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Quantifying the site selection effect in the uncertainty of moving-boat ADCP discharge measurements

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ABSTRACT

Quantifying the uncertainty of discharge measurements (or "gaugings") is a challenge in the hydrometric community. A useful tool to empirically estimate the uncertainty of a gauging method is the field inter-laboratory experiment (Le Coz et al., 2016). Previous inter-laboratory experiments conducted in France (in 2009, 2010, 2011 and 2012) showed that the expanded uncertainty (with a probability level of 95%) of an ADCP gauging made of six successive transects is typically around 5% under optimum site conditions (straight reach, uniform and smooth streambed cross-section, homogeneous flow, etc.) and may be twice higher under poorer site conditions. In practice, the selected cross-section does not always match all quality requirements which may result in larger uncertainty. However, the uncertainty due to site selection is very difficult to estimate with predictive equations.

From 9 to 10 November 2016, 50 teams from 8 different countries, using 50 ADCPs simultaneously, conducted more than 600 discharge measurements in steady flow conditions (~14 m^3/s released by a dam). 26 cross-sections with various shapes and flow conditions were distributed over 500 meters along the Taurion River at Saint-Priest-de-Taurion, France. A specific experiment protocol, which consisted of circulating every team over half of the cross-sections, was implemented in order to quantify the impact of site selection on the discharge measurement uncertainty.

Beyond the description of the experiments, uncertainty estimates are presented. The overall expanded uncertainty of a 6-transect ADCP gaugings (duration around 720 seconds) is estimated to be around 6%.The uncertainty of the discharge measurements varies among the cross-sections. These variations are well correlated to the expert judgment on the cross-section quality made by each team. First results seem to highlight a relation between uncertainty computed for each cross-section and criteria such as flow shallowness and measured discharge ratio.

Further investigations are necessary to identify the criteria related to error sources that are possibly meaningful for categorizing measurement conditions and site selection. Moreover, experimental uncertainty and the uncertainty predicted by analytical methods such as QRev, QUant, OURSIN, RiverFlowUA or QMSys software will be compared.

INTRODUCTION

Inter-laboratory experiments of discharge measurements are a useful tool to investigate the performance of a measurement technique and so a valuable tool for empirically estimating the uncertainty of stream gauging techniques in given measurement conditions. It consists of measuring the same variable (or discharge) with several participants, or laboratories, using the same measurement procedure.

Since 2007, field inter-laboratory experiments have been conducted in the world of hydrometry, for instance in Germany, Canada, USA, England, Croatia and in France since 2009 under the leadership of Groupe Doppler Hydrométrie, a French-speaking community of hydrometry technologists (Le Coz et al., 2009; Pobanz et al., 2011; Hauet et al., 2012; Pobanz et al., 2015).

In France, a particular aim is to empirically estimate the uncertainty of stream gauging techniques based on ISO standards (Le Coz et al., 2016). Tab. 1 summarizes field experiments performed in France using ADCPs either tethered or mounted on boats and the resulting uncertainty estimates.

Experiment	**Discharge (m^3/s)**	**Number of teams**	**Uncertainty (%, at 95%)**	**Source**
Vézère, 2009	30	37	4-9	(Le Coz et al., 2009)
Génissiat, 2010	110-430	26	4-12	(Pobanz et al., 2011)
- Downstream of the dam		12	8-12	
- Pyrimont site		14	4-6	
Gentille, 2011	10-20	34	6-7.5	(Hauet et al., 2012)
Génissiat, 2012	230-550	32	4-12	(Pobanz et al., 2015)
- Downstream of the dam		12	12	
- Bognes site		11	4.4	
- Pyrimont site		9	4.3	

Tab. 1: Review of inter-laboratory experiments performed in France. Uncertainties are expressed at a level of confidence of 95% and are based on 6 successive transects (4 for Génissiat 2010). Adapted from Dramais et al. (2013).

ADCP uncertainty estimates range from 4 to 12 %. The maximum value comes from "Génissiat 2010" downstream of the dam with adverse measurement conditions (Pobanz et al., 2015; Le Coz et al., 2016) whereas, during the same experiments, the uncertainty estimate was lower at a more favorable site (Pyrimont). This highlights the importance of site selection and the need to estimate the uncertainty due to site-specific effects.

The objectives of this study include:

- Comparing discharge measurements made at differing cross-sections,
- Estimating the uncertainty by applying field inter-laboratory experiments method,
- Evaluating the site selection impact on discharge measurement.

EXPERIMENTAL DESIGN

From 9 to 10 November 2016, 50 teams from 8 countries deployed 50 ADCP and performed about 600 discharge measurements. These teams include government agencies, private companies, research institutes and ADCP manufacturers. Some operators were professional field hydrologists with daily experience of ADCP measurements whereas others worked with academic groups or consultant companies and use ADCPs more episodically. Five ADCP models were used, most of them being SonTek M9s (and one S5) and Teledyne RDI StreamPros (and a few RiverPros), plus one Ott Q-Liner (not involved in the interlaboratory experiment).

