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► **To cite this version:**

J. Le Coz. Challenges in hydrometry: some examples from France. Experiences and Advancements in Hydrometry, Mar 2008, Seoul, South Korea. 8 p. hal-00509246

**HAL Id: hal-00509246**

**<https://hal.science/hal-00509246>**

Submitted on 11 Aug 2010

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## Challenges in Hydrometry: Some Examples from France

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### Abstract

In France, the national stream flow measurement network is ruled by the Ministry of Environment through Regional Environment Agencies (DIREN) and Flood Forecast Services (SPC/SCHAPI). Other organizations such as hydropower producers (EDF, CNR), the waterways office (VNF), research institutes (e.g. IRD in Brazil and Africa) also produce hydrometric data. The main gauging techniques are the velocity-area method (currentmeters), Doppler profilers (aDcp) and chemical dilution. Some efforts are needed to improve and quantify the quality of discharge measurements, and also to diversify the range of measuring techniques available to practitioners. In close connection with hydrometry services, research projects are being conducted on conventional and innovating instruments and techniques for flow measurement. In particular, the following issues are currently investigated: rating curves assessment and extension, uncertainties associated with various gauging methods (especially aDcp), evaluation of horizontal Doppler profilers (H-aDcp), video-based flash-flood monitoring (LSPIV).

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### Introduction

Accurate river discharge measurements are requested for hydrological studies, water resources, flood risk and ecological habitat management. However measuring and monitoring stream discharges is a challenging and time-consuming task due to technical difficulties and metrological questions. Apart from usual field deployment problems, French rivers offer specific technical challenges such as flash floods, in the Mediterranean area and in overseas tropical French islands. This paper presents an overview of the French hydrometric networks, and some applied research works on innovating techniques and uncertainty analysis associated with discharges.

## 1) National stream flow measurement programs

### 1.1 National hydrological service system

In France, the national stream flow measurement network is ruled by the Ministry in charge of Environment and Infrastructure (MEDAD) through Regional Environment Agencies (DIREN) and Flood Forecast Services (SPC). Two major reforms of the National hydrological service system are currently on-going. Since 2002, the national flood alert network was re-organized with the creation of 22 Flood Forecasting Services (SPC), each responsible for a hydrological sub-catchment. As a technical service of the MEDAD, the Central Hydrometeorological and Flood Forecasting Service (SCHAPI, located in Toulouse) coordinates the actions of the 22 SPC. Since 2006, the on-going reform of hydrometry services aims at a unified organization, with precisely distributed tasks: 6 basin DIRENs rule the hydrometry networks over the whole territory, SPCs collect data, and the SCHAPI is in charge of national coordination and data bases. The flood forecasting services (SCHAPI + SPC) gather around 200 operators, as well as general hydrometry services (DIREN).

### 1.2 Hydrological observation networks

The data from flood forecasting gauging stations are usually collected at a hourly or half-hourly time rate and are transmitted to the Vigicrues database (1200 stations approximately). Around 3500 stations (including half of the flood forecasting stations) produce data for general hydrometry that are stored in the Hydro II database. A Hydro III database is under development with improved software tools for discharge computation and validation. Other organizations such as hydropower producers (EDF, CNR), the waterways office (VNF), research institutes (e.g. *Cemagref*, IRD in Brazil and Africa) also produce hydrometric data and may feed the Hydro database. For instance, the CNR hydrometric network consists of about 150 gauging stations for the Rhône river and main tributaries.

In association with the renewed organization of data production and collection, a national flood vigilance system was launched in July 2006, with real-time flood forecast information delivered on the Web ([www.vigicrues.ecologie.gouv.fr](http://www.vigicrues.ecologie.gouv.fr)). For documented river reaches, the forecasted hydrological conditions are indicated according to 4 warning levels (Fig. 1):

1. normal hydrological situation (green)
2. risk of flood unlikely to produce damages except for directly exposed activities (yellow);
3. risk of flood likely to affect the security of people, infrastructure and networks (orange);
4. risk of extreme flood, direct and general danger for people and goods (red).

