Università
Ca'Foscari
Venezia

Corso di Dottorato di ricerca
in Scienza e Gestione dei Cambiamenti Climatici
ciclo XXXI

Tesi di Ricerca

Reforming water resource allocation: climate change adaptation in water management

GEO/04; SECS-S/03; SPS/09

Coordinatore del Dottorato
Prof. Carlo Carraro

Supervisore
Dr. Jaroslav Mysiak

Supervisori cotutela
Dr. Silvio Gualdi
Dr. Carlos Dionisio Pérez Blanco

Dottoranda
Silvia Santato
Matricola 956249

Reforming water resource allocation: climate change adaptation in water management

Silvia Santato

Venice, 2018

[... When you feel life coming down on you,
Like a heavy weight
When you feel this crazy society,
Adding to the strain
Take a stroll to the nearest waters
And remember your place
Many moons have risen and fallen long, long before you came ...

So follow, follow the Sun]

...

- Xavier Rudd -

...

To my beloved nephews, Nicolas and Tommaso

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BLRB	Brenta Land Reclamation Board
DSC	Drought Steering Committee
EU-WFD	European Water Framework Directive
FIA	Forested Infiltration Areas
LV	Large Volume
SM	Small Volume
MAR	Managed Aquifer Recharge
NCPD	National Civil Protection Department
PRBA	Po River Basin Authority
PRBD	Po River Basin District
TC	Transaction Costs
WAL	Water Abstraction Licence

EXECUTIVE SUMMARY

Italy has recently experienced a series of drought events which caused relevant economic impacts. Upward trend water demand projections, due to population growth and changing distributions of wealth, and downward trend water supply projections, due to climate change, suggest that the frequency and intensity of droughts and their socioeconomic impacts will aggravate in the future. This context has prompted a series of water governance and water resources management initiatives characterized by an emergency-driven approach.
The objective of the thesis is to analyse non-structural adaptation options in Italy that include economic, institutional and legal aspect of water allocation and sharing in Italy. The results will inform future policy water reform and offers adaptation insights for policy-makers involved in the management of the water resource. Based on the comparison between water abstraction licence databases collected from the regions comprised in the Po and review of the current legislative framework, the first part of the research **(Ch. 1)** reveals that the water abstraction licences system in place is widely fragmented to cope with drought management at river basin scale, therefore hampering bottom-up conflict resolution, such as the Drought Steering Committee. Although Italy is far from starting a discussion about a new water reform, the turn of drought events which affected the Northern part of the country started the Drought Steering Committee of the Po River Basin District, an informal institution which proven to be effective in managing water scarcity in the period 2003-2016. The second part of the research **(Ch. 1)** identifies, categorizes and analyses transaction costs and their influence on effective organisation and informal institutional management of scarce resources, showing a loose downward trend over the course of several recent drought events. When the framework on water management is not flexible to cope with drought conditions and informal institutions such as the DSC may not reach an agreement in time for limiting drought impacts, local solutions are required to manage challenges such as water scarcity at a catchment level. In Italy an effective and efficient management of aquifers move to the center stage of the contemporary policy debate. With the aim to provide useful insights for the improvement of management of underground water resources and local drought risk management in Italy, the third part **(Ch. 3)** describes the current stage of implementation of managed aquifer recharge in Italy and possible economic instruments for ground water management considering the case study of Forested Infiltration Areas in the Veneto region.

Keywords: water allocation; institutions; drought management; stakeholder engagement

INTRODUCTION

Water is becoming an increasingly scarce asset in several places worldwide (IPCC, 2014). Population growth and climate change are gradually exacerbating the competition over water resources. On a river basin scale, the upper catchment part is linked to the lower via hydrological processes. One of the fundamentals of water allocation is that any form of abstraction, transfer, or storage that influences the natural stream has effects on the entire downstream river system. In a hydrologic framework in which there are multiple uses or demands for water, water allocation determines who can use water resources, how, when and where (OECD, 2015).

