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Methods note/

## **A simple low-cost method to monitor duration of ground water pumping**

Massuel S.<sup>1\*</sup>, J. Perrin<sup>2</sup>, M. Wajid<sup>2</sup>, C. Mascré<sup>2</sup>, B. Dewandel<sup>3</sup>

<sup>1</sup>International Water Management Institute, c/o ICRISAT Patancheru, India

<sup>2</sup>Indo-French Centre for Groundwater Research, NGRI, Uppal Road, Hyderabad-500 007, India.

<sup>3</sup>BRGM, Montpellier, France

\*Corresponding author: s.massuel@cgiar.org

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### **Abstract**

Monitoring ground water withdrawals for agriculture is a difficult task while agricultural development leads frequently to an overexploitation of the aquifers. To fix the problem, a sustainable management is required based on the knowledge of water uses. This paper introduces a simple and inexpensive direct method to determine the duration of pumping of a well by measuring the temperature of its water outlet pipe. A pumping phase is characterized by a steady temperature value close to ground water temperature. The method involves recording the temperature of the outlet pipe and identifying the different stages of pumping. It is based on the use of the low-cost and small-size Thermochron iButton temperature logger and can be applied to any well, provided that a water outlet pipe is accessible. The temperature time series are analyzed to determine the duration of pumping through manual and automatic post-treatments. The method was tested and applied in South India for irrigation wells using electricity-powered pumps. The duration of pumping obtained by the iButton method is fully consistent with the duration of power supply (1.5% difference).

## Introduction

In many countries, especially in India, ground water irrigated areas have surpassed surface water irrigated areas, since the 'green revolution' of the 1970s (Shah et al., 2006). This rapid change in usage induces a high stress on ground water due to massive extraction for agriculture and threatens the sustainability of water availability and agricultural development. However, ground water withdrawals for irrigation are difficult to estimate at the watershed level and are usually assessed through indirect methods (e.g., cultivated area *versus* crop water requirement, statistics on the number of wells). This information is however essential to determine irrigation practices, crop water consumption, water productivity assessment as well as ground water management. At the local scale, probably the most efficient direct method to measure withdrawals is to install a flowmeter on each well, but the cost increases drastically with the number of instrumented wells. Such invasive equipment may also not be accepted by the well owner who may deny access to his well. In this note, we show that the duration of pumping is a parameter that can be accurately measured through a simple low-cost methodology, providing good estimates of ground water withdrawals as well as reliable information on farmers' ground water irrigation practices.

The temperature of the water outlet pipe is monitored by a portable automatic recorder and the discharge of the well is gauged regularly. The ground water draft is calculated based on the duration of pumping and the measured discharge of the well. The robustness of the method is tested by monitoring a well, where a detailed pumping schedule based on power supply is available (electric pump).

