (about 6 weeks) is highly desirable.

Evaluation of equipment that replaces discontinued or obsolete equipment, typically a HIF catalog item that will be or is no longer available, is important because it helps to maintain the USGS's ability to provide reliable water information. Frequently, these evaluation needs are identified by the Chief of Field Service Section.

Evaluation of equipment that increases commercial choices for the sensor or instrument for which only one commercial choice exists is important because the number of equipment choices can foster competition among suppliers. The equipment selected for evaluation may offer an alternative to equipment that is offered by only one vendor. Multiple, capable vendors for an instrument will help to keep instrument costs reasonable to the USGS and encourage vendors to continue to improve products.

Evaluation of equipment that reduces equipment purchase costs or equipment that has significantly better performance than existing equipment at a similar cost is important to evaluate because it can lower equipment costs. The evaluated equipment may offer improved accuracy at the same cost as less accurate equipment or, because it is used extensively by the USGS-WRD, the identification of the most cost effective and robust equipment will result in savings.

Evaluation of equipment that improves safety by reducing the exposure of the field hydrographer to vehicular traffic, deep or high-velocity water, or hazardous chemicals is extremely important because it helps protect employees from injury. Equipment that is significantly safer to use than existing equipment is important to evaluate. If an instrument reduces the field hydrographer's accident risk or reduces or eliminates disposal of hazardous materials it may be a good candidate for evaluation.

Equipment selected for evaluation is usually a commercially available item for the environmental monitoring market. Occasionally evaluations will be made on equipment that hasn't completed development by the vendor or was not developed for the environmental monitoring market. These evaluations are performed to provide either the vendor/developer with constructive feedback that helps the USGS get a product that can be used or to identify instrumentation methodologies that may be userful to the environmental monitoring market. Most evaluations of this type will be of equipment that provides a solution to an unmet need.

ACQUIRING INSTRUMENTS OR EQUIPMENT

It is usually desirable to purchase equipment so that the tested instrument is typical of a vendor's production. Evaluations may be conducted on loaned instruments. Evaluation reports will explicitly state the method used to obtain the equipment.

Equipment or instruments that are selected for evaluation because they may replace discontinued/obsolete equipment, reduce equipment costs, or increase commercial choices, will usually be acquired through purchase. In some cases equipment or instruments selected for evaluation may only be obtainable through purchase. A third party may be used to purchase the equipment for the HIF in order to ensure that an instrument typical of a vendor's production is obtained.

Loaned equipment may be used for collaborative evaluations where the partner, either a WSC or Other Federal Agencies (OFA), provides equipment. Vendor loaned equipment may be used for evaluations on equipment that is being developed by the vendor. Occasionally, when it is to the USGS advantage, equipment loaned by the vendor may be used for evaluation of equipment that is commerically available.

EVALUATION PLANNING AND TESTING PROCEDURES

Written test plans must be developed and approved prior to the start of evaluation testing. These plans may include both laboratory and field testing. Evaluation tests are usually designed to determine whether the equipment meets manufacturer specifications and USGS requirements for collecting hydrologic data. Typically, not all features of an instrument will be tested.

Test plans usually include laboratory testing. The testing facilities at the HIF usually allow equipment to be tested over the published operating temperature range and over the range of the sensor. Temperature and other conditions that may take at least a year to occur in the field can often be simulated in the laboratory on demand. However, laboratory testing does not duplicate all of the installation and environmental conditions that equipment is exposed to under field conditions. Field testing is desirable because it can provide information about how hard an instrument is to service and maintain in fouling conditions.

The following sections contain guidance on developing test plans and on conducting laboratory and field testing of instruments or equipment. Both types of tests require planning, development of timelines, the keeping of test notes, collection of data, and the summarizing of the data and test results usually in tables and or charts.

Laboratory Testing

Laboratory testing of the instrument typically includes testing over the operating temperature range and the sensor(s) operating range. Instruments used for unattended monitoring will usually need SDI-12 compliance testing, and an evaluation of the software. Power consumption testing may be done on instruments that can be powered by SDI-12 cables. Accelerated age testing (cycling over the operating temperature range many times in an environmental chamber) can be used to estimate the effects of extended field deployments on instruments. Because accelerated age testing requires additional weeks of testing in an environmental chamber, accelerated age testing is done infrequently.