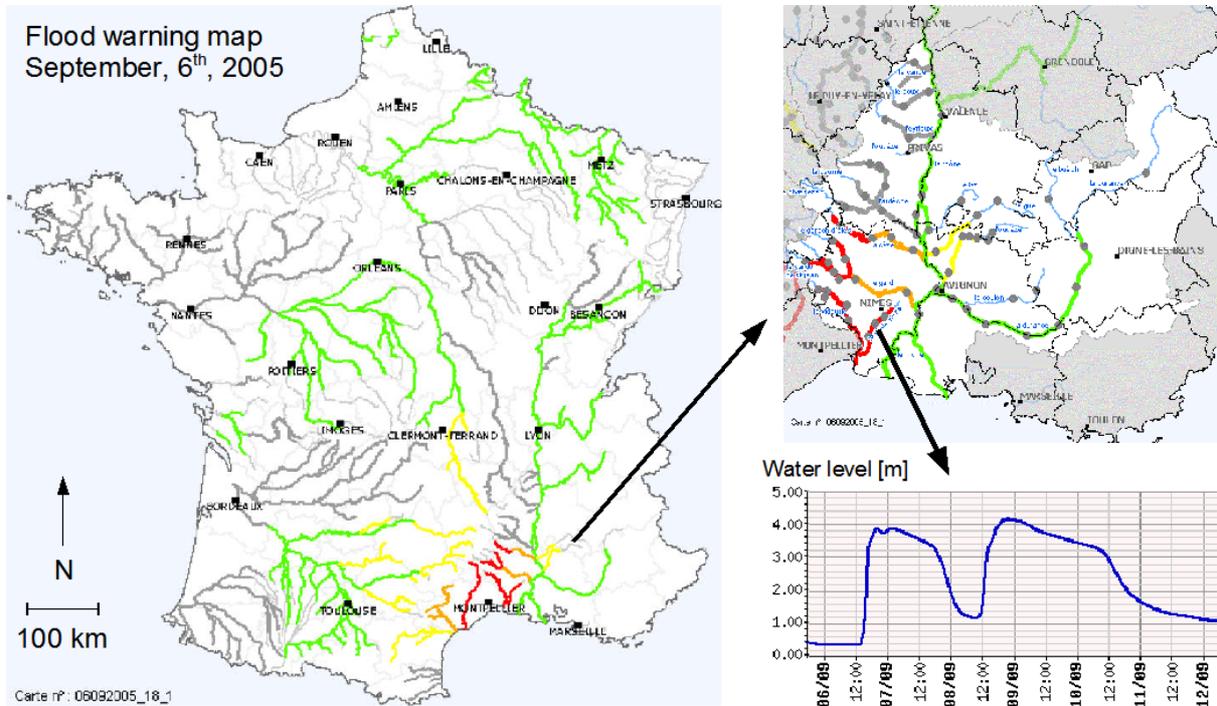


Fig. 1 - Flood Warning Map (source MEDAD/DE/SCHAPI, [www.vigicrues.ecologie.gouv.fr](http://www.vigicrues.ecologie.gouv.fr)). NB. Reaches in grey were not documented in 2005 (tests) but most of them are documented now.

### 1.3 Instruments, techniques, documentation

A number of hydrometry reference documents and manuals written in French are widely used by hydrometry teams, in particular recent quality guidelines for hydrometry services [1,2] and practical guides in hydrometry [3,4,5,6,7,8]. Most of French gauging stations consist of a reference staff gauge and a continuous water level measuring device, located whenever possible upstream a stable hydraulic control section or work (weir, sill, etc.). Thus one-to-one rating curves (i.e. stage-discharge relationships) are established, surveyed and updated if necessary through extensive stream discharge measurements (gaugings). Much less frequently, two-level rating curves are used for influenced reaches. The most commonly used techniques for water stage monitoring are float-well systems, pressure gauges, pneumatic (bubbler) sensors, ultra-sonic and radar transducers. Ultra-sonic systems were generally found to be quite sensitive to the air temperature variability, especially below bridges. Radar systems are much more appreciated, though expensive.

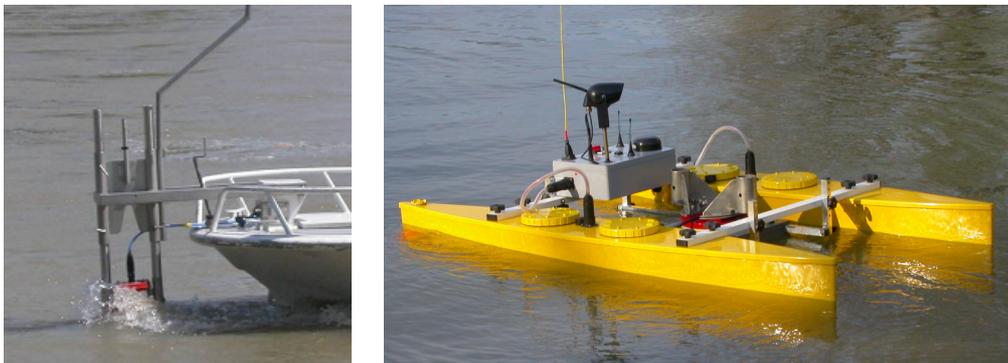


Fig. 2 – ADcp deployed on a bow-swing mount with a powered boat (left); on a remotely controlled mini-catamaran (right, source CNR).

For stream gauging, the velocity-area method [9] is routinely followed with mechanical (horizontal axis), electromagnetic or Doppler (aDv) currentmeters, and floats in extreme flood conditions. Chemical dilution (salt, WT Rhodamin) appears very useful especially for mountain torrents and floods, but much care must be dedicated to sample contamination or tracer reduction [10]. Since 1994, acoustic Doppler current profilers (aDcp) are increasingly used to gauge streams [11,12]. Teledyne RDI Doppler profilers are the most widespread in France, but other manufacturers such as SonTek, LinkQuest, OTT Qmetrix are also present. ADcp mounts are quite diversified, from swing side- or bow-mounts on powered boats to floating systems either tethered or remotely controlled (Fig. 2). Among flow monitoring systems based on continuous velocity measurements, French hydrometers use continuous Doppler flowmeters (for small streams or urban networks), transit-time acoustic flowmeters and more recently, fixed horizontal Doppler profilers (H-aDcp).