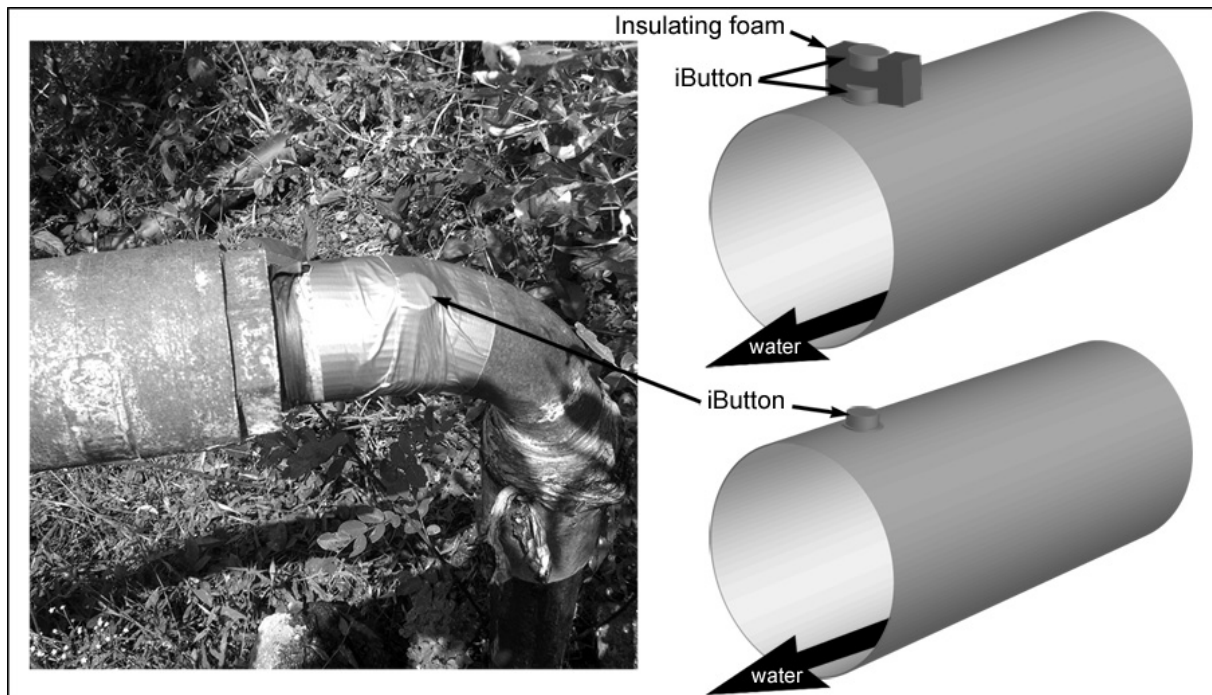
## Method and materials

The method was developed in 2007 to assess season-wise ground water withdrawals in a small basin (Gajwel, South India, 84 km<sup>2</sup>) in order to implement a Decision Support Tool for ground water management (Dewandel et al. 2007). The present method is based on a simple observation: when a borehole is running, the temperature of the water outlet pipe is in equilibrium with the temperature of the pumped water. According to Constantz (1998), ground water temperature is nearly constant at the daily time scale (e.g., Abis and Mara, 2006; Conant Jr., 2004) and the pumping phase is characterized by a steady pipe temperature close to ground water temperature. By monitoring the temperature of the water outlet pipe of a well, pumping stages can be identified through an analysis of temperature variation.

Among existing products and technologies (Hobo, TidBiT, etc.) for temperature measurements, we have selected the Thermochron iButton manufactured by Dallas Semiconductor, a temperature logger that meets our criteria of low cost (<\$60) and small size (16mm). Until now, the Thermochron iButton has seen limited applications in hydrogeologic investigations, but has shown good capabilities (e.g., Hubbart et al., 2005; Johnson et al., 2005; Wolaver and Sharp, 2007). The model we used (DS1921H-F5) can measure temperatures in the range of 15 °C – 46 °C with  $\pm 1$  °C accuracy and a 0.125 °C resolution, according to the manufacturer. Recording time intervals are defined by the user (ranging from 1 to 255 minutes) and up to 2,048 temperature values can be stored in the memory. Data are transferred from the logger to the computer through a specific USB cable (1-Wire<sup>®</sup> protocol). For our needs, the Thermochron iButton logger has three principal advantages over more common wired and stand-alone logging devices: (i) the self-sufficient nature does not require the instrument to be located near a control-recording system, (ii)

the small size allows for easy and discreet installation, and (iii) the low cost of the loggers allows for monitoring several wells simultaneously.

For the present study, the Thermochron iButtons were simply fixed on pipes with strong adhesive tape (Figure 1). Two configurations were tested: (i) a single iButton measures the pipe temperature; (ii) two iButtons are deployed to simultaneously measure both air temperature and pipe temperature, respectively (Figure 1).



**Figure 1.** a) Thermochron iButton fixed on the water outlet pipe of a borehole in the Gajwel basin, India; b) sketch of the monitoring apparatus, one (down) and two (top) iButtons configuration.