Planning and timelines

Test planning forms are located in appendix C. A completed "Instrument Evaluation Plan" form is a required part of each test plan. This form is usually filled out by the primary tester. If the equipment or instrument is a sensor, the "Sensor Evaluation Test Form" must also be completed. If the evaluation will employ either an environmental chamber or water bath then the "Environmental Chamber Test Plan" form or the "Water Bath Test Plan" form must also be completed. Documentation of the proposed testing method will be included with the test plan. All test plan forms and supporting documentation must be submitted for review and approval by the HIF Testing Chief. A timeline for the testing will also be developed. The completed forms for environmental chamber and water bath temperature testing in appendix C can be used as an aid in estimating a timeline for the evaluation.

The "Sensor Evaluation Test Form" is not used for describing tests on radios, power systems, and loggers. However, the forms for planning temperature testing may be useful for planning tests of these kinds of equipment. If the test is a collaborative effort, test plans should be discussed with the partner and may need review by the testing partner. Existing Standard Operating Procedures (SOPs) and test procedures should be investigated and used if they provide the accuracy needed. Estimates of the accuracy of the reference and whether the reference measurement is adequate should be conducted during test planning, especially when no previous test SOP is available.

Test methods

Testing methods used for evaluations will be documented. Either existing HIF SOP's or citable protocols such as those documented in published literature can be used with or without modification. Possible sources for specific testing methods include the Alliance for Coastal Technology (ACT) web site (*http://www.act-us.info/*) and Standard Methods for the Examination of Water and Wastewater (*http://www.standardmethods.org/*).

If a new testing method is developed, it must be documented. Any testing method that compares an instrument's measured value against another reference instrument or standard must include an estimate of the accuracy of the reference instrument or standard measurement. Traceable reference instruments or standards should be used whenever possible. Depending on the accuracy of the reference measurement, the test may or may not conclusively demonstrate that an instrument meets a specification. Care must be taken to ensure that the selected reference instrument or standard will meet the test requirements.

Notebook and test records

A bound, laboratory notebook should be maintained during the evaluation tests. Good notes on the details of the test set up, records of the problems during the testing, records of when each test was performed and all hand written measurement data should be recorded in ink in the laboratory notebook. Also noted in the laboratory notebook are the computer file names and computer in which the test measurements are recorded and the date of the file creation. Photos should be taken of the laboratory test setup. Test results should be plotted as soon as possible. This allows problems in test set ups to be detected as soon as possible and remedied. Both the laboratory notebook and the raw measurement data will be archived at the HIF. The raw measurement data will be archived, in a standard file format such as Excel, on the HIF "common" server computer. Laboratory notebooks will be archived in the HIF archive file cabinet along with other HIF archives, such as non destructive test documents.

Field Testing

Field testing of the instrument typically yields information on how field conditions can affect the instrument. Field testing may require partnership or collaboration with USGS WSC offices.

Planning

Similar to laboratory testing, field test plans should be developed by the primary tester. Field test plans should include objectives for the field test and what independent reference measurement will be used for comparison. Accuracy specifications for the instrument under test and the reference instrument will be provided with the field test plan. Details on the field installation and on the sampling period and length of deployment are included as part of the test plan. Field measurement forms, as needed, should be developed during test planning and included as part of the test plan review. Field forms can help to maintain uniform data quality. Field test plans will have appropriate independent technical review prior to being submitted for approval and testing begins. The HIF Testing Chief approves field test plans. If the testing is a collaborative effort, the testing partner may need to review the test plans.

Test records and field notes

A field notebook should be maintained during field testing. Good notes on the field site, and photos of the installation should be taken. Problems that occur during the test and records of when the test installation was completed and discontinued should be recorded in the field notebook. Names of the computer files containing the field data should also be recorded. Field measurement forms, as needed, should be developed to help maintain uniform data quality. All hand written measurement data, such as check measurements made with a reference instrument, should be recorded in ink in the field notebook. Test records should be archived. The logger data files will be archived, in a standard file format on the HIF “common” server computer. Any field measurement forms should be archived appropriately, either as computer files on the HIF “common” server computer or in the HIF archive file cabinet. Field notebooks will be archived in the HIF archive file cabinet along with other HIF archives, such as non destructive test documents.