Droughts challenge the water allocation of resources, causing the reduction of available water supplies and adverse effect to human activities and environmental systems. To tackle this problem, jurisdictions have been set worldwide. Historically, these mechanisms have been emergency-driven. However, the more frequent and severe droughts that are threating the good ecological status of the European water bodies (EC 2000) and short-circuit the performance of a wide array of sectors driving economic growth (EC 2012) is pushing the governments to shift to a more proactive approach, emphasizing drought preparedness and local involvement. Existing institutions may provide inflexible water governance arrangements that constrain ability to take corrective action. This has led international institutions to dub the current water crisis as a crisis of governance (OECD, 2015; World Bank, 2016). Now more than ever there is an urgent need to take stock of recent experiences, identify good practices and contribute to the policy-oriented debate for effective, fair and sustainable institutional management of water resources. Changes in the climate and of water demands is affecting the development and evolution of water allocation institutions which are progressively adapting to new conditions. For instance, countries are renewing and strengthening the regulatory and planning framework; improving the management capacity; stimulating the conservation and efficient use of water resources.

The European Climate Adaptation Strategy (EC 2013) has diagnosed that the risk posed to water security (OECD 2013) will make up the bulk of the expected climate change environmental and economic impacts. However, the mitigation of water scarcity and droughts is but the last among the aims declared in Article 1 of the Water Framework Directive (WFD), (EC 2000) and the least substantiated. The issues of water scarcity and droughts have been further addressed in the EC Communication on water scarcity and droughts (EC 2007) which has identified a more efficient water allocation among the seven European concerted actions. Efficient water use is also a cornerstone of the EU Resource Efficiency Flagship initiative, as a part of the Europe 2020 Strategy. The EU Water Policy Review (EC 2012, Strosser et al., 2012) has noted some progress, though as yet insufficient, in drought management in Europe, and in the application of economic principles (e.g., cost recovery and water pricing). It has encouraged, cautiously, the use of market mechanisms (e.g., the water right trading scheme) where this represents a value-added increase (EC 2012) Along with this process the European Parliament (EP) has recommended on several occasions a targeted European policy on water scarcity and droughts (EC 2011).

Along with the growing demand for water, the effects of the water supply crisis induced by climate change will become particularly pronounced in Southern Europe (OECD 2013; EC 2012) and especially in Italy (Ciscar et al., 2014). It is widely accepted that the most effective and efficient ways of adapting to amplified scarcity and droughts are a combination of economic instruments (e.g., insurance, and water pricing and trading) along with legislation and regulation in order to plan more successfully for scarcity and drought spells (EC 2012; OECD 2013; UN 2014).

Italy has been increasingly hit by droughts events in recent years. The states of emergency which have been declared since 2003 demonstrated that the water management system is not flexible enough to cope with climate variability. Indeed, the successful implementation of proactive water management instruments such as those listed above demands flexible, consistent and sustainable Water Abstraction License (WAL) regimes (Mysiak et al. 2013; Young 2011; OECD 2015).

The first part **(Ch. 1 –** paper published in the Journal "Water", co-authored with J. Mysiak and C. D. Pérez Blanco) reviewed the water allocation license regimes across the administrative regions comprising the Po River Basin District (PRBD), the largest and economically most important in Italy. PRBD's WAL regime includes a rigid and scattered WAL normative that hinders the performance of bottom-up conflict resolution mechanisms at a basin scale; a water pricing scheme that does not reflect the cost of water conveyance and use, and does not encourage efficient water allocation; and the lack of a central WAL register, which delays and in some cases impedes an environmental impact assessment for issuing new licenses or renewing existing ones, and does not allow prioritizing applications according to their full economic value. Such deficiencies in water management in Italy may compromise both the integrity of riverine and water dependent ecosystems and the economic uses of water.

