

# THE USE OF ACOUSTIC DOPPLER SENSORS TO IMPROVE FLOW MEASUREMENTS DURING DROUGHT CONDITIONS IN SPAIN

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## ABSTRACT

In recent years, the northeast region of the Iberian Peninsula has experienced extreme drought, thus creating a need for water managers to have a better understanding of the available water resources. In the spring of 2007, the Agencia Catalana de l'Aigua (ACA) contracted Qualitas Instruments, SA to install five pulsed acoustic Doppler profilers at key sites near Girona, Spain with the goal of obtaining more accurate open channel flow measurements. In the past, these sites used water level as a surrogate to measure flow, however due to site conditions, rating curves at the site did not provide sufficient flow accuracy. In the scenarios presented in this paper, backwater effects from irrigation gates and water control structures in streams had an influence on flow monitoring at the sites. Rating curves typically break down in these situations because each water level does not have a unique associated flow value; that is to say for a given water level, there may be multiple flow values. Doppler sensors measure water depth and a velocity profile. Water depth data is used to determine flow area, which is multiplied by the average velocity that is measured by the Doppler sensor ultimately providing increased resolution and accuracy on flow measurements. Preliminary data indicate that for two sites (Canal Vinyals and Sentmenat), the rating curve method overestimated low flows conditions by an average of 68%, while the rating curve method at Resclosa Canet underestimated flows by 25%. Another irrigation canal, Canal Marge Esquerra, the Doppler sensor and Rating Curve provided similar data. Additionally, a stream monitoring site that applied a rating curve measured well during base flow, but was found to underestimate high flow conditions by approximately 31% when compared to the acoustic Doppler instrument, therefore additional investigations are needed for the site.

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## INTRODUCTION

During 2004 to 2008 Catalunya (Figure 1), the autonomous region of Northeast Spain experienced the worse drought in nearly 100 years. In 2008 the drought conditions left many reservoirs at less than 20% capacity (Figure 2). Various options were studied to rectify the situation; among these were to transport water to the region by diverting and pumping water from another watershed as well as transporting water from southern France by train or boat. Additional drinking water resources will be provided from a desalination plant due to be completed in mid 2009. However considering the continuous stress on streams to provide source water to public works systems, irrigation water to growers, diversions for hydroelectric plants all while trying to maintain an ecosystem along the stream corridor this project was seen as a potential key for future water resources management.

In the spring of 2007, the Catalan Water Agency (ACA, L'Agencia Catalana de l'Aigua) contracted Qualitas Instruments SA ([www.qualitasinstruments.com](http://www.qualitasinstruments.com)) to upgrade five key gauging stations, near Girona, Spain. These stations are located in area where the drought forced a delicate balance between irrigation, municipal and ecological use. Previously, the stations used water level as the primary surrogate measurement for flow, but have experienced problems with accuracy due to the back-water effect and irregular cross-section and distribution of flow. For the project, Qualitas Instruments SA installed 5 pulsed acoustic Doppler profilers (ADP) to monitor flow velocity and determine channel flow. ADPs measure a water velocity and calculate flow by multiplying the measured average velocity by the calculated flow area. Flow area is determined from a site specific stage-area relationship.