ANALYZING AND CHARTING OF DATA

Simple statistical analysis of data will be used to quantify test results and as quality indicators. Estimates of the instrument measurement uncertainty (or accuracy) and components of measurement uncertainty; precision, bias, and drift, will be made using the test data. Differences between the instrument under test and the reference instrument or standard will be used as estimates of instrument uncertainty and as an indicator of whether an instrument meets accuracy requirements. The differences are computed to give positive differences for measurements that are higher than the reference value and negative differences for measurements that are lower than the reference value. Differences may be non-dimensionalized and expressed as percentages.

Estimates of precision (random uncertainty) are obtained by computing the standard deviations from the test data. Usually the standard deviations will be computed from the differences unless a large number of replicated measurements are made. Estimates of the bias (systematic uncertainty) are obtained by computing the average difference. Estimates of instrument drift are computed by differencing the readings made at the same conditions but at different time intervals. Estimates of the accuracy of the instrument are computed as a combination of the bias and the precision for a 95% confidence interval.

Estimates of accuracy may be made for each test type and instrument or combined to give a general estimate for all the conditions and units tested. The guidance given in the Guide to the Expression of Uncertainty in Measurement (ISO, 2008), or the GUM, for computing measurement uncertainty will be used to estimate the uncertainty in the reference measurement and the test as needed.

Data that is collected as a time series can be initially charted with time on the x axis and the varied measured value (for example, water-level) on the y axis. This can be used to check and count the length of missing data and if operational problems (such as lightning hits) occurred during the test. Differences between the instrument under test and the reference should be plotted on the y-axis against the varying test parameter on the x axis. For example, differences in water-level would be plotted on the y-axis against varying temperature on the x axis for tests on the effect of varying temperature on a water-level sensor.

Frequently, more than one unit is tested in order to capture manufacturing variation in the instrument. Whenever possible, charts and statistics should be plotted and computed for individual and for the group of units tested.

REPORTING EVALUATION RESULTS

Evaluation results should be shared in a timely manner. Ideally, evaluation results should have at least two qualified peer reviews. Because instrumentation can change rapidly over very short time frames (< 12 months) delays in reporting evaluation results can make the instrumentation testing not as meaningful. This may limit, in some cases, the amount of peer review to an internal review by the Testing Chief or their designate. Evaluation results can be shared using internal USGS meetings, such as the regional data conferences, professional conferences, internal only reports and peer reviewed reports.

Oral presentations can be used to quickly disseminate test results but do not replace the requirement to document the evaluation in a written report. Instrument and equipment evaluations may be reported in internal USGS only reports, such as the WRD Instrument News, in official USGS publications, external conference proceedings or in professional journals and books. For many instrument evaluations a WRD Instrument News article or a professional conference may be the timeliest means for reporting evaluation results.

The standard report format in appendix D should be used whenever possible for report instrument evaluations. This format can be directly used for WRD Instrument News articles and USGS open file reports. See USGS publications standards for additional requirements for USGS reports. Outside publications will have different publication standards. However, the standard report format and guidance may be suitable with a few modifications.

REFERENCES

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Wilde, F.D. and Radtke, D.B. (editors), 1999, National field manual for the collection of water-quality data, Field measurements: U.S. Geological Survey, Techniques of Water-Resources Investigations, book 9, Chapter A6. *http://water.usgs.gov/owq/FieldManual/*

Appendix A: EVALUATION REQUEST FORM

Evaluation Request Form
Submitted by: Date:
Email address of submitter:
Instrument type (circle one): wq /sw / gw/ logger / telemetry / power
Manufacturer:
Model:
Communication: SDI-12 / serial / USB / other:__________
Power: AC / DC(internal/external) voltage range:__________________
Temperature operating range:

Manufacturer accuracy (include units):
Manufacturer resolution:
Range:
Temperature compensated range:

USGS requirement accuracy:
USGS requirement resolution:
USGS requirement range:

□ Attach manufacturer specification sheet.
Previous or similar model has published independent evaluation: yes / no
(If yes attach copy of published evaluation.)
Previous or similar model has HIF evaluation: yes / no
(If yes attach test report.or Instrument News article)

Desirable Characteristics of Equipment (check all that apply):

- □ Unmet measurement need. Specify:_________________________
- □ Reduces field maintenance and ownership costs
- □ Replaces discontinued/obsolete equipment
- □ Increases equipment choice
- □ Reduces equipment cost
- □ Improves safety
- □ Other:____

Please describe the need for the instrument evaluation (attach additional pages as needed):

-----------------------------------Do Not Write Below this Line ------------------------------
Date: Signed:
Recommend for evaluation: yes / no
Priority: urgent / high / average / low
Acquisition method: direct purchase / loan OFA USGS / vendor loan
Justification (attach additional pages as needed):

Appendix B. EQUIPMENT SPECIFIC ADDITIONAL REQUIREMENTS

The requirements below are in addition to the requirements presented in the section “minimum requirements” and are specific to instrument type. When the term accuracy is used to describe instrument required performance, it is defined as meaning how close an instrument’s measurement is to the “true” value of the measurand. Required instrument accuracy is the range around the “true” value that the instrument measurement will occur for 95% of the instrument’s measurement population.

DATA LOGGERS

Typical uses of data loggers by the USGS-WRD include: 1) Data is logged from a SDI-12 compliant water-level sensor, battery voltage, and a tipping bucket rain gauge. Logger and sensors are powered by 12V batteries that are recharged by a solar panel. Data is logged usually at a 15 minute interval. Data is transmitted at regular intervals, every 4 hours or less, usually through GOES radio. 2) Data is logged from a SDI-12 compliant water-level sensor, battery voltage, and a tipping bucket rain gauge. Data is logged from a reference velocity sensor such as a side looking ADCP, radar or UVM. Data is logged usually at a 15 minute interval. Data is transmitted at regular intervals, every 4 hours or less, usually through GOES radio. 3)Data is logged from a SDI-12 compliant water-level sensor, battery voltage, and a tipping bucket rain gauge. Telemetry is usually GOES, but cell modems are used either in addition to GOES or alone. 4) Data is logged from a SDI-12 complaint water-level sensor, water-quality monitor and tipping bucket rain gauge. Data collected for transmission include water-level, three to six water-quality parameters, battery voltage, and rain fall amounts. Data is transmitted at regular intervals (<= 4 hours) using GOES radio. Other telemetry methods may be used in addition to GOES.

Data loggers must use menu type or GUI type software that does not require any programming skills in order to use. GOES radios that are either compatible with the logger or supplied with the logger must have a failsafe switch that can be reset by the user without having to remove parts from either the logger or the logger enclosure. Screw terminals or similar connections used for sensor and peripheral connections should allow users to fabricate cabling from readily available industry standard mating connectors and cables. Users should be able to download and upload logger setups, and logger programs as well as data by using either USB, or serial (RS232) with a PC laptop. It is desirable that users to be able to upload logger software upgrades. Standard interfaces such as RS232 or USB should be used for the connection of telemetry devices. A summary of data logger requirements is listed in table 1.

Table 1. Table 1. USGS HIF data loggers minimum requirements.

Feature	Requirement
Operating temperatures	-40 to 70 C
Power	12 VDC nominal
Current consumption Radio/cell modem transmit Quiescent consumption Active – display off Active – display on	 5 Amps maximum 10 mA typical 60mA typical 300 mA typical
Input ports (2 ports minimum)	SDI-12 (at least 1) Switch closure, internally debounced (at least 1) Analog 0-5 V (optional)
Output ports	Serial or USB (USB desired) Switched 12-Volt output Digital output line (optional) Analog 5V (optional)
Display	-20 to 60 C operating temperature Show current reading (minimum) Visible in bright daylight Activated by an external switch Automatically time out and turn off after <=60sec
Enclosure	NEMA 4X or better preferred No larger than 11 x 7 x 9 inches No heavier than 10 lbs
Logger setup & user communication	With menu driven software With generic terminal emulation program on laptop With program on laptop thru RS232 or USB connection
Memory	1 Gb internal minimum
Removable memory card	Required
Telemetry	GOES radio capable, Cell modem, Hayes compatible (optional) RS232 or USB connection with logger
Price range	Without radio < $2K With radio <$5K