When drought occurs, the negative supply-demand differential intensifies conflicts within different administrative units of management and economic sectors, which often have developed expectations for water availability based on previous periods of abundance, and have allocated resources accordingly (Hanna, 1995). Adverse conditions demonstrate the inherent limitations of the existing institutions and in the process of adapting to new supply-demand conditions, allocation and conflict resolution mechanisms have to be either created or strengthened. Such changes that affect the evolution of institutions are one of the key premises in institutional economics and can be measured with transaction costs. The second part **(Ch. 2 -** paper submitted to the Journal "Agricultural Water

Management", co-authored with A. Loch, C. D. Pérez Blanco and J. Mysiak) analysed transaction costs for the case study of the Drought Steering Committee in the and their influence on effective organisation and institutional management of scarce resources. During times of drought, formal institutions may provide inflexible and more costly management arrangements that may increase total transaction costs. Conversely, informal institutions may be less likely to deliver robust and enforceable water management and reallocation outcomes during stressful periods of low supply. We measure and track these transaction costs with respect to drought periods and identify a loose downward trend over the course of several recent drought events. Informal drought management planning is now enshrined in the Po River Basin District Plan, and that basin's Drought Steering Committee model has also been mandatorily adopted by the six other River Basin Districts in Italy. This informal institutional model represents potential alternative drought management arrangements beyond formal (less flexible) planning approaches and has important implications for the current management of drought events elsewhere in Europe.

The emergency driven response to droughts shows that the institutional and legislative national framework in Italy on water management is not flexible enough to cope with drought conditions and projected climate changes (Ch. 1). On the other hand, informal arrangements, which may provide a more flexible and less costly management of water resources, may not reach an agreement in time for limiting drought impacts (Ch.2). In both cases, a time delay for drought implementation measures could be expected, which may lead local impacts if water becomes scarce. Water managers are therefore in need of the ability to alleviate droughts threats and anticipate the possible impacts at local level. A possible way forward for adapting to future droughts is represented by *Managed Aquifer Recharge.*

Groundwater represents the Earth's largest freshwater resources and has been used extensively in modern times for irrigation, potable water, and industrial activity. In many areas around the world, groundwater reserves are depleting as the resource is exploited faster than renewed by rain infiltrating through the soil. Moreover, increasing global temperatures are affecting hydrologic cycle, changing precipitation patterns and increases in the intensity and frequency of extreme events; reduced snow cover and widespread melting of ice; rising sea levels; and changes in soil moisture, runoff and groundwater.

Annual precipitation, which is the primary source of groundwater recharge, has progressively declined in Italy and droughts became more frequent. Decision makers, water resource managers and water users have started to explore alternative measures for enhancing resilience to droughts and reliability of water supply for domestic, industrial, livestock watering and irrigation which include underground storage (Clifton et al.,2010; Taylor et al., 2013). *Managed Aquifer Recharge*

(MAR) involves building infrastructure and/or modifying landscapes to promote groundwater recharge. The Forested Infiltration Area (FIA) is a method to recharge groundwater aquifers by channelling surface waters during non-irrigation months into designated areas that have been planted with various species of trees and/or shrubs. The last part of the thesis considers local solutions for drought management at a catchment level and indicates some possible potentialities and limitations of economic instruments for the management of groundwater considering the case study of FIA in Italy (**Ch. 3** – draft paper co-authored with C. D. Pérez Blanco and J. Mysiak). The results are a comprehensive framework about groundwater management and recharge in Italy, including possible policy-oriented insights that support the MAR process and in particular on the FIA technique.

As a part of my research I have also contributed to another article, already published in the Journal of Environmental Management (Marzi et al., 2018), which contributed to the Italian National Climate Adaptation Plan (MATTM, 2017) with an innovative approach to analyze adaptive capacity. For this work, a large body of knowledge addressing economic, social, and institutional ability was collected to induce and promote climate adaptation. Two out of 21 indicators considered for the analysis are related to water resources. The article explores the adaptive capacity at various administrative levels (NUTS2 and NUTS3), and factors-in the variability at a lower administrative level in the assessment of the next higher levels using a robust methodological framework which encompasses advanced statistical and fuzzy-set techniques. The results employed as an input for the construction of a climate risk index (Mysiak et al., 2018) which is one of the fundaments of the Italian Climate Adaptation Plan.