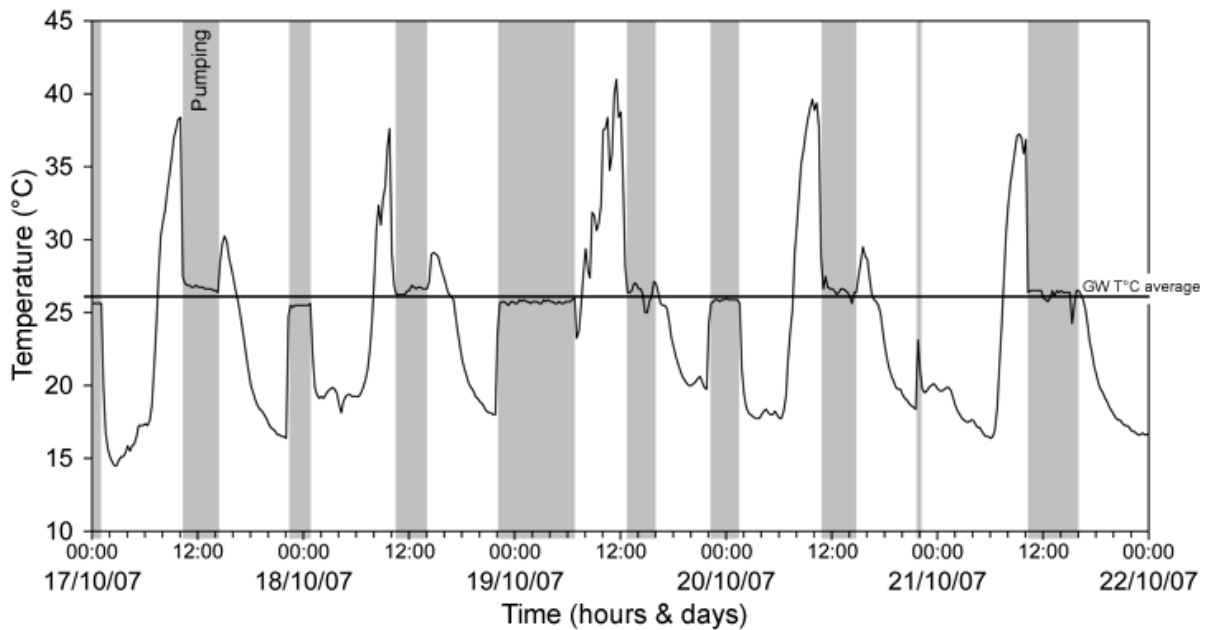
## Results

The method has been applied to monitor several irrigation wells located in the Gajwel watershed, Andhra Pradesh, southern India. In this semiarid region, irrigated agriculture represents the largest share of ground water use, with paddy fields and other high water-demanding crops. This leads to a large-scale overexploitation of the ground water resources (Massuel et al., 2007) which requires efficient management of ground water.. As such, ground water draft is a very important parameter of the ground water budget and it is necessary to monitor pumping accurately (as this has not been recorded by water authorities so far).

### - Single iButton configuration

The experiment was conducted on eight wells simultaneously where temperatures were recorded every 15 minutes during three months. Figure 2 shows an example of a typical temperature time series of a well water outlet pipe. During the experiment, the average ground water temperature was around 26.2 °C. The distinction between pumping and non-pumping phase is clear when air and ground water temperatures are contrasted. It is more problematic when the differences are slight, which requires the subjective interpretation of the operator. A simple Excel macro has been developed for building a user-friendly graphic

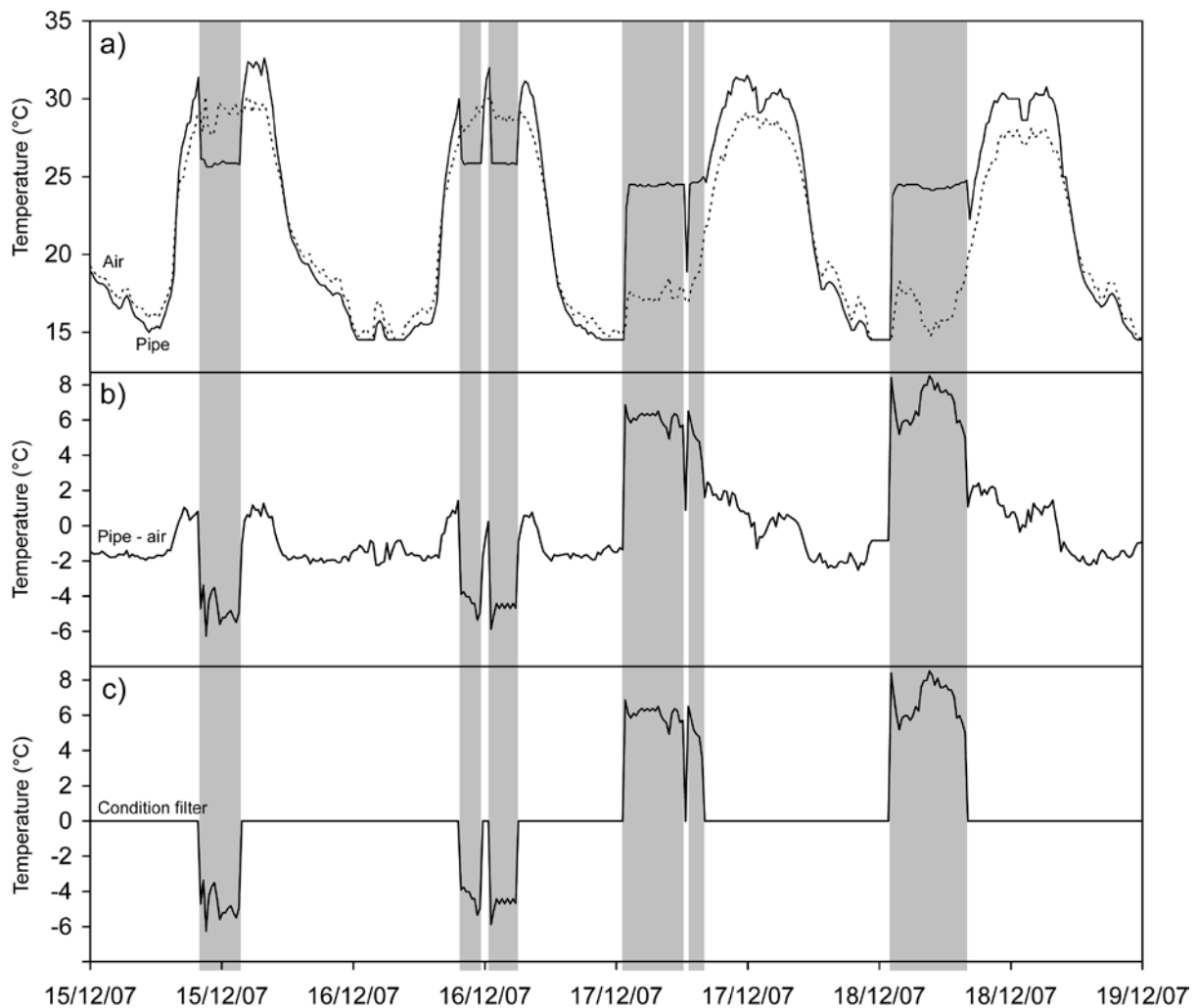
interface that helps manual interpretation. Time series are displayed daily and start and stop points can be easily selected, stored and listed by users when daily duration of pumping is automatically calculated.



