

Article

# The Magnitude and Cost of Groundwater Metering and Control in Agriculture

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**Abstract:** Volumetric pricing as envisaged within the Water Framework Directive (60/2000) is a considerable challenge in terms of irrigation in Mediterranean regions, since a large share of the water source is groundwater. Enforcing this pricing scheme involves systematic metering and control (M&C) systems with subsequent high costs. This paper aims to fill the gap in the literature related to the assessment of costs for the metering and control of irrigation groundwater. The full operational cost of all activities related to the hypothetical services provided by a public agency is assessed for Apulia (a region in southern Italy). The results show that point-to-point metering services are quite costly, ranging from 38.5 to 59 euros per delivery point. New questions arise regarding whether the M&C of groundwater abstraction should be fully charged to end users (i.e., farmers), or also shared with the whole society as a public service aimed at environmental enhancement.

**Keywords:** groundwater; volumetric pricing; metering; irrigation; Apulia

## 1. Introduction

The Water Framework Directive (WFD) issued by the European Union (EU) in 2000, recommends full cost recovery and suggests direct water pricing as the most effective approach to managing irrigation water. In order to implement this directive, EU member countries need to extend water-pricing policies, traditionally applied to on-demand pressured water services (e.g., drinking water) to other types of water services. In this regard, a recent decree of the Italian Agriculture Ministry [1] paved the way towards the accounting in irrigation-water uses, which in turn allows for fully recovering of associated costs (i.e., financial, resource, and environmental costs).

Field and Field [2] noted that there is a natural tendency to think that the enactment of a law automatically leads to the rectification of the problem to which it is addressed. This tendency is obviously too simplistic, since the enactment of a policy is only one aspect of the regulatory process. At present, the literature [3] considers five stages in the lifecycle of a policy: agenda-setting, formulation (or enactment), public decision-making, implementation and evaluation. In order to implement a policy effectively, many resources are needed throughout the different stages of its cycle.

Enforcing water-pricing policy entails the metering and control (M&C) of water uses. Viaggi et al. [4] discussed water pricing under asymmetric information in the context of the directive 60/2000, arguing that the economic feasibility of volumetric pricing in agriculture is hindered by the excessive transaction cost incurred for irrigation water metering.

With reference to groundwater, it is worth mentioning that this resource exhibits the common pool features (i.e., non-excludable and rival), which in turn makes the problem quite difficult to be

solved [5]. The economic theory defines a common good as an economic good with high rate of rivalry and a low rate of excludability. When the rate of excludability is low, there are problems in excluding someone from the use of the good (i.e., high cost of excludability, practical or legal obstacles in implementing excludability). Indeed, it is generally difficult and costly to implement and enforce any policy management of groundwater use. While paradigms for management of common pool resources (e.g., groundwater) have been theorized [6], and various solutions have been investigated and tested [7], with a few exceptions worldwide, little has been done to regulate groundwater extraction [8]. Undoubtedly, the adoption of volumetric pricing to groundwater resources is the greatest challenge for agriculture.

In the case of groundwater sources, which are distributed and often managed directly by farmers, the metering as well as recording can be costly. As the water is self-supplied, this sector generally falls outside the scope of pricing charges. In the case of groundwater, the farmers have typically only paid the private costs of directly accessing the aquifer; such as drilling the well or installing the pump, but the other costs associated with groundwater use have traditionally been offloaded on the general public. Although the ability to charge users according to actual use is beneficial, it is questionable whether that benefit is worth the increased expense of metering.

A key issue in groundwater management is the size of the groundwater user community. In general, farmers operate in rural areas, therefore the costs for an individual point control on groundwater withdrawal are expected to be highly relevant [9]. In principle, it is difficult for government authorities to measure and register all water flows to many smallholders, who may extract the water in relatively small quantities, or to prevent cheating [10,11]. As argued in [12], water administrations are often not able to enforce volumetric pricing, due to the large social costs involved in metering and controlling the actual water volumes extracted by farmers.

A number of studies have investigated the feasibility of irrigation groundwater monitoring. The proposals for water meters in aquifer management have ranged from centralized online information-management systems to measuring collective aquifer water extraction [13] based on controlled electricity usage [14] to prepaid smart meter systems [15].