During the Phd I am one of the authors that contributed to the chapter on water resources of the National Climate Adaptation Plan (MATTM, 2017).

THE WATER ABSTRACTION LICENSE REGIME IN ITALY: A CASE FOR REFORM?

Introduction

Water scarcity, along with more frequent and severe droughts, are threats that may undo the efforts to achieve the good ecological status of the European water bodies [1], and short-circuit the performance of a wide array of sectors driving economic growth [2]. The financial crisis of the past decade has revealed a high exposure of the EU to economic shocks, including that of extreme weather and climate-related hazards, exacerbated by fiscal and "other macro-economic imbalances" [3]. The European Climate Adaptation Strategy [4] has diagnosed that the risk posed to water security [5] will make up the bulk of the expected climate change environmental and economic impacts. However, the mitigation of water scarcity and droughts is but the last among the aims declared in Article 1 of the Water Framework Directive (WFD) [1], and the least substantiated. The issues of water scarcity and droughts have been further addressed in the EC Communication on water scarcity and droughts [6], which has identified a more efficient water allocation among the seven European concerted actions. Efficient water use is also a cornerstone of the EU Resource Efficiency Flagship initiative, as a part of the Europe 2020 Strategy. The EU Water Policy Review [2,7] has noted some progress, though as yet insufficient, in drought management in Europe, and in the application of economic principles (e.g., cost recovery and water pricing). It has encouraged, cautiously, the use of market mechanisms (e.g., the water right trading scheme) where this represents a value-added increase [2]. Along with this process, the European Parliament (EP) has recommended on several occasions a targeted European policy on water scarcity and droughts [8].

There is reason to believe that, along with the growing demand for water, the effects of the water supply crisis induced by climate change will become particularly pronounced in Southern Europe [5,9,10], and especially in Italy [11]. It is widely accepted that the most effective and efficient ways of *adapting* to amplified scarcity and droughts are a combination of economic instruments (e.g., insurance, and water pricing and trading) along with legislation and regulation in order to plan more successfully for scarcity and drought spells [2,5,12]. The successful implementation of proactive water management instruments such as those listed above demands flexible, consistent and sustainable Water Abstraction License (WAL) regimes [13–17]. Some EU Member States, most notably Spain and UK, have already started a reform of WAL regimes to address this need.

Water abstraction permits in England and Wales were regulated by the Water Act of 1963 [18].

The permits took into little or no consideration what level of abstraction the water body could actually supply, and the allocation system has since proved to be unsustainable. Current abstraction levels are causing significant ecological problems in over 1000 river water bodies [19] and 42% of groundwater bodies are failing [20]. The Water Resources Act of 1991 delegated the task of issuing abstraction licenses to the Environment Agency [21]. The payment of a fixed fee proceeds with the application whose amount is stated in the Abstraction Charges Scheme collected by the Environment Agency (EA). There are three types of licenses: a full license (>20 m^3/day); a temporary license (<20 m^3/day over a period of less than 28 days); and a transfer license (trading of full licenses). Only full licenses are charged the fixed fee by the Environment Agency (as of 2015, the minimum annual charge for full licenses is £25.00) [22]. All new abstraction licenses granted after April 2004 are required to include a time limit of typically 12 years. Temporary and permanent water trading for the whole or part of the WAL are possible but typically require the parties involved to apply to the Environment Agency for a new license and to change or cancel (revoke) any existing license. The current WAL regime has proved inadequate in coping with growing challenges. A reform has been recommended in the Cave Report [23] and supported by the analysis of the Water Service Regulation Authority (OFWAT) and the EA. The reform, announced in the Natural Environment White Paper [24] and further substantiated in the Department for Environment Food & Rural Affairs (DEFRA) [25,26], introduces a transition to a new regime by the 2020s. The scope of the reform is to install flexible and sustainable tradable licensing regime capable to respond to current and future challenges.