SURFACE WATER-VELOCITY MEASUREMENTS

The requirements for sensors and instruments used to measure water-velocity differ depending on whether the instrument is being used to measure velocity for a discharge measurement made using the velocity-area method or measure a reference velocity, typically continuously, that is used to determine discharge from a stage-velocity discharge rating relationship. The following sections contain information on the requirements for water-velocity instruments.

Velocity Instruments for Velocity-Area Discharge Determinations

The requirements for velocity instruments used to measure discharge with the velocity-area method are based on the performance characteristics of the Price Type AA and Price Pygmy current meter. These meters have been the standard meter used by the USGS for many years for velocity-area discharge measurements and their accuracy is the minimum requirement for velocity sensors used by the USGS. The typical minimum velocity range is 0.20 fps to 12 fps. Ideally the velocity range should range from <0.15 fps to 20 fps. Non-profiling velocity instruments, or point velocity meters, should be able to measure a 40 second average velocity, as well as other averaging periods.

Table 2. Minimum velocity accuracy requirements for velocity instruments used for velocity-area discharge determinations.

Velocity (feet per second)	0.25	0.50	0.75	≥ 1.10
+/- Accuracy in percent	6.0	3.4	2.5	2.0

Depth and Width Instruments for Velocity-Area Discharge Determinations

The requirements for instruments used to measure width and depth for velocity-area type discharge measurements are based on the information presented in U.S. Geological Water-Supply Paper 2175 (Rantz, 1982) and the traditional equipment used by the U.S. Geological Survey. Table 3 list the minimum accuracy requirements for depth measurements and table 4 list the minimume accuracy requirements for width measurements.

Table 3. Table 3. Minimum requirements for instruments used for depth measurements for velocity –area discharge determinations.

Depth Range (feet)	Accuracy	Resolution (feet)
≤ 6	0.05 ft or 0.1% of reading	0.05
>6	0.10 ft or 0.1% of reading	0.10

Table 4. Table 4. Minimum requirements for instruments used for width measurements for velocity-area discharge determinations.

Width Range (feet)	Accuracy	Resolution (feet)
≤ 150	3% of reading	0.1
>150	3% of reading	1

WATER-LEVEL MEASUREMENTS

The requirements for sensors and instruments used to measure water-level differ depending on the application (surface water or ground water) and the sensor type. The following sections contain information on the requirements for water-level sensors.

Surface Water-Level Measurements: general requirements

This section contains the accuracy requirements for stage measurement systems used by the USGS to measure water level at sites where the computation of discharge from a stage-discharge relationship are required.

Stage measurement systems used to measure water level (or stage) shall sense and record stage with a total measurement uncertainty of no more than 0.01 ft or 0.20 percent of indicated reading, whichever is larger. Total measurement uncertainty includes the uncertainties due to all components of the stage measurement system, not just the sensor. (USGS Office of Surface Water Technical memorandums, No. 93.07 and No. 96.05.)

Ground Water-Level Measurements: general requirements

Measurement systems used to measure ground-water levels should be capable of performing with an accuracy of +/- 0.01 ft for most applications (Freeman and others, pg 16, 2004). For cases where large, rapid changes in water level occur (such as aquifer tests) an accuracy of 0.1% of the expected range in water-level change is acceptable. For ground-water sites where measurements are made continuously over a week or more, the water-level changes should be measured to 0.01 ft resolution and 0.1 % of annual change in water level. Minimum acceptable sensor resolution is 0.01 ft.