Despite the fact that the cost of M&C is an important component of all irrigation water services, to the best of our knowledge there has been little research into the evaluation of such costs related to the water-pricing policy. Although specific studies on irrigation groundwater are not available, some studies in the literature deal with “cap and trade” mechanisms for irrigation water, for instance in Colorado and California [16].

Our aim was to evaluate the metering and control cost of a water-pricing policy applied to irrigation groundwater. In this paper, we refer to the set of operations needed to verify water users' compliance with the water-pricing policies, including the application of specific sanctions. We thus took into account the operations needed to: (i) meter the volume of water withdrawn by the users; (ii) verify that users are not violating the rules; (iii) record, update and maintain a database of users; and (iv) implement the sanctioning system.

Considering the fact that metering and control is the key issue in order to enforce volumetric pricing policies, the aim of this paper was to assess the operational cost incurred for the point-to-point metering of groundwater resources in agriculture. In doing that, we also attempted to improve the understanding of cost-effectiveness of M&C operation, specifically for groundwater resources. On the contrary, we did not attempt to assess the overall transaction cost associated to the implementation of volumetric pricing in agriculture, of which metering and control are expected to be a large share.

Two study cases were analyzed, which refer to the land-reclamation and irrigation boards (RIBs) of Capitanata (Consorzio di Bonifica e Irrigazione della Capitanata—CBC) and Ugento Li Foggi (Consorzio di Bonifica e Irrigazione Ugento Li Foggi—CBU). Both CBC and CBU are located in Apulia (southern Italy), a Mediterranean region, which is severely affected by groundwater over-exploitation [17], water-table depletion and coastal seawater intrusion [18]. Since there are no data with reference to

the cost of M&C in irrigation water, the study cases were used to carry out the cost assessment of an at-farm-gate metering and control system on irrigation groundwater.

We assumed that the water organization of the Apulia region had gathered complete information on the groundwater users and delivering points [19], which were supposed to be already equipped with metering devices. At the same time, RIBs were considered as fully operative and as taking advantage of a consolidated routine, with adequate equipment and skilled personnel. Finally, we assumed farmer transaction costs as negligible.

Section 2 describes Apulia and the methodology applied. Section 3 reports the results, while the concluding remarks are presented in Section 4.

## 2. Materials and Methods

### 2.1. Apulia

Apulia (southern Italy) (Figure 1) has a Mediterranean climate, characterized by warm-to-hot dry summers, and mild-to-cool wet winters. Irrigation is important for the overall economy of the region, especially for agriculture. In 2009/2010, the total irrigated land amounted to 238,546.02 ha with an estimated volume of 655.29 million m<sup>3</sup> [20]. Permanent crops such as olive and grape are widespread, followed by fresh-cut vegetables (broccoli, carrot, spinach, artichoke, asparagus, etc.) and processing tomatoes. Overall, these crops account for 80% of the region's irrigated land.

The average size of the irrigated land is smaller than 5 ha with 63,909 farms using irrigation [6] (23.5% of total farms). In addition, half of the farms that use irrigation have on-farm wells, while less than 30% are connected to collective delivery systems. In Apulia there are six reclamation and irrigation boards (RIB): in Gargano, Capitanata, Arneo, Stornara e Tara, Terre d'Apulia, and Ugento Lì Foggi.