In Spain, water has been managed within hydrological units ever since the River Basin District Authorities (RBDAs) were instituted back in 1926. The water license holders are granted the right to abstract and use water of specified volumes and for specific purposes. Water is public, and only a fraction of groundwater resources is privately owned [27]. WALs are awarded, supervised and managed by RBDAs, which can limit abstractions either temporarily or permanently, e.g., to meet environmental regulations. Water charges are exerted through a regulation fee (in Spanish: *canon de regulación*, charges for the abstraction and storage costs of surface water), a water use tariff (in Spanish: *tarifa de utilización de agua*, charges for the transportation costs of surface water), sanitation and treatment tariffs, and additional contributions raised by water user boards (e.g., irrigation communities) [27,28]. The 1999 reform of the Water Law allowed for trading of water entitlements [28]. Successive reforms have designated a more flexible WAL regime that is able to channel water abstractions towards economically more efficient uses [27–29]. The RBDA may not authorize the trading deal in the case of conflicts with pre-existing uses, although the rule of positive administrative silence applies [30].

In Italy, the WAL regime is tortuous and substandard, reflecting a Byzantine interplay of water institutions [31]. An abstraction license is required under the Royal Decree (R.D.) n˝ 1775 of 1933 [32] for the abstraction of surface waters (such as from rivers, streams and canals) and groundwater. Since then the regime has evolved through a process of political decentralization and devolution of environmental protection [33]. As a result, the regional administrations (hereafter Regions) have gained full jurisdiction over WAL matters. The transposition of the EU WFD in Italy has prompted a number of legislative and institutional reforms, in which include the 2006 Environmental Code (EnC, in Italian: *Testo Unico Ambiente,* Legislative Decree 152/2006) [34].

According to the EnC, license holders are entitled to abstract a specified quantity of water from a particular source and for a specific purpose. The license award is conditional to conformity with minimum environmental flows. If the latter are not guaranteed, the regulator may impose revision or revocation of WAL. Temporary limitations may be enacted during prolonged periods of droughts. WAL holders are obliged to pay Water Concession Fees (WCF), a part of which, according to a recent regulation, is earmarked for implementing measures to improve and maintain a proper ecological status of water bodies [34]. The licenses are specified in *absolute* terms and are not transferable. Moreover, the temporal horizons for which the licenses are issued do not take into account the changing availability of water resources in the medium and long-term, as a result of climate change. Nor do they consider changes in the demand for water driven by population growth and economic development. Since human-induced climate change will likely result in a lower average annual water availability and a greater intra- and inter-annual variability [35], the *National Climate Adaptation Strategy* for the Po River Basin District (PRBD) has suggested revising the WAL regimes [36]. From our analysis of the PRBD case study, we propose recommendations on priorities for a national water abstraction reform, in line with international best practices on water abstraction reform [37–39].

Water Management in the Po River Basin District

The PRBD is the largest single river basin in Italy, spreading over 71,000 km^2 (24% of the state territory) and is home to a growing human population of more than 17 million (+6% since 2001, and expected to increase up to 18–21 million by 2050), most of whom live in small towns and cities with fewer than 25,000 inhabitants. The PRBD extends over several regions: Valle d'Aosta, Piedmont, Lombardy (all three almost entirely included in the basin), Emilia Romagna (about half of whose area is included in the basin), Veneto, Liguria and Tuscany (marginally included in the basin area). The Autonomous province of Trento is also partly covered by the PRBD. The river basin district hosts a dynamic economy that generates around 35% of Italy's GDP, fuelled by some of the most vibrant industrial hubs in the proximity of the large urban centers of Milan, Turin, Brescia, Modena, Parma, Reggio nell'Emilia, Ferrara, Monza, Bergamo, Novara and Piacenza. The PRBD also offers services of strategic importance, including about 1200 hydroelectric power stations representing 41% of Italy's hydropower installed capacity, and 1180 thermo-electrical plants that produce around half of the country's thermoelectric energy. The PRBD also includes Italy's largest contiguous agricultural land area, nearly 21% of its total agricultural area, 21.5% of its utilized agricultural area, and almost 30% of its agricultural value added [17]. Total water abstractions (consumptive uses) from the Po river account for more than 20.5 billion m^3per annum (Table 1.1) most part of which (16.5 billion m^3) is used in the agricultural sector, 2.5 billion m^3 for drinking water and 1.5 billion m^3 for industrial uses. Abstractions account for 14.5 billion m^3 for surface waters and for 6 billion m^3 for groundwater [40].

