COMMISSION FOR HYDROLOGY

Proposal and Project Implementation Plan for the Assessment of the Performance of Flow Measurement Instruments and Techniques[1]

Abstract

Several new hydrometric instruments and measurement techniques have been developed over the last few decades, but National Hydrological Services [2], who have a responsibility to measure surface water characteristics, have not witnessed an equal growth in knowledge and practices pertaining to the procedural manuals and standards for the use of the newer instruments and techniques nor for establishing the uncertainty associated with the estimate of the measurement. The World Meteorological Organization's (WMO) Commission for Hydrology (CHy), in recognizing this deficiency, identified at its Twelfth Session in 2004 the need "to develop a proposal and to implement a project to assess the performance of flow measurement instruments and techniques". The proposed project and its implementation are expected to improve the understanding of the accuracy of various types of hydrometric instruments, thereby contributing to the management of water resources. This document provides the substance of the proposal and its implementation plan, and experts are invited to come forward to contribute to this worthwhile initiative.

Introduction

There is increasing attention being given to the realization that the world's freshwater supplies are finite, with overuse and drought exasperating tensions. At the same time, there has been a growing awareness of society to the often historically overlooked need of the aquatic ecosystems for these same resources. As a result of these and other needs, there have been increasing demands on National Hydrological Services (NHSs) to quantify the uncertainty of hydrological measurements. The ability of NHSs to provide the associated uncertainty has been hampered by the dramatic changes in the instrumentation available for use in hydrometry over the past twenty five years and in the development of procedures for the measurement of discharge. The availability of inexpensive computer systems has permitted the increased use of instrumentation and techniques, such as acoustics and radar, which were previously too computationally intensive to use. As well, electronic data recording media that eliminate the use of paper have advanced dramatically and are now widely used.

Due to the need for guidance on selecting appropriate instrumentation and procedures for the measurement of discharge, as well as recognition of the need to compute and quantify the associated measurement uncertainties, the 12th session of the Commission on Hydrology identified (WMO, 2004, p. 30) an activity "to develop a proposal and implement a project to assess the performance of flow measurement instruments and techniques against WMO standards" in the theme area "basic systems in hydrometry and hydraulics." A small group of

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[2] For the sake of conciseness, the term National Hydrological Services is used throughout this document to indicate those organizations that deal operationally with flow measurement and/or with flow measurement instrument calibration, recognizing that in the case of many countries this will encompass several organizations of different affiliation.

experts was formed to develop an initial proposal to fulfill this activity. This initial proposal was reviewed and was discussed in-depth at a meeting of experts in April 2007 (WMO, 2007). This meeting resulted in modifications to the proposal, with one of the most important being the development of an implementation plan. The revised proposal and its associated implementation plan are contained herein. This document is also intended to allow for a broader sharing of knowledge of the initiative amongst experts who may be interested in participating in the endeavour.

WMO and Its Commission for Hydrology

WMO was established in 1950 and one year later it became the specialized agency of the United Nations responsible for meteorology (weather and climate), operational hydrology and related sciences. It was the direct successor of the International Meteorological Organization, which was founded in 1873. The Organization operates on the basis of cooperative action by the National Meteorological and Hydrological Services of its member countries and territories, which numbered 190 in 2006. Eight WMO technical commissions exist to advise the Organization on specific technical and scientific matters and to promote international cooperation in their individual areas of responsibility.

The Commission for Hydrology is responsible, among other things, for (WMO, 2003):

- Advisory activities in hydrology and water resources, including the measurement of basic variables characterizing the quantity and quality of water and sediment in the hydrological cycle;
- Promoting and facilitating the international exchange of experience, transfer of technology, and education and training to meet the needs of National Hydrological Services (NHS) or other organizations fulfilling the functions of such Services;
- Promoting and facilitating the international exchange and dissemination of information, data, standards, forecasts and warnings.

Background

Existing WMO guidance pertaining to flow measurements include: the *Technical Regulations – Volume III Hydrology* (WMO, 2006); the *Guide to Hydrological Practices* (WMO, 1994) Chapters 10, 11, 12, and 13; and the *Manual on Stream Gauging* (WMO, 1980). These documents are intended to provide information ranging from general guidance to more specific details on stream gauging practices. They are not intended to provide detailed results of testing of flow measurement technology and measurement techniques.