Pressure Sensors Requirements

Typically, only gauge pressure ranges between 0 and 30 pounds per square inch (psi) will be considered for evaluation. Non-submersible, gauge pressure sensors used in bubbler systems shall have an accuracy of 0.01 ft or 0.10 percent of indicated reading, whichever is larger, over a temperature range of 0 to 60 ^{o}C. Submersible, gauge pressure sensors (vented to atmosphere) used for continuous measurement of discharge or ground water levels shall have an uncertainty of 0.01 ft or 0.10 percent of indicated reading whichever is larger, over a temperature range of 0 to +40 ^{o}C. Minimum acceptable sensor resolution is 0.01 ft.

Less accurate pressure sensors used in surface-water applications are only appropriate for difficult measurement sites, such as hurricane storm surge locations, ephemeral streams, or for replacement of nonrecording crest stage gages. Absolute pressure and non vented (or sealed) pressure sensors are often used at difficult measurement sites in combination with a barometric sensor and are, for convenience, grouped with the less accurate pressure sensors. These sensors will have an accuracy of 0.1% full scale (FS) reading or better and a resolution of 0.01 ft and will include a logging system. Less accurate pressure sensors may be used in groundwater applications, however, these sensors will have a low evaluation priority.

The percent FS accuracy required to meet the accuracy requirement is a function of the pressure range of the sensor. A 22 pounds per square inch gauge (psig) pressure sensor must have a 0.02 percent FS accuracy over its operating temperature range (using a conversion factor of 2.307 ft-H20/psig to convert pressure in psig to feet of water) to meet the sensor performance requirement. A 30 psig pressure sensor with 0.02 percent FS accuracy will not meet the sensor performance requirement throughout the measurement range. (assumes accuracy is 0.010, meets 0.0144444 requirement)

WATER-QUALITY SENSORS REQUIREMENTS

The minimum operating temperature range for water quality sensors is -5 to 45 ^{o}C . The minimum compensated temperature range is 0 to 40 ^{o}C . In general, the commonly used water quality sensors, such as temperature, conductance, pH, dissolved oxygen, and turbidity, should have a response time that is less than 90 seconds. Only the common water-quality parameters requirements are summarized and listed in the table below. Values in table 1 are based on the information in Chapter A6 of the National Field Manual for the Collection of Water-Quality Data (Wilde and Radtke, 1999). Please refer to other USGS water quality documents for other parameters.

Table 5. Minimum requirements for common water quality sensors. (minimum compensated temperature range is 0 to 40 °C).

Sensor	Accuracy	Resolution	Range	Units
Temperature	+/- 0.2 °C	0.1 °C	-5 to 45 °C	Celsius
Specific conductance	+/- 3% Full Scale or 5 µS/cm		<100 to 60,000 µS/cm	µS/cm
Dissolved Oxygen	+/-5% reading or +/-0.2 mg/L	0.01 mg/L	>=0.05 to 20 mg/L	mg/L and % saturation
pH	+/- 0.1 pH unit +/- 1.0 mV	0.1 pH unit 0.1 mV	2 to 12 pH units (minimum) 0 to 14 pH units (preferred)	pH units and milliVolt readings
Turbidity	+/-5% or 2 NTU	1 NTU	0 to 1000 NTU	

Appendix C: INSTRUMENT EVALUATION PLAN

Submitted by: date:
Reviewed by: date:
HIF Test Chief: date:

GENERAL INSTRUMENT INFORMATION

INSTRUMENT TYPE : (circle one)	/ WQ / SW / GW / logger / telemetry / power /
MANUFACTURER:	
MODEL:	
COMMUNICATION:	/ SDI-12 / serial / USB /other:__________________
POWER:	/ external battery 12V / internal battery / line power /
Operating Temperature Range:	
Compensated Temperature Range:	
SENSOR(S)/PARAMETERS:	

TESTS PLANNED

POWER CONSUMPTION:	/ no / room temp only / over temp range /
SDI-12 VERIFICATION:	/ no / yes / not applicable /
TEMPERATURE Equipment need:	/ none / water bath / temp chamber /
SENSOR(S)/PARAMETERS to TEST:	

EQUIPMENT NEEDS FOR TESTS:

ATTACHMENTS (check attachments):

- ☐ Manufacturer’s specifications from manual
- ☐ Manufacturer’s specifications from web site
- ☐ Sensor test forms (must be completed for any sensor tested)
- ☐ Written test procedures for tests (either SOP or custom), one for each test type.