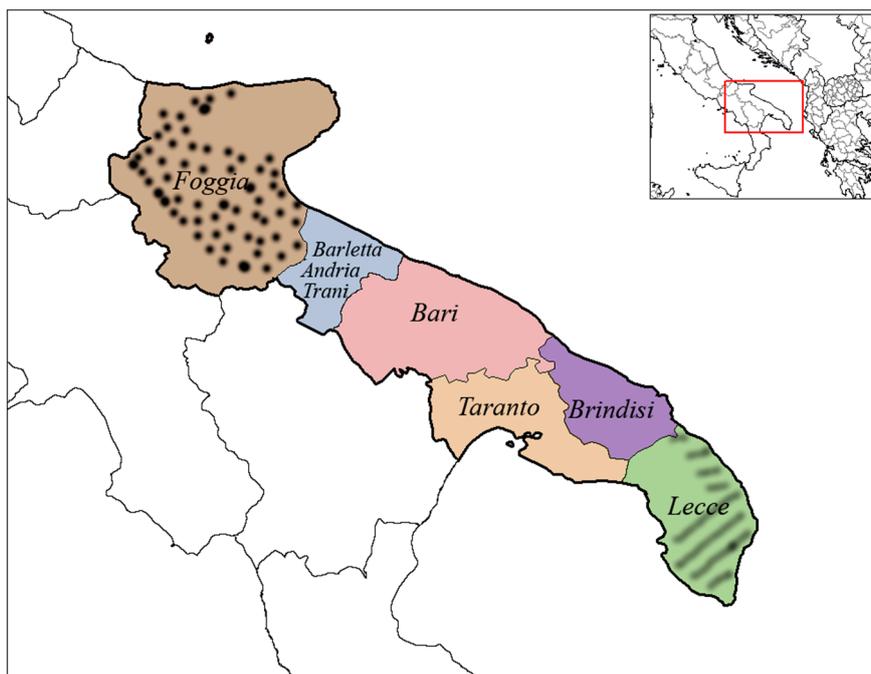
The situation differs across the region. For example, while the Province of Foggia represents the best example of a collective irrigation delivery system of surface water, within the Province of Lecce, almost 80% of the irrigation water is derived from direct on-farm access to groundwater resources. In addition, considering the lack of surface-water bodies, in the Province of Lecce the collective irrigation delivery systems rely mostly on groundwater sources.

In Apulia, groundwater use is subject to permits issued by the local authorities [21], which are supposed to monitor the groundwater access (e.g., illegally accessed) and metering of extracted volumes. The groundwater irrigation rights are issued for five years and are subject to renewal according to the Water Protection Plan requirements. The license has the allotment limited to 20,000 m<sup>3</sup> per year and farmers are required to install on-farm metering devices. In addition, restriction areas and buffer zones have been established. Groundwater licenses are no longer issued within restriction areas, and license holders are subject to flow limits. Metering and control (M&C) plays a primary role for the enhancement of the good ecological status according to the WFD's goals

Although the drilling of private wells is subject to public authorization or licensing, groundwater resources have been exploited almost everywhere by a large number of private small users, thus creating a situation that is difficult to monitor and regulate.

In general, the M&C system is fragmented, and current compliance with the regional law falls far short of the target [22,23]. In many areas where groundwater is the main freshwater source, pumping rates exceed the natural recharge rate and cause continuous water-table drawdown, well depletion, increased pumping costs, and severe seawater intrusion in coastal areas [17,18]. Considering the current settings of property rights, the legislation, and the nature of the aquifers, the right to use each well is detained by farmers cultivating the attached farmland. The use right on groundwater cannot be allocated to neighboring farmers (with some rare exceptions). Therefore, the possibility to regulate the groundwater by establishing local committees of farmers is not currently feasible.

Our research focused on the Provinces of Foggia and Lecce (Figure 1), as they are representative of the heterogeneity of the Apulia region with respect to irrigation water. Figure 1 shows how the CBC regulates most of the Province of Foggia and the CBU stands over most of the Province of Lecce.



**Figure 1.** Schematic diagram of the areas of the CBC, Capitanata, (spots); and CBU, Ugento Li Foggi, (stripes), across Apulia.

In the Province of Foggia, the main irrigated crops are vegetables (37.5%), followed by grapevines (26%) and olive trees (14.5%). By contrast, in the Province of Lecce the main irrigated crops are olive trees (59.5%), followed by vegetables (17.5%) and grapevines (5.5%).

Table 1 reports the irrigated crop pattern within the Provinces of Foggia and Lecce.

**Table 1.** Irrigated crop pattern (percentage of the total irrigated area).

Province	Grapevines	Olive Trees	Open Air Vegetables	Other Irrigated Crops
Foggia	26	14.5	37.5	22
Lecce	5.5	59.5	17.5	17.5

Source: Our data processing from [6].

Table 2 shows the number of licenses issued for groundwater irrigation wells and groundwater withdrawal for the Provinces of Foggia and Lecce.

**Table 2.** Irrigation groundwater estimates in Apulia Region.

Province	Issued Licenses <sup>1</sup> (Number)	Groundwater Withdrawal <sup>2</sup> (m <sup>3</sup> /Year)
Foggia	35,888	85,709,211
Lecce	34,059	44,016,701

Source: our analysis; <sup>1</sup> regional database [19]; <sup>2</sup> MARSALa project [24].