## 2) Innovating instruments and techniques for flow measurement

### 2.1 Acoustic Doppler current profilers (aDcp)

The principle of flow and vessel (bottom-track) velocity measurements by aDcp is based on the pulsed Doppler effect: ultrasonic pulses are emitted in the water column by transducers, and the apparent velocity of reflectors (suspended particles / river bed for bottom-track) is deduced from the frequency shift in backscattered echoes. The integration of bathymetry and velocity measurements over a river crossing yields the discharge through a mobile-boat discharge computation procedure. GPS-referenced or stationary measurements are also possible without use of the bottom-tracking function. Due to technical limitations, the flow velocity can not be measured in top/bottom/edge parts of the cross-section (Fig. 3-a), where water fluxes must be extrapolated.

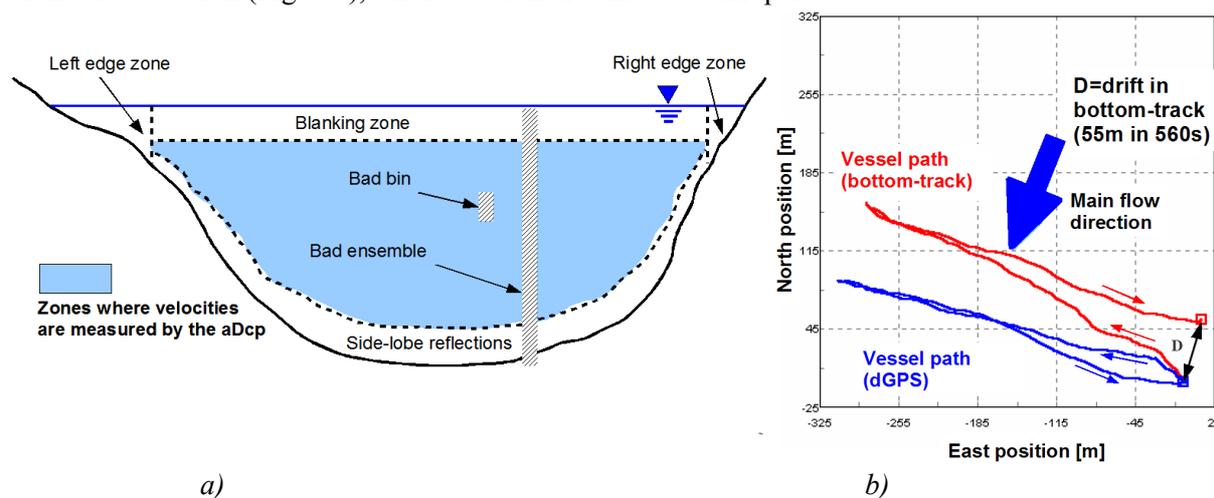


Fig. 3 – a) Cross-section areas where velocities are measured by the aDcp and unexplored areas where discharges have to be estimated; b) Typical aDcp bottom-track biased by mobile bed effects (Rhône river at Beaucaire, November 27, 2002)

An aDcp user group (so-called Groupe Doppler) was created in early 2005 by French operators independently from manufacturers. Experiences are shared and methodological guidelines have been established in a practical aDcp guide [12]. For instance, 6-8 replicate aDcp crossings (instead of 4 for USGS [13]) are recommended for a gauging campaign under steady hydraulic conditions. The Groupe Doppler is involved in training sessions, national and international symposia, field tests and especially “regattas”, i.e. simultaneous aDcp gauging with several profilers, differing parameter configuration and deployment modes. River sections gauged with aDcp by French users show a wide range of scales, from 10 m wide and 0.5 m deep (small streams) to 3 km wide and 50 m deep (Amazon river, gauged by IRD). Very low velocities (a few cm/s) have been measured with acceptable accuracy. The main practical limitation is high flow velocity (safety concern, flow disturbance around the sensor), but velocities greater than 4.5 m/s or even 5 m/s have been measured successfully. Other gauging techniques may also be more recommended than aDcp in case of shallow sections, eddies, unstable free-surface, bubbles, etc.