SENSOR EVALUATION TEST FORM

This form is completed for each sensor/parameter to test.

Sensor/Parameter to Test		Units of Measurement:	

	Accuracy	Resolution	Publication for Accuracy
Manufacturer			
USGS requirement			

Test Standard or Reference:	
Range or Value of Reference:	
Units used by Reference:	
Accuracy of std/reference:	
Resolution of std/reference:	
TEST GUIDANCE SOP # *(If no sop, written procedure is attached)*	
Check instrument	
Accuracy of check instrument	
Test Temperature	

Attached Temperature Test Plan (check one):

- □ Room temperature only, no plan needed
- □ Water bath temperature test plan form attached
- □ Environmental chamber test plan form attached

□ Attached written test procedures

ENVIRONMENTAL CHAMBER TEST PLAN

Date:
Prepared by:

Instrument Model:

Parameter under test:

Chamber Name:

Ramp rate used to estimate elapsed time (^{o}C/minute):

Soak time needed for equipment to reach temperature:

Total time for temperature test (use worksheet below for estimating):

WORKSHEET FOR TESTING TIME
The value in the table is the test value for parameter under test at that test step. Please indicate with an X in the ramp or soak column to indicate whether test step is a temperature soak or ramp (changing temperature).

Test	**Initial**		**Final**		**Time**		
step	**Parameter value**	**^{o}C**	**Value**	**^{o}C**	**elapsed**	**Ramp**	**Soak**

Comments:

WATER BATH TEST PLAN

Date:
Prepared by:

Instrument Model:

Parameter under test:

Water Bath:

Soak time needed for equipment to reach temperature:

Total time for temperature test (use worksheet below for estimating):

Parameter value	Set temperature	Time to reach temperature	Sampling time	Total time

Comments:

Appendix D. Article Format for HIF Instrumentation News Evaluation Articles by the Testing Section

The required format and structure for articles by the Testing Section on the evaluation of instrumentation are given in this appendix. In general each article reporting on evaluation results will have the following sections:

- Overview
- Description of Instrument
- Test Procedures
- Test Results
- Testing Tidbits

The font and layout of the report will follow the guidance used for USGS open file reports (ofr). Word templates for USGS ofr's are available at the publication web site at: *http://internal.usgs.gov/publishing/toolboxes/author.html* Guidance for the contents of each section follow.

Overview

This section is similar to a paper abstract. It should briefly state what instrument was tested, what kind of testing was performed, whether the instrument(s) passed manufacturer specifications and whether the instrument passed any USGS requirements. It is recommended that a table summarizing the tests and results be included with this section. An example table follows in table 1. The table should be only one column (half page width) wide and the table caption must identify the instrument make and model.

Table 1. Summary of Sutron Model 56-113 evaluation.

Specification	Compliance no. of units (% passed)
Water-level accuracy	
OSW	0 of 3 (0%)
Manufacturer	0 of 3 (0%)
SDI-12	3 of 3 (100%)
Power consumption	
< 7mA	2 of 3 (67%)
Temperature	
+/- 1^{o}C	3 of 3 (100%)

Description of Instrument

This section contains a description of the instrument being evaluated. The following should be used as a check list for the contents of this section.

1. <u>Brief description of the instrument tested</u> that includes text on the unique features and the uses that the vendor recommends it for.
2. <u>A sentence that references a photo of the tested instrument</u>.

3. A photo of the tested instrument with caption labeled as figure 1. The caption should include the manufacturer's name, and the instrument make and model.
4. A reference to the vendor's web page.
5. A table that contains the manufacturer specifications for the instrument.

Manufacturer specification tables for similar types of instrument (for example pressure sensors) should contain the same information for all makes and models. This allows readers to do side by side comparisons between instruments. For pressure sensor testing, see recent articles since 2002 in the newsletter for example spec tables. The table should have a entries on the housing dimensions, communications and power consumption of the instrument. The table should have a separate section for each type of sensor tested if it is a multi-sensor instrument. Don't spread manufacture specifications across pages, unless absolutely necessary. An example table for the manufacturer specifications follows in table 2 and 3. If possible, this table should be one column wide.