There are two main reasons why the Province of Foggia has greater groundwater withdrawal. Firstly, in this area the main irrigated crops are open-air vegetables (very water-demanding crops). Secondly, the irrigated area of the Province of Foggia is more than four times that of the Province of Lecce. However, regarding the number of issued licenses, there is not such a big difference between the two provinces. This because in the Province of Lecce, the groundwater resource is the main irrigation water source (about 80% of the total irrigation water source).

## 2.2. Methodology to Assess the Cost of Metering and Control (M&C)

At the first, we had to set out the methodology for assessing the cost of M&C. Indeed, as in many irrigated areas, there are no firms or public organizations which are exclusively devoted to irrigation groundwater metering. With lack of market prices, we took the RIB as good example of an agency performing a metering and control services for irrigation water.

Implementing an on-farm M&C system typically involves fixed costs (i.e., installing measuring devices, setting up the administration and facilities, and variable components that increase with the water proceeds, i.e., collection activities). The operation may include both measuring the performance of water users and controlling their compliance with regulations, as well as the development of monitoring technologies. On the other hand, if there has been lack of compliance, sanctioning includes the costs of prosecution and conflict resolution.

According to local laws on groundwater use, farmers are required to install on-farm metering devices, while the local council is responsible for collecting and controlling accessed groundwater points. As a consequence, we assessed the cost of M&C in cases where on-farm withdraw points are known [19] and already equipped with metering devices. According to Williamson's conceptualization [25], this implies that organizations obtain full information on the location of wells, the personnel devoted to the activities are loyal to the organizations, farmers are collaborative in providing the information, while access to all wells is guaranteed.

In order to evaluate such costs, we considered the M&C as a service provided by a public agency. The provision cost of monitoring and control services was calculated as shown in Equation (1):

$$K = W + S + Q + T + M + I \quad (1)$$

where:

K = operational cost of the M&C service;

W = wages of employees involved in the M&C operations, from intellectual labour;

S = salaries of employees involved in the M&C operations, from manual labour;

Q = quota regarding costs for depreciation expenses and insurance policies of the machinery inventory used in M&C;

T = taxes for M&C operations;

M = miscellaneous expenses for M&C operations;

I = interest on financial capital used for W, Q, T and M.

In terms of M&C operation taxes, we considered only the tax paid by the agency for vehicles, while in terms of miscellaneous expenses, we considered the costs paid by the agency for consumable goods and the furniture maintenance of its offices. Note that we considered the annual operational cost of M&C services.

We then took the reclamation and irrigation boards as a good example of organizations operating in the sector of water irrigation. While they manage the collective delivery of irrigation systems, the key points in terms of being a reference agency are: (i) the high number of on-farm water-delivering points throughout the region's irrigated areas; (ii) the on-demand irrigation services; (iii) the presence of metering devices; (iv) at-farm-gate metering and control services; (v) the volumetric charges.

We considered an optimal situation where the RIBs have complete knowledge of the water-delivering points, already equipped with metering devices. The RIBs were thus considered as fully operative and as taking advantage of a consolidated routine, with adequate equipment and skilled personnel. Nonetheless, the RIBs did not report expenditure items with specific reference to the cost for running on-farm metering and control services. As a consequence, we used the subsequent methodology to assess the cost of M&C.

In order to estimate the cost of the M&C services for irrigation groundwater, we firstly estimated the annual provision cost of M&C service (K) made by the selected RIBs. We then related K to the

number of access points of the RIBs' irrigation water (i.e., delivery points), obtaining EUR/access point, and to the RIBs' cubic meters delivered annually, obtaining EUR/m<sup>3</sup>. Then we applied the results obtained for the RIBs (EUR/access point and EUR/m<sup>3</sup>) to the irrigation groundwater, considering the access points (the wells) and the annually delivered cubic meters of the provinces where the RIBs that were used to evaluate the operational cost of the metering and control service were located.