One of the main problems with aDcp flood measurements stems from mobile bed effects [14]. When aDcp velocity measurements are bottom-track referenced, the discharge computation assumes that the river bed velocity is zero. In case of active bedload transport or high-concentrated near bed suspended load, the vessel-track measurements may be biased upstream, leading to velocities and discharges biased low (see example Fig. 3-b, with actual vessel path measured by unbiased dGPS positioning). The bottom-track bias magnitude increases with the operating aDcp frequency. A simple way to correct the discharge underestimation consists in quantifying the mean apparent bed velocity over a looped aDcp transect starting from and ending to the same fixed point. The MG distance  $D$  (cf. Fig. 3-b) divided by the corresponding time yields the mean bed velocity estimate. In this example, two aDcp RioGrande (TRDI) 600 kHz and 1200 kHz were simultaneously deployed, the latter being coupled with a centimetric dGPS. The bottom-track referenced 1200 kHz raw discharge ( $8\,400\text{ m}^3/\text{s}$ ) was significantly lower than the bottom-track referenced 600 kHz raw discharge ( $8\,900\text{ m}^3/\text{s}$ ), itself slightly lower than the dGPS referenced 1200 kHz raw discharge ( $8\,950\text{ m}^3/\text{s}$ ). Considering the mean bed velocity given by the loop method ( $9.8\text{ cm/s}$ ), the bottom-track referenced 1200 kHz discharge was acceptably corrected ( $8850\text{ m}^3/\text{s}$ ).

## 2.2. Fixed side-looking (H-aDcp)

Since 2005, several fixed side-looking aDcp (H-aDcp) were installed in France: Rhône and Saône rivers in Lyon and Isère river at Romans by CNR [15], Rhône river near St-Alban and Tricastin nuclear power plants by EDF [16]. Following the same principle of operation as conventional aDcp, H-aDcp offer the continuous (one multipings average each minute typically) measurement of horizontal velocity components along a horizontal line across the river section. The most commonly used methods for discharge computation from velocities measured by a H-aDcp are the Index Velocity Method (IVM) and the Velocity Profile Method (VPM). The IVM [17] relies on an empirical relationships between an index velocity measured by H-aDcp and the discharge velocity  $V = Q/A$  with  $Q$  discharge and  $A$  wetted area. The VPM is based on a user-defined vertical profile law, in order to compute elementary discharges for each H-aDcp bin across the river section.

In order to assess the H-aDcp performance for velocity measurements and discharge computation, 18 aDcp gauging campaigns were achieved in front of the H-aDcp installed in St-Georges gauging station (Saône, river in Lyon, Fig. 4-a). During floods in February-April 2006, a wide discharge range was investigated ( $100 - 1800\text{ m}^3/\text{s}$ ). ADcp data (bathymetry, velocity) were post-processed in order to establish a mean velocity field from the replicate crossings of each aDcp campaign [18].

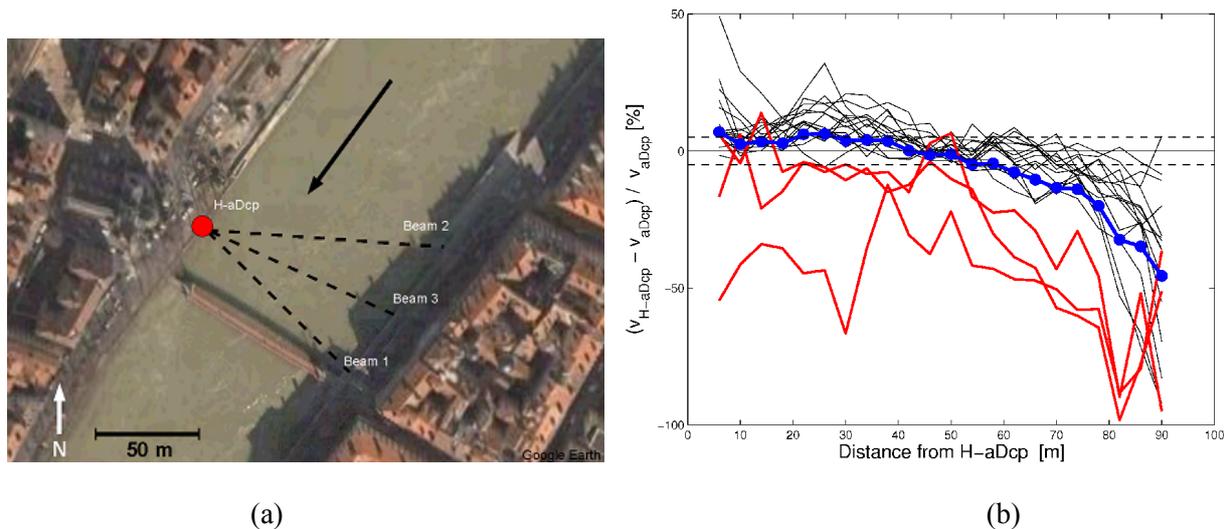


Fig. 4 – (a) Aerial view (Google Earth) of the St-Georges gauging station (Saône river in Lyon) with the 3 H-aDcp beams; (b) Deviations (%) of H-aDcp velocities from corresponding aDcp velocities for each of the 18 gaugings (lines) and average (dots). Red bold lines correspond to the 3 campaigns for  $Q < 300\text{ m}^3/\text{s}$ .