The existing documents address the proper use of propeller type water-velocity meters, flumes, weirs, and dye dilution methods to measure discharge and the use of floats and bubbler (mercury manometer pressure measurement) systems to continuously measure water level. Automated data recording systems described in the documents were either paper chart recorders or paper punch tape, and the publications largely predate the use of strain-gauge type pressure systems for water-level measurements. These earlier publications also introduced newer methods for discharge estimation including the moving boat, ultrasonic and electromagnetic. However, since their initial publication, there have been significant advances in the “newer” technologies such as hydrometric acoustic and radar instrumentation, as well as remote sensing systems.

New instrumentation technologies for discharge measurements include acoustic Doppler current profilers (ADCPs), point acoustic velocity meters, surface-velocity radar, and large-scale particle image velocimetry (LSPIV). For water-level measurements, the new technologies include strain-

type pressure sensor (submersible sensor and bubbler system), acoustic, radar and laser systems. For data recording, paper systems have been almost entirely replaced by largely automated electronic logging, analysis and data transmission systems.

The new instrumentation and methodologies may offer more and better quality data at a lower cost while being easier and safer to use. Acoustic velocity technologies can offer vector components of water velocity that allow improved measurement accuracy in situations of bi-directional flow. Surface velocity radar can make non-contact or non-intrusive measurements of water velocity during conditions that are too hazardous for instruments that need to be submerged in the water (Cheng et al., 2001). Some of the newer instrumentation for water level measurement also requires less installation effort than the older instrumentation.

However, the methodology used by surface velocity radar and ADCP instrumentation does not duplicate the methodology used by the older propeller and electromagnetic current meters. The newer water level instrumentation may be more sensitive to data aliasing due to sampling intervals. None of the existing WMO guidance and standards, or, for that matter, those of other international organizations, such as ISO, sufficiently address the newer instrumentation and methodologies for arriving at discharge measurements and their associated uncertainties. Information on the appropriate use and accuracy of these newer instruments and methodologies is needed.

Analyses of uncertainty of data measured with the older and newer instrumentation and methodologies are also needed to quantify the uncertainty in hydrological measurements. Some uncertainty analyses, such as ISO (1983 and 1993) are available. However, few if any uncertainty analyses are available for the newer instrumentation and methodologies. These analyses are of fundamental importance to the application of risk management procedures and sustainable water resources management, by ensuring that the methodology and instrumentation selected for a task will deliver the accuracy that is needed. These analyses would also enable investments in hydrological instrumentation in the most cost-effective manner. Guidance on uncertainty analysis is available from several sources including the US National Institute of Standards and Testing (NIST), the United Kingdom Accreditation Service, International Organization for Standardization (ISO) and the American Institute of Aeronautics and Astronautics (AIAA). Existing WMO guidance and standards documents do not sufficiently address the computation of the uncertainty of these newer hydrological measurements.

A new edition of the *Guide to Hydrological Practices* is currently in the final stages of preparation and should be published in 2007. Even if it will contain sections addressing new instrumentation technologies, those sections will likely reflect the experiences of a small group of experts and currently available literature. A concerted effort of the international community as reflected in this proposal could greatly advance our current state of practice.

Objectives and Approach

The main objective of this project is to help make information and standardized test results on hydrometric instrumentation and measurement methodologies generally available to National Hydrological Services (NHSs) by providing a web site as a forum for the exchange of instrumentation and measurement methodology test results and information. A secondary objective of this project is to encourage and solicit the testing of the newer hydrometric instrumentation and methodologies.

Many NHSs test the performance of hydrological instrumentation and are developing or testing new flow measurement methodologies. Some NHSs are also involved in field studies comparing the newer methodologies with the older methodologies. Mueller (2003) provides an example of an existing report on field testing of new flow measurement methodology for boat-mounted acoustic Doppler instruments used to measure streamflow. Sharing such test results would be advantageous for the NHSs as the large number of new instruments and testing costs limit the number of instruments and methodologies that any one NHS' laboratory can test.