In order to estimate the M&C service cost, data were gathered through: (i) interviews with experts in resources management; (ii) accounting data of RIBs (2014 and 2015 results); and (iii) in-depth interviews with the director of each RIB. In this regard, at the beginning of 2015, the two directors were asked to complete an e-mail questionnaire in order to gather information regarding the formal and informal routines concerning the M&C services (The accounting data are available at the web page of two RIBs (<http://consorzio.fg.it/>; [www.bonificaugento.it/](http://www.bonificaugento.it/)) while the questionnaire is available on request to the authors). The directors provided details regarding the way they carry out services, how many divisions are involved and how many workers are employed, which job positions (e.g., permanent and temporary personnel), how many resources are consumed (e.g., electronic devices, cars, office furniture).

The most difficult item in assessing the M&C services was the joint cost allocation; for instance, the cost related to the offices and technological devices, and above all, the personnel.

In order to allocate the joint costs, we focused on the share of items involved in the M&C operations during a second interview with the director. The engineering method based on physical quantities and measurements such as the duration of the service was used to evaluate the proportion of each item (e.g., personnel, car fleet, devices). A recursive learning process was followed during the interview. The director was first asked to estimate some proportions, then, after having completed the cost estimates, he was asked to check the results against the accounting sheet (2014 and 2015 results). Accordingly, a few adjustments were made.

### 2.3. The Capitanata (CBC) and Ugento Li Foggi (CBU) Case Studies

As reported in Table 3, the irrigable area of CBC is much greater than CBU. This has implications for the size of the irrigation supply structures of CBC and CBU. On average, within the CBC, each delivering point supplies 5 ha of irrigable area, while 1.6 ha within the CBU. Moreover, the distribution of delivering points is not the same between the two systems, with CBU showing a huge fragmentation of delivering systems and dispersion of delivering points. In both cases, one delivery point can serve more than one user. At the same time, one user may use more than one delivery point. In the case of CBC, the number of users is almost double the number of delivery points, meaning that the same delivery point serves several users.

**Table 3.** Main characteristics of CBC and CBU irrigation supply structures (mean 2011–2014).

Irrigation and Reclamation Board	Delivery Points (Number)	Active Users (Number)	Irrigable Area (ha)	Irrigated Area (ha)	Delivered Volume (m <sup>3</sup> /Year)
CBC	27,936	55,919	147,131	146,000	116,778,121
CBU	6554	1204	10,786	1000	1,289,084

Source: our analysis, considering ISTAT (Central Institute of Statistics) [6] data.

From 2011 to 2014, CBC delivered 2000 m<sup>3</sup> per user, while CBU delivered almost 1000 m<sup>3</sup> per user. The difference in irrigation volume reflects the crop pattern of the respective provinces and its irrigation requirements (Table 1).

### 3. Results

#### 3.1. The Organization of the M&C Service within the Two Consortia

The interview with the director of CBC revealed that M&C is concentrated during the irrigation season, which starts in April and ends in November. M&C is simultaneously performed with other operations (e.g., maintenance of water-delivery points), therefore the CBC does not rely on a division devoted to M&C.

The CBC is divided into three hydraulic districts, and each one is under the responsibility of a district manager. Every district includes about four operating centers (OCs), each of which is located in a different office (the OC office), and relies on one technical manager, an office assistant and six workers. The CBC has 13 OCs and 14 OC offices (one of the 13 OCs has two offices). The OC is responsible for irrigation services (i.e., all of the operations including M&C), and each one covers an area of about 12,500 hectares, with about 2500 delivery points.

Each CBC delivery point of is equipped with mechanical meters. Only a very small percentage of CBC delivery points are equipped with electronic devices (AcquaCard) to meter the water withdrawn [26]. However, the delivering points that have an AcquaCard system are also equipped with mechanical meters.

There are four levels of tasks throughout the annual M&C process. At the beginning of the irrigation season (in April) the on-site inspection starts within each OC. All the farms with CBC delivering points sources are checked. The aim is to check how the delivery points and metering devices are actually performing. During the irrigation season, the water volume is also recorded. This is a comprehensive on-site inspection that takes place three times a year. The inspection is carried out by a team of two people who use a car to move around. A report of each inspection is made, and the office assistants fill in an electronic datasheet.