The comparison with aDcp data (Fig. 4-b) revealed that H-aDcp velocity measurements were reliable (deviations  $< 5\%$ ) in a near-field range only (60 m out of a 95 m total section width) and for discharges values high enough ( $Q > 300 \text{ m}^3/\text{s}$ , i.e.  $V > 0.4 \text{ m/s}$ ). The reasons why H-aDcp velocities are unacceptably biased low in the far-field and for low velocity (and low suspended sediment concentration) conditions are still under investigation.

Consequently, the index velocity was defined as the average H-aDcp velocity over the validated near-field range; the VPM was performed in the near-field range with several velocity extrapolation methods in the rest of the section, such as a constant-Froude assumption [19]. From the analysis of aDcp mean vertical profiles, several profile laws were fitted and tested: log [20], power, log/constant, and Van Rijn laws [21]. At St-Georges gauging station, both the IVM and VPM give acceptable discharge values (deviations  $< 5\%$  typically) for  $Q > 300 \text{ m}^3/\text{s}$ . The results for different parameter options were not found to be very contrasted. For  $Q < 300 \text{ m}^3/\text{s}$ , discharges are underestimated, as expected from the velocity analysis. Further work is required to understand and correct this low-flow (and low-concentration) problem.

### 2.3 Large-Scale Particle Image Velocimetry (LSPIV)

Image analysis can be used to quantify the displacement of floats or turbulence-driven patterns advected at the flow free-surface, and therefore the 2D surface velocity field. Usually, video images are recorded from the river bank, then orthorectified with geo-referenced ground points, and a correlation technique similar to the conventional PIV technique is applied to visible tracing patterns. Knowing the cross-section geometry and assuming a vertical velocity distribution, the LSPIV technique can be used to compute stream discharge estimates [e.g. 22,23,24]. In connection with hydrometry services and other research teams, the *Cemagref* conducts mobile LSPIV tests during floods, as well as the instrumentation and validation of fixed LSPIV gauging stations. The main goal is to reduce the uncertainty associated with high flow rate estimates, especially during mediterranean flash flood events when conventional stream gaugings are scarce or impossible.

For instance, some mobile LSPIV tests have been conducted during the November 22-23<sup>th</sup>, 2007 flood at the Sauze gauging station in the Ardèche river, a mediterranean river prone to flash-floods (Fig. 5-a). On the first day, aDcp discharge measurements were performed simultaneously with the LSPIV campaign. As for the H-aDcp analysis reported above, the aDcp data were post-processed in order to establish the mean velocity field [18]. From the analysis of aDcp vertical velocity profiles, an experimental value of 0.90 for the depth-average to surface velocity ratio (so-called float coefficient) was established. Fig. 5-b shows that LSPIV velocities multiplied by the experimental float coefficient fall in good agreement with the depth-averaged aDcp velocities over the whole velocity range (0.1-1.2 m/s). Discharge values from simultaneous LSPIV and aDcp measurements are also in good agreement (maximal deviation 2.6%) and close to the rating curve estimate (320  $\text{m}^3/\text{s}$ , maximal deviation 3.4%).

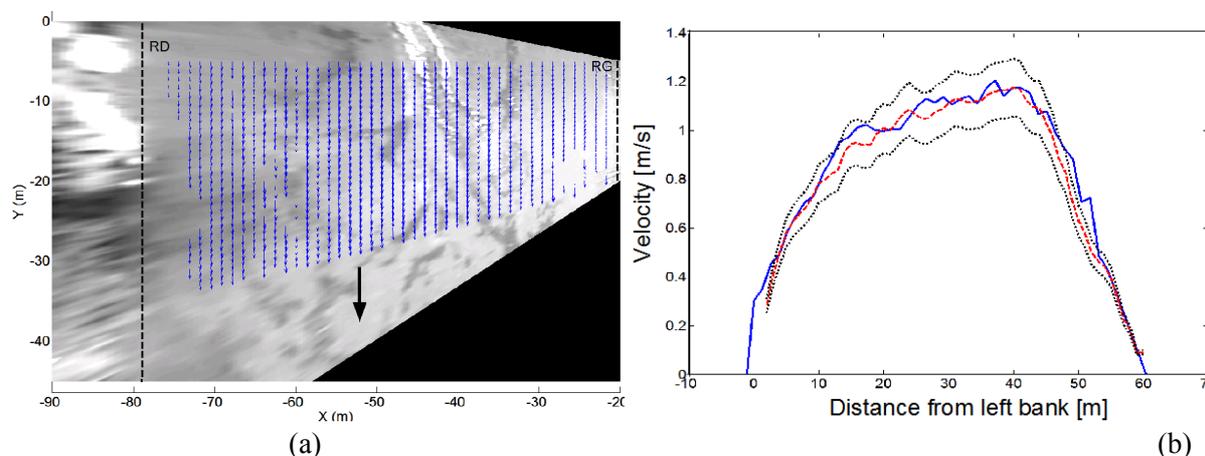


Fig. 5 – (a) Orthorectified gray-scale image of the flow surface at Sauze and LSPIV-derived surface velocity field; (b) Depth-averaged aDcp velocities (dashed red line with 10% deviations) and LSPIV velocities (solid blue line) along the aDcp transect across the section (at  $Y=-15\text{m}$ ).