Typically instrumentation test results, especially for commercially available instruments, are internally circulated within a NHS. This existing source for instrumentation test results could be made available to the project. For example, the United States Geological Survey routinely writes internal reports on the testing of commercially available hydrometric instrumentation and could be a source of testing information. NHSs would be encouraged to submit their instrument test results in a standardized test format that would facilitate comparisons between similar instruments. The NHSs would also be encouraged to use a standard uncertainty analysis when reporting test results for various instrumentions. Test results would be made available to NHSs on a web site maintained by the project.

Flow measurement methodology test results are frequently published by NHSs in technical journals or conference proceedings as well as in internal documents. NHSs would be encouraged to make such documents available on the web site maintained by the project. The NHSs would also be encouraged to investigate the uncertainty of the methodology using a standard uncertainty analysis for experiments (see, for example, Coleman and Steele, 1999) and to make such analyses available on the web site. Examples of uncertainty analysis for acoustic Doppler current profiler discharge measurements are provided by Dongsu et al. (2005) and Muste et al. (2006).

The project would compile a list of existing information on the newer and older instrumentation, the existing and new methodologies for flow measurement and of NHS standards for hydrometric measurements with the help of staff from contributing NHSs. The compilation would be used to help revise and update WMO guidance manuals and measurement standards and to identify WMO testing requirements.

The project would encourage and solicit testing by contributing NHSs of the newer instrumentation and methodologies. The project would solicit loans of instrumentation and/or funding from instrumentation manufacturers and contributions from NHSs of personnel, equipment and test facilities in order to test newer instrumentation and methodologies identified by the contributing NHSs. Contributing NHSs would participate in writing and reviewing test plans, and contributing manufacturers would participate in reviews of test plans. In special cases, the WMO may consider providing supplemental funding for testing by a NHS of new methodologies for discharge measurement. Contributing NHSs would provide their written test results. Manufacturers and NHSs would contribute to an independent-peer review of results. Test results, including uncertainty analyses, would be disseminated on the project web site and would be used to help develop WMO measurement standards for existing and newer technologies and methodologies.

Expected Outputs

Six outputs are expected from the project:

1) A summary of field discharge measurement instrumentation and techniques, where "techniques" includes methodologies and procedures for field measurements. This would include, for example, site selection, vertical velocity distribution models, and algorithms for the determination of discharge. This includes instruments and techniques used or for potential use by NHSs.

2) Collection of international and national standards and guidelines regarding field discharge measurement instrumentation and techniques identified using the structure under 1) above.

3) Framework for the assessment of uncertainty in discharge measurement and guidelines for its implementation, including:

    - standardized approaches to uncertainty analysis
    - uncertainty analysis implementation examples
    - guidance in the form of decision-aid tools
    - uncertainty analysis database (information on uncertainties acquired with the standardized approach)
    - uncertainty analysis outcomes/inferences (recommendations for optimization of instrument configuration, operation and algorithms).

    Note that the last three items would initially be limited to two examples of velocity instruments (profilers and point current meters) to help facilitate the overall design of the framework and to illustrate its utility.

4) Guidelines for conducting and reporting results of instrument calibration and performance tests on instruments and techniques.

5) Collection of test reports on the performance of instruments and techniques, including

    - manufacturer specifications
    - multiple instrument comparisons
    - reports of tests performed under laboratory conditions
    - reports by NHSs
    - contact details of institutions where testing is conducted
    - other relevant information

6) Overall web site design to disseminate all of the above for promoting the exchange of information and fostering the use of common standards in testing and presentation of results.

A summary of the field discharge measurement techniques and instrumentation would describe selected techniques and instrumentation and include verification results. It would also estimate and compare the effort and costs associated with use of each technique/instrument. The uncertainty of the data collected with the technique/instrument would also be included when possible. Standard techniques for computing and reporting the uncertainty of measurements have been adopted by various organizations such as American Society of Mechanical Engineers (ASME), AIAA, NIST, and ISO. The intent would be to develop or adopt standard techniques for use by all NHSs.