**Figure 2.** Example of a temperature time series recorded by a Thermochron iButton showing the temperature plateau occurring when ground water flows into the outlet pipe. The duration of pumping is overlaid in grey.

#### - Two iButtons configuration

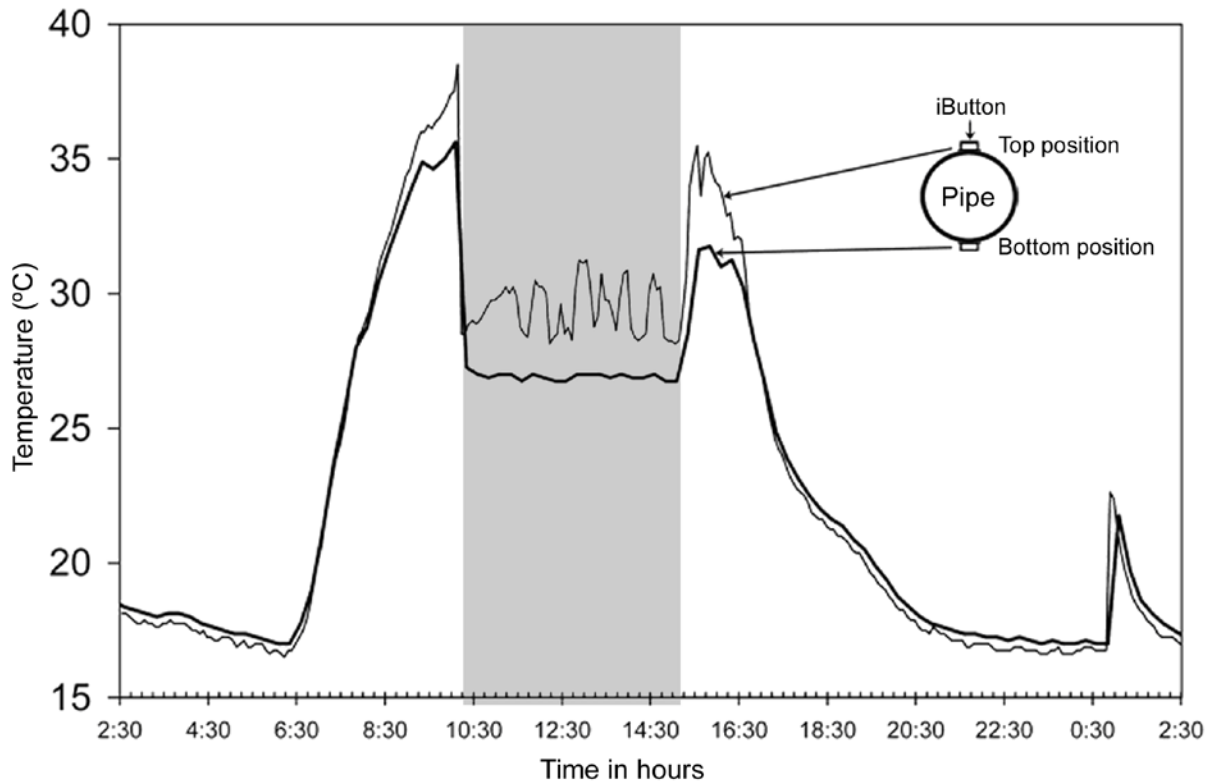
The same pipe is equipped with the two Thermochron iButtons. They are thermally insulated from each other with foam to simultaneously and separately measure pipe and air temperatures (see Figure 3a). Differences between pipe and air temperatures show a strong amplitude when the water is running (Figure 3b). By applying a condition filter which produces (1) the original value if a cutoff is exceeded, or (2) 0 otherwise. 'Anomalies' corresponding exactly to the pumping phase can be separated and automatically detected (Figure 3c). This process is less time-consuming than manual interpretation and is therefore well suited to analyze data on numerous wells. Manual versus automatic duration of pumping determination was compared on a well during 15 days. The same time series have been analyzed with both methods. The daily pumping average found was 5h59 for automatic and 5h57 for manual detection. The difference between the results of the two methods is therefore not significant.