On the second day, LSPIV measurements were conducted without concurrent aDcp gauging. The float coefficient was assumed to remain constant (0.90) though the hydraulic conditions had changed. With maximal surface flow velocities exceeding 3m/s, the LSPIV discharge value was 825 m<sup>3</sup>/s, i.e. 8% above the corresponding rating curve value (760 m<sup>3</sup>/s). Further research works (field tests and numerical simulation of errors [25]) are needed to analyse the source and magnitudes of errors associated with the LSPIV discharges.

### 3) Assessment of quality for techniques implementation

#### 3.1 Rating curves

French hydrometry services are concerned by the assessment of the quality of discharges computed with rating curves (stage-discharge relationships). For instance, one of the best monitored rating curve maintained by the CNR (Rhône river at Beaucaire, 54 gaugings over 1994-2003, Manning-Strickler fit) was analysed following the standard NF ENV 13005 "Guide for the expression of the Uncertainty of Measurement" (1999) [26]. The mean discharge uncertainty was estimated to be  $\pm 9\%$ . The uncertainty level associated with other rating curves may be higher. Generally speaking, a compromise must be found between the density (number, discharge range, time period) of the gauging data used to build the rating curve, and the possible changes in the stage-discharge relationships over the retained time period. Anyway, recurrent stream gauging is necessary to control the validity and uncertainty of each rating curve, especially during flood events.

Much more uncertainty is associated with discharges stemming from extrapolated parts of rating curves, for instance above the highest gauged flow rate. This situation is common when floods (especially flash floods) occur. For instance, the survey of a set of about 300 French rating curves (Fig. 6-a) showed that more than half of the rating curves have not been gauged more than a two year return period flood [27]. A methodology based on 1D/2D hydraulic modelling and uncertainty analysis was developed by the *Cemagref* for high-flow extending of rating curves, and was applied to a set of French gauging stations [27]. For instance, Fig. 6-b shows the predicted high-discharge interval for the Hérault river at Ganges-Laroque, with error estimates 20 – 30%. Such a modelling-based extrapolation technique is useful in taking into account discontinuities induced by floodplain overflow or changes in hydraulic control, with all available information on the hydraulic conditions during the flood (gaugings, water marks, photographs, bathymetry, hydraulic works, etc.). Hydrological analysis is often helpful.

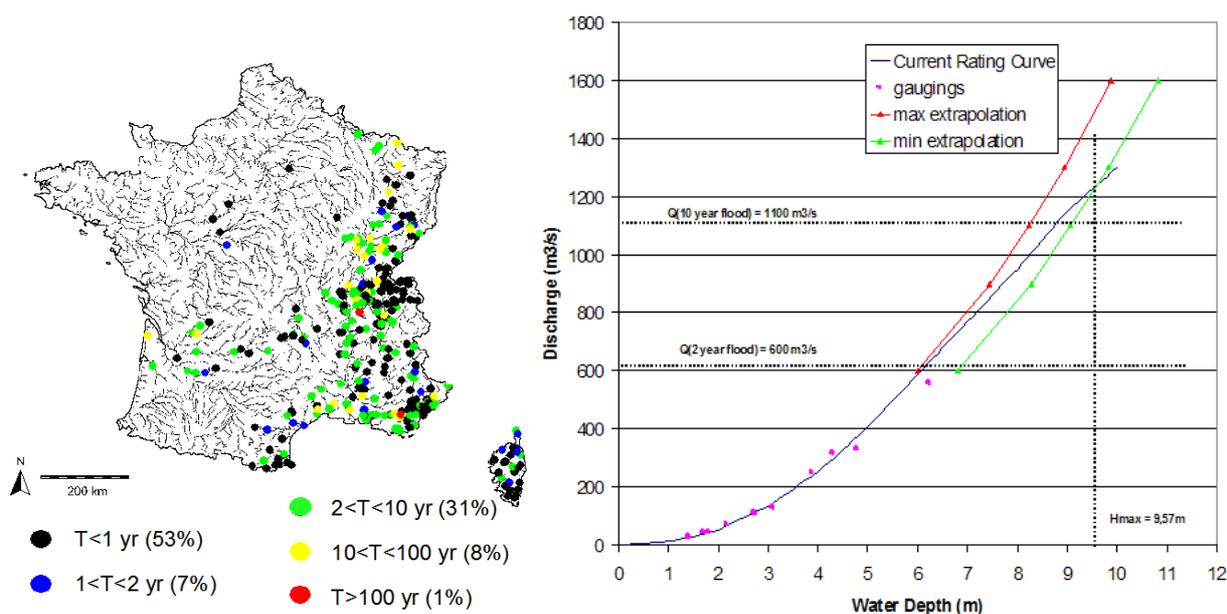


Fig. 6 – (a) Rating curve survey (not evenly distributed over the whole French hydrometry network); (b) Example of rating curve modelling-based extension (Hérault river at Ganges-Laroque)