A summary of current instrumentation standards (and policy) of WMO and those used by member NHSs would be compiled. The summary could be used by instrumentation manufacturers as

guidance for instrumentation development. The compilation would be helpful for reviewing and revising WMO standards. NHSs could use the compilation to help develop or revise their instrumentation standards, flow measurement techniques or as guidance in developing instrumentation test plans. Entries in the compilation, for example, could include reference material on test facilities such as tow tanks to help ensure credibility of test results.

Guidance would be developed on verification testing to manufacturer specifications and NHS/WMO standards and manuals. An early output of this project would be the development and adoption of a prototypical test report format and recommendations on the technique used to develop and compute uncertainties of the collected test data. The test report format would allow easy comparisons among tested instrumentation and techniques.

A central web site for the distribution of NHSs laboratories tests of hydrological instrumentation would be developed. The web site would facilitate communication of instrumentation testing among NHSs.

Expected Results

The proposed project is expected to improve planning and management of water resources by: (1) improving the understanding and knowledge of the accuracy of various types of hydrometric instruments; (2) encouraging the development of instrumentation that meets the measurement needs for water planning and management; (3) encouraging the standardization of hydrometric measurements and the computation of estimates of measurement uncertainty, leading to improved quality of data and their comparability; and (4) improving cooperation amongst NHSs.

Specific Activities

Several specific activities for the project are needed to accomplish the proposed outputs. The identified specific activities include reviews of: (1) flow measurement standards and manuals of NHSs, (2) existing instrumentation and techniques used for flow measurement, and (3) existing NHS testing facilities and measurement standards. Other identified specific activities are (4) guidance for testing instrumentation and techniques to a known standard, (5) development of a reporting format for documenting instrument and technique test results, (6) adoption of a technique to use for estimating the uncertainty of hydrological measurements, and (7) the development of a central web site for sharing hydrometric instrumentation information.

Potential Linkages

The proposed project has potential linkages with several international and national hydrological organizations. For example, the American Society of Civil Engineers/ Environmental Water Resource Institute (ASCE/EWRI) has a workgroup, which is part of the committee on Hydraulic Measurements & Experimentation, that is investigating uncertainty analyses for hydraulic measurements. Such a group would be an excellent resource for contributing to the development of the uncertainty methodology. WMO's Commission for Instruments and Methods of Observation (CIMO) has experience with a web site that presents information on meteorological instrumentation that could be useful to the project (see http://www.wmo.int/pages/prog/www/IMOP/WebPortal-AWS/Index.html).

A few of the potential linkages are listed below:

- WMO Commission for Instrumentation and Methods of Observation (CIMO)

- WMO Regional Associations' Working Groups on Hydrology
- UNESCO International Hydrological Programme (IHP)
- International Association of Hydraulic Engineering and Research (IAHR)
- International Association of Hydrological Sciences (IAHS)
- ASCE/EWRI
- International Organization for Standardization (ISO)
- The Association of Hydro-Meteorological Equipment Industry (HMEI)

Work Plan

At the meeting of experts (WMO, 2007), a work plan was established for each of the outputs with the roles of specific experts and the estimated amount of time to complete certain tasks. The material provided below is adapted from the output of the meeting of experts.

The tables provided below list the specific task that needs to be accomplished, with overall efforts being prioritized. It is recognized that on-going or planned activities of others may be leveraged to help achieve the overall results. For example, there are currently on-going efforts to update the *Manual on Stream Gauging*, while the *Technical Regulations Volume III – Hydrology* and the *Guide to Hydrological Practices* undergo a continuous revision process. As well, ISO has projects geared to developing and issuing standards on, for example, ADCPs and other new technologies. All of these efforts require the documentation of modern technologies and measurement techniques, which may prove a valuable source of material for input to task 1) a, and these efforts would potentially benefit from the implementation of this proposal.

During the meeting of experts (WMO, 2007), it was noted that the authorship of the publications and documents associated with this project that are posted on the web site or published by other means by WMO should be acknowledged. Given the importance of recognition by contributors, it was deemed necessary to mention this point within this document.

Where appropriate, each major project output has an associated table. In each table are the tasks needed for each output. Identified for each task are: the responsible expert(s); the estimated time required for each aspect; and a tentative completion date for each aspect.