To investigate the site selection effect, 26 cross-sections with various shapes and flow conditions and more or less favorable conditions were distributed over 500 m along the Taurion River near Saint-Priest-de-Taurion, France. Cross-sections were about 35 m wide and 1 m deep. 24 cross-sections were named with a letter from A to X (see Fig. 1). In contrast with earlier experiments, the experimental design consisted in circulating every team over at least half of the cross-sections during three sessions of measurements. A constant discharge around 14 m^3/s was released by the dam.

Two teams continually deployed their ADCP during each session using a Q-Liner and a StreamPro respectively at two "fixed" cross-sections named SCP and FIXE respectively, close to the hydrometric station. Water level was monitored at cross-sections X and P by two Paratronic differential pressure gauges and at the hydrometric station by a VEGA radar gauge. By applying a stage-discharge relation (or rating curve), water level recorded was converted into discharge. Dye dilution gaugings using fluorescein as a tracer were also performed during the tests.

These measurements show that discharge stability was reached at all cross-sections from upstream to downstream and during the 3 measurement sessions.

During the measurements, each team rated the quality of each cross-section they measured as poor, fair or good. This analysis is subjective since each team has a different appreciation of standard of quality. Fig. 2 shows the quality evaluation for each cross-section. It seems clear that cross-section E was considered as the worst cross-section. This is explained by the presence of a tree upstream of the cross-section that created eddies. This cross-section was also the shallowest.

Fig. 1: Location of each cross-section (map from OpenStreetMap). The triangle shows the hydrometric station located upstream of a weir.

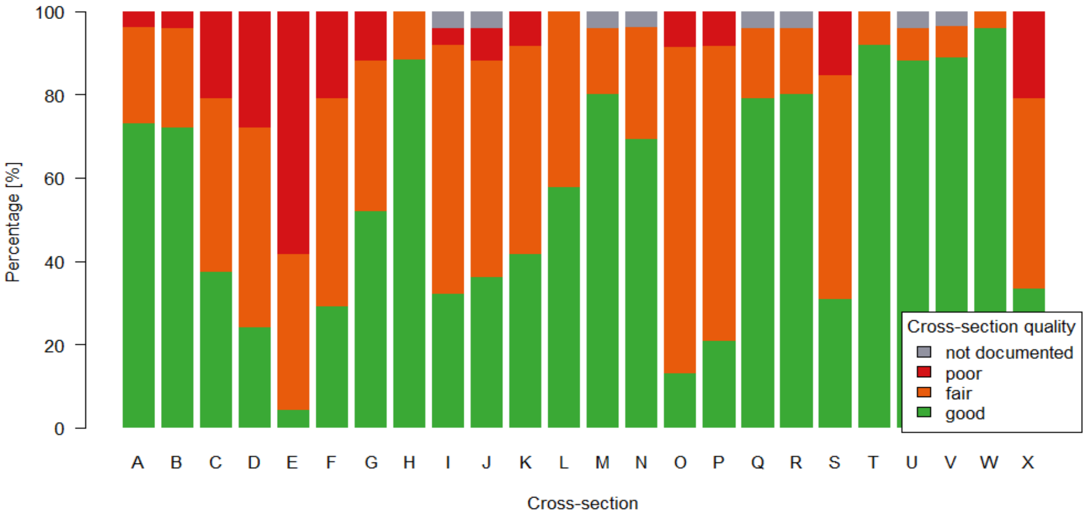

Fig. 2: Distribution of votes on the quality of each cross-section (from upstream to downstream).

RESULTS

Discharge results at cross-sections are shown in Fig. 3. Most of the measurements are within ±5% around the overall mean discharge (14.75 m^3/s). The associated standard-deviation is 0.30 m^3/s.

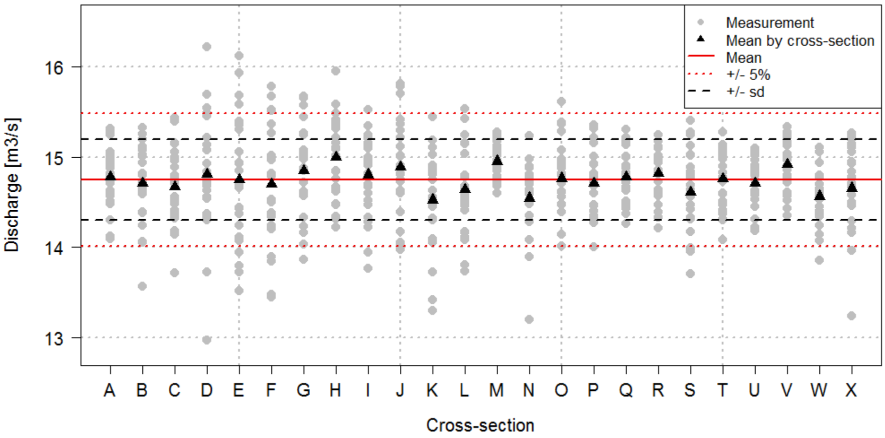

Fig. 3: Discharge values measured at the 24 cross-sections (at least 24 measurements were performed at each cross-section by 24 different teams).