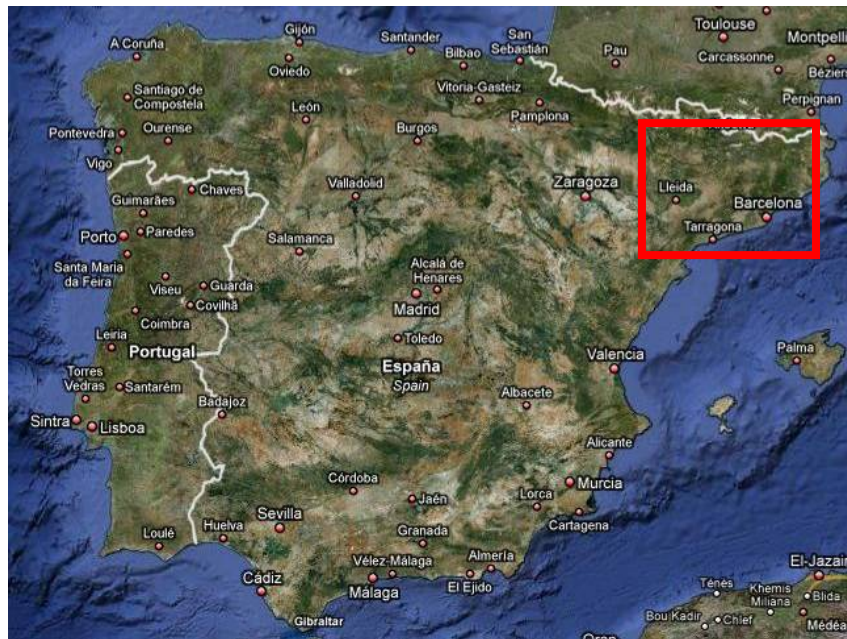


Figure 1. Map describing the general area of interest, Catalunya, Spain



Figure 2. Images from the extreme drought in Catalunya

## MATERIALS AND METHODS

All sites in this study are equipped with a device to measure water level; that is used in conjunction with a rating curve (based on gagings in the field) to calculate flow. The rating curve converts water level data to flow data. Additionally, all sites for this study have included ADPs to determine flow. Both instruments, water level and ADP, were configured to collect data every 15 minutes with the ADP programmed to utilize a 1 minute averaging interval. Figure 3 below presents a detailed site map of the 5 stations involved in the study. All are located in the province of Girona, Spain. The following section provides detailed site descriptions of each site. In addition to Doppler sensors, each site was equipped with a QFL datalogger, designed and developed by Qualitas Instruments SA. The QFL not only logs and stores data files, but also allows for instrument signal processing, thus calibrating flow values reported by the ADP or gauging values conducted onsite by applying the modified power law.

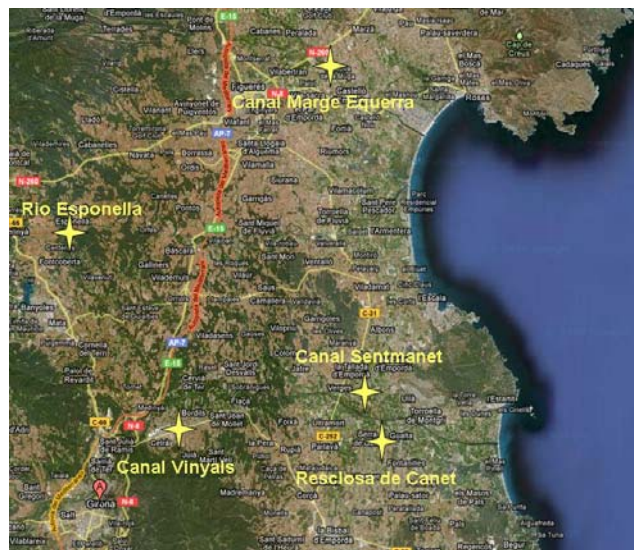


Figure 3. Detailed map of Doppler Instrument locations

### Site Descriptions

Canal Vinyals This channel, as shown in Figure 4, is a rectangular cement irrigation canal with a regular distribution of water velocities and a low sedimentation rate. An Argonaut SW (3.0 MHz) was installed at the bottom of a straight section of the canal approximately 100 ft from the gage house. Typical flow depths range from 1 to 5 ft of water.



Figure 4. Photo of Canal Vinyals

Resclosa de Canet This irrigation canal (Figure 5, looking downstream) has an unpaved irregular bottom as well as an irregular distribution of water velocities across the channel. An Argonaut SL (1.5 MHz) was installed on the right bank of the canal at 1.70 ft from the bottom. The installation depth was determined to be optimal based on the review of historical data at the site. The SL was installed approximately 40 ft from the gage house.



Figure 5. Photo of Resclosa de Canet

Canal Sentmenat This irrigation canal (Figure 6) is a rectangular channel with an irregular bottom. Due to the curvature of the canal and the irregular bottom, irregular velocities are often observed. An Argonaut SL (1.5 MHz) was installed 2.62 ft above the deepest point of the canal and 2,600 ft from the gage house.



Figure 6. Photo of Canal Sentmenat

Canal Marge Esquerra de la Muga (Pont de Molins) This rectangular irrigation canal is concrete lined with a low sediment load. Since the canal has a regular distribution of velocities, the SW (3.0 MHz) was installed on the bottom of the canal just below the foot bridge and next to gage (Figure 7). The distance between the gaging station and the sensor is approximately 20 ft.



Figure 7. Photo of Canal Marge Esquerra de la Muga

Rio Fluvia - Esonella The Argonaut SL (1.5 MHz) was installed on the right bank of the Fluvia River near Eponella at 1.5 m from the deepest portion of the stream at a level

that should always be submerged based on historical data. The stream has an uneven rocky channel bottom and irregular flow velocities. The SL is installed some 230 ft from the gage house. Figure 8 presents a photo of the downstream section of the Rio Fluvia, just upstream from where the SL is installed.



Figure 8. Photo of the Fluvia River near Esponella

## RESULTS

Tables 1 -5 present results from verification gagings at each sites involved in the study. The results present good agreement between the gaging and the acoustic Doppler sensor flow data. One trend observed that the acoustic Doppler sensor generally provided a good measurement of flow at all sites however, low flows were nominally underestimated at the Resclosa de Canet and Vinyals and slightly overestimated flows at the Canal Marge Esquerra. It is important to note that the Vinyals and Canal Marge Esquerra sites are using the “Theroretical Method” for flow calculation, that is to say that the flow values are determined only by using the flow area (determined by the vertical beam/pressure sensor and the cross-sectional area of the station) and velocity profile determined by the acoustic Doppler sensor. All other sites are applying the adjusted power law via the QFL to calibrate raw data from the sensor to gaged data from the site. Additional accuracy can be obtained by using the velocity index method which allows the user to “calibrate” acoustic Doppler sensor to gaging data; in other words using regression analysis to compare the mean velocity from the gaging data to the mean velocity of the acoustic Doppler sensor.