M&C is also carried out on-desk by the technical manager of each OC and his/her assistant, assisted by three employees from the data-processing center. The records of each user are checked against the theoretical irrigation requirement of each crop. However, the historical consumption is used as the reference in order to check for any unusual observation. Only for the few delivering points that have an AcquaCard system are the data obtained during the ordinary inspections also compared with the AcquaCard data. If the comparison between the theoretical consumption (or AcquaCard data) and the consumption detected during the ordinary inspections produces a deviation greater than 5%, another inspection is carried out to discover the reason for the deviation.

This additional inspection is to verify the compliance with the CBC rules and, when necessary, sanctioning is applied. Penalties depend on the specific rule violated, how long it has been going on etc.

Overall, 90 employees are involved in the M&C operations (Table 4) using 65 cars and 14 offices.

**Table 4.** Allocation shares for the CBC joint costs.

Item	Detail	Number	Share of Items Involved in M&C
<i>Personnel</i>	District manager	3	30%
	Personnel operating at operating centers (OCs)	28	50%
	District manager	3	30%
	Employees partially assigned to M&C	52	30%
	Employees fully assigned to M&C	4	100%
<i>Car fleet</i>	Depreciation, fuel, insurance, maintenance, tax	65	40%
<i>OC offices and equipment</i>	Maintenance of consumable goods and furniture	14	20% <sup>1</sup>

Note: <sup>1</sup> 20% of the sum of the personnel and car fleet. Source: our analysis from direct surveys.

The most difficult item in assessing the M&C services of the CBC has been the joint cost allocation, for instance the cost related to the car fleet which is jointly used for ordinary inspections as well as for

any other activities where transport is needed. In fact, the car fleet is not fully at the expense of the M&C operations. This also applies to the offices and technological devices, and above all, the personnel assigned to each operational center. Table 4 reports the allocation share for joint costs.

Depending on their particular role regarding the M&C service, the percentage of work hours dedicated to M&C varies from 30% to 50%, except for four employees assigned exclusively to M&C. Regarding the cars used to carry out the M&C field operations, the percentage use of CBC vehicles is about 40% for M&C operations in terms of depreciation, fuel, insurance, maintenance, tax. The CBC offices are only partially utilized for M&C and the costs are related to consumable goods (i.e., electronic devices) and furniture maintenance. On the basis of the RIB accounting sheets and the information obtained from the interviews with the RIB directors, we obtained the percentage of OC office use related to M&C by calculating 20% of the other M&C service costs related to the personnel and to the car fleet. Considering Equation (1), the sum of the items personnel and car fleet relate to the items W, S, Q, T and the part of M regarding the use of the car fleet.

The director of the CBU was also asked to complete the same email questionnaire as the CBC Director in order to gather as much information as possible on the formal and informal routines concerning the M&C services.

The CBU is divided into 32 hydraulic districts, with a single operating center (OC) for all the 32 districts. In the OC, the working unit consists of two technical managers, one technician and 18 workers. All of the 6554 delivering points are equipped with mechanical meters, while 80% points also use the AcquaCard system.

The CBU irrigation season normally lasts from 15 April to 30 September. As a whole, M&C follows the same procedures as the CBC. At the beginning of the irrigation season, the ordinary inspections are performed. A total of 18 workers (working in groups of two) carry out the ordinary inspections. Each delivery point is inspected once a month. A report is drafted at the office, an electronic datasheet is filled in.

In the office, as with the CBC, the records of each user are checked against the theoretical irrigation requirement of each crop. If the comparison between the theoretical and the actual consumption detected during the ordinary inspections produces a deviation greater than 20%, then the CBU organizes additional inspections. The tolerance limit is greater than the CBC, due to the lower hydraulic efficiency.

The aim of this additional inspection is to verify compliance with CBU rules and, when necessary, sanctioning is applied. The maximum penalty is EUR 4000, which equals the water cost for the maximum possible consumption.

With regard to joint costs, unlike CBC, the yearly cost of the hired personnel and the car fleet are reported in the CBU accounting sheet. On the other hand, the permanent staff, office services and device costs are jointly shared with other services. Thus, Table 5 reports the allocation share for the joint costs.

**Table 5.** CBU allocation shares for the joint costs.

Items	Details	Number	Share of Items Involved in M&C
<i>Personnel</i>	Technical manager	2	25%
	Technician	1	5%
	Workers	18	70%
<i>Car fleet</i>	Depreciation, fuel, insurance, maintenance, tax	0	0
<i>OC's offices and equipment</i>	Maintenance of consumable goods and furniture	1	15% <sup>2</sup>

Note: <sup>2</sup> 15% of the sum of the items Personnel and Car fleet. Source: our analysis from direct surveys.