### 3.2 ADcp discharge measurements

The analysis and quantification of uncertainties associated with stream gauging techniques is a point of paramount importance in hydrometry [28]. Even if guidelines for aDcp field deployment and discharge computation are already available [12,13,29], a widely recognized and practical method for quantifying the uncertainties associated with aDcp river discharge measurements is still needed by hydrometers. From reported field assessments based on comparison with other gauging or flow monitoring techniques, properly conducted aDcp discharge measurements are usually within 5% from the considered reference. For instance, the CNR analysed 19 representative aDcp stream gaugings controlled by simultaneous currentmeter gaugings under steady conditions; from the 7% uncertainty level computed for currentmeter gaugings, a 5% uncertainty level was deduced for aDcp gaugings [30]. The USGS analysed a dataset of more than 1000 aDcp transects corresponding to 100 reference discharges and wide ranges of channel width (7 – 500m) and depth (0.5 – 9m) [31]; aDcp discharges appeared to be unbiased and the 5% uncertainty level was confirmed.

However, a framework for quantitative uncertainty analysis [32] would be useful for i) application to any given aDcp gauging; ii) sensitivity analysis of instrumental and environmental parameters for any given field situations. In collaboration with IIHR (University of Iowa), a post-doctoral position at *Cemagref* will aim at establishing, testing and implementing in a software tool [33] a comprehensive methodology for quantifying the uncertainty associated with aDcp stream gauging, according to available international standards for uncertainty analysis (in particular NF ENV 13005 GUM). The research task will be conducted in close connection with the IIHR and several hydrometry teams from the French hydrological services and from hydro-power producers (EDF, CNR).

### Conclusion

The French hydrological observation network is currently being reformed in order to enhance its efficiency in terms of both flood forecasting and warning, and general hydrometry. Metrological works on innovating techniques and uncertainty analysis fruitfully associate hydrometers and researchers. Indeed, the knowledge and expertise of field practitioners is the base for any advances in hydrometry. Also, international initiatives and conferences in hydrometry are very useful to share experiences and projects worldwide.

### Acknowledgements

This paper is based on works and information provided by many engineers and technicians from hydrometry teams of the national hydrological services, as well as EDF, CNR, *Cemagref* and other organizations. They are gratefully acknowledged.

### References

- [1] Forray N., Auer J.-C., Brochot J.-F., Eraud Y., Favriau A., Ghio M., Lallement C., Lang M., Odier M., Scherer C. (1998). Charte Qualité de l'Hydrométrie. Code des bonnes pratiques (*Quality Plan for Hydrometry. Best Practice Code, in French*), 49 p.
- [2] Ministère de l'écologie et du développement durable (2003). Guide de référence qualité dans les services d'hydrométrie (*Reference guide for quality in hydrometry services, in French*).
- [3] André, H. (1964). Hydrométrie pratique des cours d'eau (*Practical stream hydrometry, in French*), ENSEHRMA, 88 p.
- [4] Aldegheri, M. (1979). Manuel d'hydrométrie – tome IV: mesure des débits à partir des vitesses (*Hydrometry manual – vol. IV: discharge measurement from velocities, in French*), ORSTOM, 313 p.
- [5] Jacon, G. (1986). Manuel d'hydrométrie – tome V : tracé de la courbe de tarage et calcul des débits (*Hydrometry manual – vol. V: rating curve fit and discharge computation, in French*), ORSTOM, 225 p.
- [6] Ferry, M., Rosique, J.-L., Ribot-Bruno, J. (1991). Guide pratique d'hydrométrie (*Practical guide in hydrometry, in French*), 119 p.
- [7] Audinet, M. (1995). Hydrométrie appliquée aux cours d'eau (*Hydrometry applied to streams, in French*), Eyrolles, Paris, 453 p.
- [8] Bertrand-Krajewski, J.-L., Laplace, D., Joannis, C., Chebbo, G. (2000). Mesures en hydrologie urbaine et assainissement (Measurements in urban hydrology), Tec & Doc, Lavoisier, Paris, 794 p.