Table 1. Flow data results for Canal Vinyals

Stage (ft)	Gaging (ft <sup>3</sup> /s)	SW Discharge (ft <sup>3</sup> /s)	% Difference
2.03	49.0	46.6	5.24
2.49	32.5	31.8	-1.96
3.58	47.3	45.9	2.99
3.61	43.4	45.2	-4.15

In addition to the data described in Table 1, data from a four day test deployment during steady flows in August 2008 indicated that the uncalibrated SW measured an average flow value of 42.3 ft<sup>3</sup>/s compared to the rating curve value of 82.6 ft<sup>3</sup>/s. Gaging at the site indicated that the flow value was 46.9 ft<sup>3</sup>/s, thus a rating curve value overestimated flows by 95% .

Table 2. Flow data results for Resclosa de Canet

Stage (ft)	Gaging (ft <sup>3</sup> /s)	SL Discharge (ft <sup>3</sup> /s)	% Difference
4.10	24.3	24.7	0.01
5.84	79.4	70.9	11.99

Similar to the data in Table 2, flow data from an SL for three consecutive days of steady flow in August (2008) observed an average flow of 82.6 ft<sup>3</sup>/s with a gaged value of 79.4 ft<sup>3</sup>/s. This shows a good improvement from the rating curve value that corresponded to 61.8 ft<sup>3</sup>/s; thus, the rating curve was 25% below actual flow values.

Table 3. Flow data results for Sentmenat

Stage (ft)	Gaging (ft <sup>3</sup> /s)	SL Discharge (ft <sup>3</sup> /s)	% Difference
0.79	16.6	16.2	1.71

In addition to the data in Table 3, data from a three day monitoring period in June 2008 with steady flow determined that flow from the SL was 17.6 ft<sup>3</sup>/s which compared to the rating curve value of 24.7 ft<sup>3</sup>/s; gaging value from the site was 16.9 ft<sup>3</sup>/s. This identifies that the rating curve was overestimating flows by 40%.

Table 4. Flow data results for Canal Marge Esquerra

Stage (ft)	Gaging (ft <sup>3</sup> /s)	SW Discharge (ft <sup>3</sup> /s)	% Difference
3.28	12.0	10.6	10.45
3.31	13.4	14.1	-5.82
4.59	70.9	70.6	-0.40

In general, SW and rating curve data have compared well to each other during all measurement periods.

Table 5. Flow data results for Rio Fluvia - Esponella

Stage (ft)	Gaging (ft <sup>3</sup> /s)	SL Discharge (ft <sup>3</sup> /s)	% Difference
1.18	84.7	84.7	0.00
1.77	198.0	197.6	0.18
2.36	370.5	367.0	0.96

Flow data from the SL and the rating curve are comparable overtime during steady flows for four days in June; however the SL measured much higher flow values than the rating curve during high flow periods ( 917 ft<sup>3</sup>/s for the ADP compared to 635 ft<sup>3</sup>/s for the

rating curve). Additional gagings need to be completed at higher flows to determine which flow value is more accurate. In the case that the SL needs additional accuracy a velocity index can be completed to fine-tune/calibrate the acoustic Doppler instrument. Table 6 provides a summary comparing the ADP and rating curve data.

Table 6. Summary of data comparing ADP to Rating Curve data

Station	Flow ADP (ft <sup>3</sup> /s)	Flow Rating Curve (ft <sup>3</sup> /s)	Gaging (ft <sup>3</sup> /s)	% Difference (Rating Curve – ADP)
Canal Vinyals	42.3	82.6	46.9	95%
Resclosa Canet	82.6	61.8	79.4	-25%
Canal Sentmenat	17.6	24.7	16.9	40%
Canal Marge Esquerra	10.5	11.3	12.0	8%
Rio Fluvia	917	635	---	-31%

### SUMMARY AND CONCLUSIONS

Considering the intense drought in Northeast Spain during 2004-2008, water managers were forced to look for solutions to better quantify flow values in order to maintain delicate balance between municipal, agricultural and ecological use. Five gaging stations had ADPs installed as flow measuring instruments in order to provide more accurate flow measurements. Based on the information provided above, ADPs provided increased accuracy for flow measurements by applying the theoretical flow calculation or by applying the adjusted power law to velocity. Additional fine-tuning or accuracy can be achieved over time by calibrating or conducting a velocity index for the sites, however some sites performed well using raw data from the ADP. The gaging sites included four irrigation canals and one river. Preliminary data indicate that for two irrigation canals the rating curve method overestimated low flows conditions by an average of 67.5%, while one canal underestimated flow by 25%. An additional irrigation canal using a rating curve compared fairly well to ADP data. Lastly, a stream monitoring site had comparable data during base flow, but was found to underestimate high flow conditions by approximately 30% when comparing data from the ADP and rating curve, however no gaging data was available as a check; this suggests that additional investigations need to be completed.