Table 0.1. Annual average water uses by sources. Legend (*energy production excluded) [41].

Uses	Volume (10^6 m^3/year)	Surface Water (%)	Groundwater (%)
Potable	2500	20	80
Industrial*	1537	20	80
Irrigation	16,500	83	17
Total	20,537	63	37

Water use in the PRBD has increased over the last decades, and the volume of authorized WAL exceeds average water availability [42]. The problems become more pronounced during the irregular periods of drought spells. During the spring and the summer of 2003, a severe, persistent drought afflicted Southern Europe, including the PRBD. The Po River reached its absolute minimum at the closing section in Pontelagoscuro: - 6.99 m or 270 m^3/s compared to an average of 1400 m^3/s. In 2006 and 2007, Northern Italy experienced another anomaly in terms of precipitation, and in 2007 river discharges were lower than in 2003. Since 2003, a State of (national) Emergency (SoE) under the law 224/1992 has been declared three times (2003, 2006, and 2007) for a total duration of 21 months [43].

Water restrictions during droughts respect the priorities specified in the EnC [34], e.g., first the household water demand is satisfied, then the irrigation demand and lastly any other miscellaneous uses. The maintenance of minimum environmental flows was imposed in the late 1980s and later included in the EnC [34]. If shortages worsen to a SoE, the central government appoints a Commissioner Delegate with full powers to manage water bodies. With the aim of limiting welfare losses, the Commissioner Delegate may issue extraordinary water allocation rules that do not necessarily follow the EnC [34] protocol. The contemporary regulatory framework encourages voluntary agreements among users before the SoE is activated [34]. These agreements are managed in the context of the Drought Steering Committee (DSC).

The DSC was initiated and presided over by the Po River Basin Authority (PRBA) in May 2003, amidst a severe water crisis posing a threat to urban water supplies in the lower part of the district, and to irrigation throughout the whole district. The cooperative decision of the DSC was sanctioned by signing a Memorandum of Interest (MoI, in Italian: *Protocollo d'Intesa*), which stipulated the commitments of irrigators to reduce water withdrawal by 25% to 50%, and hydropower operators to release more water from Alpine reservoirs and large regulated lakes. Moreover, the DSC sanctioned a close monitoring of evolving drought conditions. Since 2003, the DSC has been convened whenever persistent drought conditions have threatened to strain Italy's most important economic regions. The DSC also played an important advisory role during the SoE in the 2007 drought, institutionalized through the decree of the Commissioner Delegate for the management of the SoE [44].

Notwithstanding the increased frequency and intensity of droughts and the improved drought knowledge and response in the PRBD, these events are still predominantly managed by resorting to emergency instruments [45]. Proactive drought management instruments being used elsewhere, such as (incremental) water pricing [46], temporary trading of water rights [15,39,47], drought insurance [48] or even drought management plans [49], rely on flexible, consistent and sustainable WAL regimes that are currently non-existent in Italy. A WAL reform is imperative to define the main framework for planning and programming activities with a long-term water security perspective whose aim is to move away from an emergency approach to drought to a proactive and ongoing one.

Water Abstraction Normative Regimes across the PRBD

In 1933, R.D. 1775/1933 [32] established that nobody, not even a landowner, could withdraw water from natural water bodies without an authorized license. The only exception was water withdrawal for domestic use by landowners or tenants. Domestic use comprises water supply and sanitation, watering of gardens and orchards, and/or water used for livestock. This use is exempt from the obligation to declare withdrawal and hence payment of water concession fees. In both quantitative and qualitative terms, the impact of this exception is marginal. Under the current regimes the abstractions that are exempt from permits and fees are subject to limits that vary across the PRBD regions. In Piedmont, the flow rate must not exceed 2 L/s and 5000 m^3/year, while in Lombardy it is limited to 1 L/s and 1500 m^3/year. Veneto allows water withdrawal for domestic use in areas not served by aqueducts and limited to 0.1 L/s. In Emilia–Romagna and Valle d'Aosta, withdrawal limits are not specified.