Test Procedures

This section should contain a description of the tests and test procedures used during the testing. The following should be used as a check list for the contents of this section.

1. Do not include test results in this section. Do not include sentences stating that it passed specifications or figures of results in this section.
2. State clearly the manufacturer specification(s) tested or checked. Examples are: SDI-12 verification (be sure to include version of the verification tester used), power consumption, and accuracy of the sensor.
3. Describe the methodology used to test/check each specification. Example sentences are: "Nitrogen gas was applied at various pressures to simulate water levels." "Water levels were varied in a 12 inch diameter stand pipe from 2 to 10 feet."
4. Describe the reference or standard used for comparison or "truth". Examples of sensors used as standards are: PS2 in stand pipes, Ruska pressure controllers, calibrated voltage source, Winkler titrations (for DO), tow tank cart speed, thermometers, or chemical test standards. All tests should routinely record the model number and last calibration date for the standard(s) used.
5. List or describe the range of the tested specification and conditions (such as water level, voltage, velocity, temperature, humidity, concentration, or salinity) over which the tests were conducted. All tests should routinely record the air temperature during the tests, even if performed at room temperature.
6. Include the dates over which the data was collected, if outdoor or onsite testing was done.

Test Results

This section contains a description of the test results for each test. Tables containing error statistics are encouraged such as mean difference with the standard, and standard deviation of the difference with the standard. Group statistics (when more than one sensor has been tested) should be used when possible. Charts of test results are required. Charts should be used to summarize the testing. The following should be used as a check list for this section.

1. For each test, state for what conditions the instrument met or did not met specifications. Reference the appropriate chart and/or table.
2. Charts of data must be included. Combine charts whenever possible, such as showing difference with standard versus temperature, instead of a chart of time versus pressure for each temperature. If multiple instruments are tested, plot the data for each instrument with a different symbol, but on the same chart. Chart formats should follow USGS style. Axis titles are all capitals. Tic marks are to the interior of the chart. Background for all charts should be white with a black border all around. Because most charts will be published in black and white, all symbols, text and lines on charts should be in black and white or gray tones. An example chart is shown in figure 1.
3. Include tables of statistics on the difference with the standard. Group (all the instruments) and individual statistics should be computed.
4. Reference every table and chart in the text.

Testing Tidbits

This section should contain recommendations (if any) and suggestions for use of the instrument. It should also contain comments or opinions on the user manual and software performance.

Table 6. Global Water Model WL14X Water Logger manufacturer specifications.

FEATURE	SPECIFICATION
Datalogger	
Housing dimensions	1 5/8 inch diameter 10 inch length
Housing material	stainless steel & UV protected PVC
Weight (logger, sensor, & battery)	1.5 lbs
Record interval	1,2,3,6,12,15,20,30, & 60 minutes
Recording period (programmable)	1hr interval: 256 days 15 minute interval: 64 days 5 minute interval: 21 days
Memory	6,000 readings, wrap-around
Battery life	Lithium 9 VDC: 1 year Alkaline 9 VDC: 6 months
Input	analog 0-4 VDC
Communication protocols	output: RS232 sensor: not applicable
Software	3.5 inch disk DOS and Windows compatible file type: comma delimited, *.CSV real-time monitoring scaling for engineering units
Resolution	12 bit (0.003ft for sensor with FS of 14ft)
Pressure Sensor	
Housing Dimensions	3/4 inch diameter 8 inch length
Housing material	stainless steel
Reading	gage (vented cable)
Accuracy	0.2% FS
Ranges	0-3, 0-15, 0-30, 0-60, 0-150, 0-250 ft
Allowable overpressure	2X range
Dynamic temperature compensation	-1 to 21 degrees C
Storage temperature	not specified
Cable	25 ft (standard) to 500ft length undetactable by user factory repairable
Desiccant system	none supplied
Communication protocol	not applicable
Power consumption	see datalogger battery life