**Figure 3.** a) Recorded pipe (black line) and air (dashed line) temperatures; b) difference between pipe and air temperatures; c) filtered curve for extracting information on the duration of pumping (cutoff threshold 2.6 °C).

## Discussion

Even if the logger is isolated from air temperature, direct solar radiations affect the pipe, and temperature fluctuations up to 3 °C can be recorded during pumping time (Figure 4). Consequently, best results were obtained with the Thermochron iButtons fixed in the lower part of the pipe diameter (bottom position, see Figure 4). Thermal conduction may also be more efficient on this side of the pipe because of a better contact with running water (by gravity). One way to get rid of these effects is to fix the iButton inside the pipe in a waterproof capsule. However, this solution was not selected because (i) our constraint was to use a very discreet and simple fixing system usable everywhere that does not disturb the flow; (ii) farmers frequently add or remove long additional pipes depending on their field configuration which can be problematic for reading the iButton memory.



**Figure 4.** Comparison of temperature recorded at top or bottom position on the water outlet pipe in case of non-thermal insulation of the iButton.

Metal and plastic pipes have been investigated with equivalent results. Their temperature gets close to running water temperature instantaneously and does not induce any significant uncertainty. However, pipe and air temperatures need more time to be balanced after the pump stops. Depending on conditions observed (solar exposure, pipe material, temperature gradient, etc.), the balancing-time remains short: <5 minutes in our case. The time sampling resolution induces also an uncertainty in determining the duration of pumping. To assess this uncertainty, a test was performed on the same well during 10 days with different recording time steps. For 5- and 15-minute time samplings, the differences with actual duration of pumping were an overestimation of 2 min.d<sup>-1</sup> and an underestimation of 4 min.d<sup>-1</sup> on average, respectively. In this case study, we chose to store a value every 15 minutes which provides a reasonable range before clearing the iButton memory (21.4 days).

### **Comparison with ground water fluctuation method**

Ground water levels were monitored in an abandoned borehole with a pressure logger (Madofil, IRIS Instruments). Ground water-level fluctuations give evidence that pumping occurs in the neighborhood. The water table decreases during pumping and rises when pumping stops. Ground water fluctuation and iButton methods were compared during one month. The mean daily pumping times given by the iButton and the ground water fluctuation methods were 6 h 01 min and 6 h 38 min, respectively ( $\Delta t = 37$  min). Depending on conditions (i.e., number of surrounding wells, distance, aquifer hydraulic properties, etc.) water table fluctuations can be smoothed but start/stop pumping phases are difficult to set. Another shortcoming of the method of water-table fluctuation is that it may integrate the influence of several wells in the vicinity, which can hinder the estimation of the duration of

pumping of each single well. All this can explain the 37-minute (10%) discrepancy between the two methods and show that the iButton method is well-suited to determine the pumping schedule for individual wells.