1) Summary of field discharge measurement instrumentation and techniques

Task	**Expert(s)**	**Estimated Time (months)**	**Tentative Completion Date**
(a) Prepare structure of summary form and populate it	J. Fulford (USA)	2	31/07/07
(b) Upload form on web and request contributions to fill gaps	WMO Secretariat	2	30/09/07
(c) Notify NHSs by circular letter	WMO Secretariat	2	30/09/07
(d) Synthesis of results	J. Fulford, other(s) to be decided	2	31/12/07 (depends on receipt of responses)

2) Collection of international and national standards and guidelines regarding field discharge measurement instrumentation and techniques identified using the structure under 1). [*Requested documents could be in "pdf", link to websites or hardcopy (identifying the source, issuing authority, and copyright restrictions). Documents would be limited to those in one or more of the 6 official languages of WMO.*

Task	**Experts**	**Estimated Time (months)**	**Tentative Completion Date**
(a) In circular letter under output 1) b, include a request for standards and guidelines.	WMO Secretariat	See 1) c	30/09/07
(b) Upload collection on the web site and request additional contributions	WMO Secretariat	See 1) d	12/30/07

3) Framework for the assessment of uncertainty in discharge measurement and guidelines for its implementation.

Task	**Experts**	**Estimated Time (months)**	**Tentative Completion Date**
Literature review of existing approaches	M. Muste (USA) & J. Fulford	8	31/12/07
Synthesis of recommended standardized approach to uncertainty analysis for discharge measurements (draft for review on web)	M. Muste & J. Fulford	8	31/12/07
Developing implementation examples of the uncertainty analysis (draft for review on web)	M. Muste & J. Fulford	8	31/12/07
Development of decision-aid tool prototype and associate uncertainty analysis database for proof of concept and demonstration purposes of point and profiling velocity instruments and multiple techniques (draft for review on the web)	M. Muste & J. Fulford	20	31/12/08
Development of examples of the utility of prototype for improvement of measurement approaches and processes (draft for review on the web)	M. Muste & J. Fulford	20	31/12/08

4) Guidelines for conducting and reporting results of instrument calibration and performance test on instruments and techniques.

Task	**Experts**	**Estimated Time (months)**	**Tentative Completion Date**
Establishment of protocols/specifications for instrument calibration and testing and verification of performance characteristics of instruments and techniques (draft for review on the web)	P. McCurry (Canada)& J. Fulford	20	31/12/08
Develop sample format for reporting testing and verification results (draft for review on the web)	P. McCurry & J. Fulford	8	31/12/07

5) Collection of test reports on the performance of instruments and techniques

Task	Experts	Estimated Time (months)	Tentative Completion Date
Request instrument comparison reports as part of the letter in 1)	WMO Secretariat	See output 1)	See output 1)
Request reports and specifications from manufacturers	HMEI	See output 1)	See output 1)
Request reports of laboratory tests of instruments	WMO Secretariat & IAHR	See output 1)	See output 1)
Add new reports developed using guidelines under 4) (draft for review on the web)	WMO Secretariat	18	After 31/12/08

6) Overall web site design to disseminate all of the above. The contents of the web site should include:

- Output of 1) to 5)
- Forum/chat-room facility
- Search engines
- News feature
- Guidance on targeting community involvement

The WMO Secretariat is responsible for the web design. The estimated time for web design completion is 3 months, and it is to be completed by August 31, 2007.

Other Potential Contributions

WMO CHy is seeking additional participation of experts from national laboratory testing facilities, National Hydrological Services, international organizations and associations, manufacturers, industry and academia that would be willing to contribute to this international initiative.

Conclusions

Estimating uncertainty and developing standards associated with newer hydrometric instruments and measurement techniques is quite challenging. Enhancing our understanding of uncertainty and making its estimation available to practitioners by water monitoring organizations would be a significant contribution to the state-of-the-practice and would result in significant benefits to society. In order to achieve this, a concerted collaborative effort is required at both the national and international levels to address this limitation. This document provides a path forward to achieving this. Working together offers the greatest potential for success.

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