Cross-sections M and V have the smallest scatter of discharge values (standard-deviation lower than 0.20 m^3/s). On the other hand, discharge values at cross-sections E and D are more scattered.

There is a link between discharge scatter and measured discharge ratio (measured discharge over total discharge). Cross-sections U and W, which have the highest measured discharge ratios, also have a small dispersion of discharge values. These cross-sections were mostly rated as good (cf. Fig. 2). By contrast, cross-section E has a small measured discharge ratio and discharge values are more scattered. This cross-section is the poorest one according to evaluations from operators (cf. Fig. 2). However, cross-section D, with a pretty high measured discharge ratio, has high discharge dispersion. Further investigation based on QRev software post-processing (Mueller, 2016) may help explain this conclusion. Default velocity extrapolation exponents set by operators are probably not suitable for this site. Supervised analysis of vertical velocity profiles will probably lead to corrected and hopefully tighter values of discharge.

In terms of bias, the mean discharges computed from cross-sections B, E, T and O are the closest to the mean discharge computed using all the discharge values. Discharge measurements at cross-section H seem to be biased low. However, average deviations from the mean are lower than 2%.

UNCERTAINTY ESTIMATION

The computations to estimate uncertainty based on inter-laboratory experiments were introduced by Le Coz et al. (2016). The data processing follows the guidelines provided by international standards (ISO, 1994b, 1994a, 2005 and 2010). The main steps of the computation consist of computing the repeatability and the interlaboratory standard-deviations from the repeated measurements over successive ADCP transects.

Speaking of streamflow measurements, a “laboratory” is the combination of one or several operators (including parameter choices), their equipment (ADCP, software and ancillary equipment), and their measurement cross-section (or site).

By applying inter-laboratory computations to all the discharge values (600 measurements) and considering an uncertainty due to the ADCP technique bias around 2%, the uncertainty of a single-transect ADCP discharge measurement is ±7.3% (at 95% level of confidence) in the given measurement conditions of the experiments. The important number of participants leads to a robust uncertainty estimate with a confidence level between 6.9 and 7.5%.

The 95% expanded uncertainty of a 6-transect ADCP gauging is estimated to be around ±6%. This value is slightly higher than previous inter-laboratory experiments due to less favorable site conditions. Averaging more transects does not reduce the uncertainty significantly. However, averaging the measurements performed by two laboratories (different operators, cross-sections and ADCPs) reduces the uncertainty to ±4%.

The interlaboratory computations were also applied to the measurements of each cross-section taken individually. The expanded uncertainty ranges from ±4.7% at cross-section M to ±11.7% at cross-section E, which highlights the importance of site effect on the measurement and on parameters chosen by the operators such as velocity extrapolation coefficients. These results are directly correlated to dispersion of discharge values (Fig. 3).

DISCUSSION & CONCLUSION

From inter-laboratory experiments in steady flow conditions, the 95% expanded uncertainty of a 6-transect ADCP discharge measurement was estimated to be around ±6% in the conditions of the experiment.

A direct link between discharge standard-deviation and site quality evaluation by operators has been observed. The dispersion is higher at cross-sections considered "poor". However, the discharge bias was not correlated with quality evaluation by participants. Default extrapolation coefficients set by operators will be compared with automatic or supervised fit of top/bottom discharge extrapolations using QRev software. This post-processing will slightly correct discharge values so that the observed bias may be reduced.

The 95% expanded uncertainty of a single-transect ADCP measurement is estimated to be around ±7.3%. However, uncertainty ranges from ±4.7% to ±11.7% depending on the cross-section. Further research will be focused on separating the site selection effect and the effect due to operators and ADCP parameters. Possible metrics for characterizing the conditions of ADCP discharge measurements related to the uncertainty due to cross-section will be investigated.

Then, the study will aim at making recommendations regarding deployment strategy to reduce the uncertainty. Further research will be conducted to assess which strategy lead to a smaller uncertainty (by using one ADCP at multiple cross-sections? or by using multiple ADCPs at one cross-section?).

Lastly, inter-laboratory uncertainty estimates will be compared with that provided by propagation computation methods such as OURSIN (Pierrefeu et al., 2017); QRev, (Mueller, 2016); QUant, (Moore et al., 2016); QMSys (Muste et al., 2012), or RiverFlowUA (González-Castro et al., 2016). The comparison of inter-laboratory and analytic uncertainty analysis methods will help evaluate and improve the methods.

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