### **Validation and application**

The method was applied in a small area of about 20 ha near the artificial tank of Sangapur village (the Gajwel watershed). The cropping pattern is mainly paddy fields and vegetables and half of the cultivated area is irrigated by ground water, the remaining half being rain-fed. In the vicinity of the tank, 14 boreholes were identified. In this area, power supply is free for farmers. According to the Central Power Distribution Company of Andhra Pradesh Limited (APCPDCL), free power is supplied 7 hours a day in 2 weekly alternative phases: (i) from 01:00 to 08:00 or (ii) from 22:00 to 01:00 and from 10:00 to 14:00. All wells in this small area are connected to the same power line and should theoretically start and stop at the same time, since the pumps are supposed to be always switched on. However, some of them are switched off randomly for activities in the field (e.g., harvesting, break before sowing, etc.) or maintenance. Consequently, validation with power data was performed on the village Drinking Water Supply well (DWS well), the only one that is always switched on. Results for a 54-day period give 6 hours and 54 minutes of pumping per day on average. This corresponds to a difference of only 6 minutes with duration of the 7 hour electricity supply declared by APCPDCL (1.5%) and shows the reliability of the temperature method to determine the duration of pumping. Stages of electricity supply are irregular, but the lack of power supply is always counterbalanced by extra delivering periods in order to meet the 7 hours a day on average.

The temperature monitoring campaign was performed on eight wells (out of 14 in the 20 ha area) for the period October-December 2007 (second half of the monsoonal season). It confirms that pumping phases of irrigation wells are very erratic with frequent manual stops and starts, compared to the DWS well. As a result, daily pumping time for irrigation wells is only 5 hours 54 minutes on average in the area, 1 hour 6 minutes less than that taken for the mean available power supply.

Well discharges were measured punctually every 15 days by the bucket method (25L). Related ground water withdrawals were assessed according to the duration of pumping. The estimated daily ground water discharge of the wells ranges from 4.1 to 24.6 m<sup>3</sup>.h<sup>-1</sup> (14.9 m<sup>3</sup>.h<sup>-1</sup> on average). This variability is not surprising in such a hard-rock aquifer context (Maréchal et al., 2004). Durations of pumping ranged from 5 h 30 min to 6 h 24 min (5 h 54 min on average). Wells displaying a discharge higher than 14 m<sup>3</sup>.h<sup>-1</sup> are pumped 36 minutes more daily than those with a discharge lower than 10 m<sup>3</sup>.h<sup>-1</sup>. Farmers tend preferentially to pumping from high-yield wells, but this observation requires further study to confirm. On average, in the area, total daily ground water withdrawals are estimated at 1,255 m<sup>3</sup>.d<sup>-1</sup> for the 14 wells. Accordingly, ground water supplies around 13 mm per day to the 9.3 ha of irrigated paddy fields. This result is close to the 10 mm given by Maréchal et al. (2006) in the same region and season. Assuming a mean well discharge rate of 14.9 m<sup>3</sup>.h<sup>-1</sup>, the error of 6 minutes brought about by the method compared to the actual duration of pumping entails an error of only 1.5 m<sup>3</sup>, which is more than satisfactory for assessing ground water withdrawals for irrigation at the basin level. In addition, when duration of pumping is used based on power supply (7 hours), withdrawals are overestimated by 16.4 m<sup>3</sup> per well and per day.

## **Conclusions**

Measuring the temperature of the irrigation well water outlet pipe is a well-suited method to determine duration of pumping when the air and ground water temperatures are contrasted (e.g., a minimum difference of 3 °C in our case). The method using temperature monitoring can be economical, simple and easy to implement compared to other methods like measuring ground water fluctuations or installing flowmeters. Information can be collected for a particular well or a group of wells for a larger-scale study. A pumping schedule of each monitored well can be determined and information provided on the strategy of irrigation by owners. Uncertainty in determining the duration of pumping is estimated at 1.5% for a sampling time of 15 minutes. Temperature loggers like the new Thermochron iButton models (DS1922L) can store 4,096 values; so, for the same duration of monitoring, the number of records can be doubled to reduce uncertainty due to the sampling interval. The main advantage is that it is a direct measurement method which does not cause any perturbation. For instance, for electric pumps, measuring power supply does not ensure that water is effectively running out of the well. Here, the duration of pumping is accounted for only when water is running out of the pipe. The present method has proven its efficiency in providing relevant information on ground water withdrawal estimates, which is a key parameter for watershed management tools. This method is also applicable in any other study that needs to account for temporary water consumption or release (e.g., industries, domestic uses, temporary outflow in natural hydrological systems, etc.).

## **Acknowledgments**

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