Unlike the CBC, for the CBU, the percentage of work hours dedicated to M&C varies a lot (from 5% to 70%). The workers are those most involved in the M&C operations. The CBU does not have a

car fleet. In fact, CBU workers use their own vehicles during the on-field operations, and thus receive a contribution for the expenses as reported in Table 6 (depreciation, fuel, insurance, maintenance, tax). The costs connected to the use of the OC offices are related to consumable goods (i.e., electronic devices) and maintenance of furniture. In the case of CBU, because there is only one OC office, the office use accounts for 15% of the other M&C service costs, related to the personnel and car fleet. Also for CBU, the sum of the items, personnel and car fleet consider the items W, S, Q, T and the part of M regarding the car fleet use in the Equation (1). As a whole, the two RIBs exhibit a very similar operational routine for the M&C operations, while the main differences relate to the categories of employees assigned to each M&C operation and the car fleet.

### 3.2. The Cost of Monitoring and Control Services

On the basis of the data gathered and following the methodology framework proposed, the cost of M&C was estimated. Table 6 shows the results of the M&C cost evaluation for CBC and CBU, taking into account each single element of the Equation (1).

**Table 6.** M&C annual costs (in euros) for CBC and CBU.

RIBs	Wages	Salaries	Quotas	Taxes	Miscellaneous Expenses <sup>1</sup>		Interest	K (M&C Cost)
					M <sub>o</sub>	M <sub>cf</sub>		
CBC (EUR)	511,546	573,650	92,481	4252	270,348	169,819	39,468	1,661,155
% of K	30.8	34.5	5.5	0.2	16.2	10.3	2.5	100
CBU (EUR)	15,004	200,698	0	0	32,335	0	4587	252,644
% of K	6	79.4	0	0	12.8	0	1.8	100

Note: <sup>1</sup> M<sub>o</sub> is the part of Miscellaneous expenses related to the OC offices and equipment. M<sub>cf</sub> is the part of the miscellaneous expenses related to the car fleet. Source: our analysis on the basis of accounting data (2014 and 2015 results).

The results in Table 6 show that there are many differences between CBC and CBU. For example, the cost of the employees is about 85% of the entire M&C service cost for CBU, while it is about 65% for CBC. The reason for this difference is that CBU does not have a car fleet and the expenses related to the car fleet use are included in the cost for the employees. For the same reason CBU has no expenses for Quotas, Taxes, and Miscellaneous expenses related to the car fleet. In addition, considering the costs related to the employees, the wages of CBU are much lower than CBC. This is because CBU has only one office (as opposed to the 14 CBC offices). The fact that CBC has more offices than CBU makes the miscellaneous expenses related to the OC's office and equipment for the CBC higher than for CBU. As Table 6 reports, it is worth mentioning that labour (i.e., wages and salaries) represents the main cost for both RIBs. Certainly, new technologies based on remote sensing and data analyses may be introduced to perform a similar task. However, this implies an increase in terms of cost for the acquisition and continuous upgrading of the technology, and a higher cost for the analysis of data. These infrastructural investments might be economically sustainable in case of large-scale application, which is feasible in the case of homogenous areas.

The total annual cost of the M&C service of CBC is higher than CBU, because of their different sizes in terms of the irrigation supply structure.

The M&C annual operational costs (K) of each RIB are reported per irrigable area, per delivered cubic meter and per access point (Table 7).

The data regarding the percentage cost of the M&C service on the total amount of ordinary annual balance sheet shows similar magnitude between the two RIBs, and are in line with the data of [27], which found a figure of 8%. The CBU M&C service has a greater incidence on the total balance of the RIB. Except for the delivery points, CBU's items are consistently higher than those of CBC. Differences are because of the fragmentation and size of the CBU's irrigation infrastructure. While CBC has a high number of delivery points, with five times the number of users, the ratio between delivery points and users in the case of CBC is 0.5.