- [9] NF EN ISO 748:2007 Hydrometry – Measurement of liquid flow in open channels using current-meters or floats, 46 p.
- [10] Dupouy, P. (1999). Jaugeages par la méthode de dilution de Rhodamine WT (*Gauging with the WT Rhodamin dilution method, in French*), EDF internal technical report.
- [11] Le Coz, J., Chastan, B., Védie, F., & Dramais, G. (2007). Emplois de l'aDcp en rivière : une revue de synthèse (*Uses of aDcp in rivers: a review, in French*). *La Houille Blanche*, **04-2007**, 119-130.
- [12] Le Coz, J., Pierrefeu, G., Saisset G., Brochot, J.-F., & Marchand, P. (2008). Mesures hydrologiques par profileur Doppler (aDcp) - Guide pratique (*Hydrological measurements by Doppler profiler (aDcp) – Practical guide, in French*), QUAE Eds., 192 p. (in press).
- [13] Lipscomb, S. W. (1995). Quality assurance plan for discharge measurements using Broadband Acoustic Doppler Current Profilers. Rapport technique, USGS.
- [14] Pierrefeu, G. (2004). Effects of a moving bottom on a discharge measurement. Discharge measurements using a DGPS. In RD Instruments ADCPs in Action - Europe, Nice, France.
- [15] Pierrefeu, G. (2006). Monitoring the Saône river discharge in Lyon by H-ADCP, *TRDI "ADCPs in Action"*, Cannes, France.
- [16] Legras, D. (2006). Setting up of a 300 kHz narrowbeam H-ADCP upstream Saint Alban nuclear power plant on the Rhône river, *TRDI "ADCPs in Action"*, Cannes, France.
- [17] Rantz, S. E. (1982), Measurement and computation of streamflow, Volume 2, Computation of discharge, U.S. Geol. Surv. Water Supply Pap. 2175, USGS, 373 p.
- [18] Le Coz, J., Pierrefeu, G., Jodeau, M., & Paquier, A. (2007). Mean vertical velocity profiles from aDcp river discharge measurement datasets, 32<sup>th</sup> Congress of IAHR, Venice, Italy.
- [19] Fulford, J. M., & V. B. Sauer (1986). Comparison of velocity interpolation methods for computing open-channel discharge, U.S. Geol. Surv. Water Supply Pap. 2290, USGS, 139–144.
- [20] Coles, D. (1956). The law of the wake in the turbulent boundary layer, *J. Fluid Mechanics* 1: 191-226.
- [21] Van Rijn, L. (1986). Mathematical modeling of suspended sediment in non uniform flows, *Journal of Hydraulic Engineering* 112(6): 433-455.
- [22] Fujita, I., M. Muste, & A. Kruger. (1998). Large-scale particle image velocimetry for flow analysis in hydraulic engineering applications, *Journal of Hydraulic Research* 36(3): 397-414.
- [23] Hauet, A., A. Kruger, W.F. Krajewski, A.A. Bradley, M. Muste, J-D. Creutin, & M. Wilson. (2008). An experimental system for real-time discharge estimation using an image-based method, *ASCE Journal of Hydrologic Engineering*, 13(2), 105-110, 2008.
- [24] Jodeau, M., Hauet, A., Paquier, A., Le Coz, J., & Dramais G. (2008). Application and evaluation of LS-PIV technique for the monitoring of river surface velocities in high flow conditions. Accepted in *Flow Measurement and Instrumentation*.
- [25] Hauet, A., Creutin, J.-D., & Belleudy, Ph. (2008). Sensitivity study of large-scale particle image velocimetry measurement of river discharge using numerical simulation, *J. of Hydrology* 349(1-2):178-190.
- [26] Olivier A., Blanquart, B., Pierrefeu, G., & Scotti, M. (2008). Incertitude sur les débits calculés à partir des courbes de transformation hauteur/débit (*Uncertainty associated with discharges computed from stage-discharge relationships, in French*), *Hydrological measurements and uncertainties SHF conference*, Paris, France.
- [27] Pobanz, K., Renouf, E., Sauquet, E., & Lang, M. (2008). Extrapolation des courbes de tarage en crue par modélisation hydraulique (*Flood extrapolation of rating curves by hydraulic modelling, in French*), *Hydrological measurements and uncertainties SHF conference*, Paris, France.
- [28] Fulford, J. M., Pilon, P., Kopaliani, Z., McCurry, P., & Caponi, C. (2007). Call for collaboration in WMO project for the assessment of the performance of flow measurement instruments and techniques. *J. Hydraulic Eng.*, **133** (12), 1439-1440.
- [29] Norme ISO/TS 24154 :2005 2005. Hydrometry – Measuring river velocity and discharge with acoustic Doppler profilers, 10 p.
- [30] Olivier A., Blanquart, B., Pierrefeu, G., & Scotti, M. (2008). Incertitude sur les mesures de débit issues d'un jaugeage à l'aDcp (*Uncertainty associated with aDcp-gauged discharges, in French*), *Hydrological measurements and uncertainties SHF conference*, Paris, France.
- [31] Oberg, K. A. et Mueller, D. S. (2007). Validation of streamflow measurements made with Acoustic Doppler Current Profilers. *J. Hydraulic Eng.*, **133** (12), 1421-1432
- [32] Gonzalez-Castro, J. A. et Muste, M. (2007). Framework for estimating uncertainty of ADCP measurements from a moving boat by standardized uncertainty analysis. *J. Hydraulic Eng.*, **133** (12), 1390-1410.
- [33] Kim, D., Muste, M. et Weber, L. (2005). Development of new ADCP post-processing and visualization capabilities. In XXXI IAHR congress, pages 338–347, Seoul, Korea.