**Table 7.** Results of the evaluation of the annual cost of the M&C service.

RIBs	M&C Annual Costs (EUR)	Cost Per Irrigable Area (EUR/ha)	Cost Per Cubic Meter Delivered (EUR/m <sup>3</sup> )	Cost Per Delivery Point (EUR/Access Point)	M&C Costs Over Total Balance Sheet
CBC	1,661,155	11.29	0.014	59	7%
CBU	252,644	23.42	0.19	38.5	10%

Source: our analysis on the basis of accounting data (2014 and 2015 results).

### 3.3. The Cost of Groundwater Metering and Control Service in Apulia

Taking the cost per delivery point as reported in Table 7 and the data in Table 2 regarding the groundwater licenses issued in the two provinces, the cost of the groundwater metering and control service is estimated: Foggia 2,117,392 euros, Lecce 1,328,301 euros. On the other hand, on the basis of the groundwater withdrawals for the Province of Foggia, the cost is 1,199,929 EUR, and 8,363,173 for Lecce.

We considered only the M&C service cost per access point because the M&C service for irrigation groundwater is less influenced by the number of cubic meters delivered, and much more influenced by the number of access points (the wells) that need to be ever inspected regardless the volume pumped. As Table 8 shows, the weighted average cost of M&C for irrigation groundwater per access point amounts to 49 euros.

**Table 8.** Total cost of M&C for the Provinces of Foggia and Lecce.

Irrigation Groundwater Access Points (Number)	Cost Per Access Point (EUR/Access Point)	Total Cost of M&C (EUR)
Foggia	35,888	59
Lecce	34,059	38.5
Weighted average	-	49
Total	69,947	-
		3,428,663.5

Source: our elaboration.

## 4. Concluding Remarks

The figures calculated in this research prove that the cost for M&C services incurred for the implementation of the pricing scheme for groundwater are high. In fact, despite the best assumption of operating in the most favourable conditions (i.e., the system and the organization are already running at full regime; the personnel hold the experience and the skills; there is full collaboration between farmers and institutions, the effect of information asymmetry is negligible), the cost ranges from 38.5 to 59 euros per delivery point. According to the findings of the two case studies, and considering the composition of the cost structure, which is mainly affected by wages and salaries, it is worth mentioning that some cost reduction may be pursued by introducing, for instance, remote sensing tools for on-time real metering of irrigation water [28]. However, despite the fact that these technologies may improve the quality of M&C operations (i.e., the accuracy and promptness of data recording) they may not be effective in terms of cutting the actual operational cost. In fact, the role of human control in rural areas, where the risk of robbery and tampering of high-tech devices may reduce their effectiveness, should not be neglected.

It is very likely that the real cost for the full implementation of direct water pricing will be higher, due to the initial investment needed to start the M&C services and the inefficiency that will arise for the time needed between acquiring experience and optimizing all operations. In other words, the overall transaction cost, of which metering and control is a sizable share, is very high. In this regard, the Sustainable Groundwater Management Act [29] enacted by the California state government has drawn attention to locally managed aquifers, also with the aim of reducing the transaction cost of policy implementation.

The implementation of the WFD to Mediterranean countries is particularly problematic due to the fact that a large amount of the irrigation water is represented by groundwater. Thus, an effective M&C service operated by the local authorities is a prerequisite for the adoption of a volumetric pricing scheme, without which the beneficiary-pays principle will not be pursued while unlicensed users will not be detected and stopped.

Despite the common acknowledgement that volumetric pricing should be applied to all water sources, there is still a lack of awareness regarding the high cost for the M&C of private wells. The magnitude of the full cost depends on the number of points to be controlled which, in the case of groundwater refer to all existing wells, both those that are authorized and those that are not. Today, in Apulia, it is estimated that there are many more wells in total than are effectively authorized, of which there are about 120,000. The question here is whether the cost for M&C should be fully recovered and paid for by farmers (at least those authorized), or should be considered as part of the programme of measures to meet the WFD goals and, therefore, also shared by the whole of society. Moreover, as the damage of groundwater over-exploitation is unevenly distributed across the irrigation areas, namely coastal areas where farmers will take greater advantage from sustainable groundwater use, the payment should also differentiate according to expected benefits.

While this research is the first attempt to account for the M&C cost of irrigation groundwater, the main challenge for the future is how to reduce the cost of M&C in agriculture.

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