An *informal* though widespread exception was made for groundwater use, which remained to a large extent outside of the WAL regime until 1994, when groundwater abstractions were converted to formal WALs after Galli Law 36/1994 [50], replaced in turn by the EnC in 2006. [34]. The GL [50] and the EnC [34] also oblige WAL owners to declare their existence and characteristics in order to make an overall census possible, although this objective has so far failed to be fully attained in the PRBD (see Section 5).

The R.D. 1775/1933 [32] distinguished between Small Volume (SV) and Large Volume (LV) WALs (Table 1.2). For SV permits, R.D. 1775/1933 [32] entrusted WAL management to the Public Works Offices (PWO, in Italian: *Ufficio Regionale del Genio Civile,* is a regional peripheral authority on a provincial basis, which ensures all the functions relating to the execution of public works, while the LVs were controlled by the government. With Legislative Decree (in Italian: *Decreto Legislativo,* D.Lgs.) 112/1998, the WAL authorities were transferred to the regional governments. Where not otherwise specified, the provisions of the R.D. 1775/1933 [32] still apply.

Table 0.2 WAL differentiation by type of use (source: [32]).

Uses	Small Volume Abstractions	Large Volume Abstractions
Hydropower [HP] generation	<3000 kW of installed capacity	>3000 kW of installed capacity
Irrigation	<1000 L/s or < 500 ha	>1000 L/s or >500 ha
Others	<100 L/s	>100 L/s

The five regions comprised regions included either entirely or substantially within the PRBD, have introduced to some extent different WAL regimes. Piedmont, Emilia-Romagna and Lombardy have adopted regulations or regional legislations throughout the period 2000–2006: first Emilia Romagna (Regional Regulation 41/2001; a Regional regulation, R.r., is not a law or primary source, but a secondary source that implements and integrates a law) [51], followed by Piedmont (R.r. 10R/2003) [52] and Lombardy (R.r. 02/2006) [53]. Valle d'Aosta, a region enjoying high administrative autonomy, applies a law which dates back to the 1950s (Regional Law 04/1956; in Italian: *Legge regionale*, L.r.) [54]. Veneto governs the WAL through sporadically updated regulations [55]. In the PRBD, regions issue licenses for LV abstractions and specify water concession fees for all types of uses. The regional authorities also have the faculty to enforce additional limits and obligations which the permit holders have to comply with, for safeguarding environmental integrity and quality and for contributing to the objectives of the regional Water Protection Plans (WPP, in Italian: *Piano di tutela delle acque*), which are revised every 6 years. On the other hand, WAL for SV abstractions are issued by lower administrative authorities, which are also in charge of making preliminary assessments of the compatibility of new and existing entitlements (both SV and LV). In Piedmont and Lombardy, the two latter roles are assumed by provincial authorities; in Veneto, by the PWO; and in Emilia-Romagna by Technical River Basin Services (TRBS), entities in charge of water management related issues and existing only in this region [56]. In Valle d'Aosta, given its small extent, the regional public water management office is responsible for both SV and LV abstraction licenses.

The administrative procedures for the concession of SV and LV WAL are rather similar across the PRBD regions (Figure 1). Permits are issued upon a satisfactory preliminary impact assessment. Preliminary assessments include the publication of the water concession application in the official regional bulletin (in Italian: *Bollettino Ufficiale Regionale*, BUR), an inspection (*conferenza dei servizi*) and, finally, the treatment of contingent oppositions and/or competing requests. Applicants are charged a fixed fee for the preliminary assessment, as opposed to the variable water abstraction fee detailed in Section 4. Preliminary assessments may also include the opinion of the PRBA, which unlike the regionally implemented Environmental Impact Assessments (EIA), is not binding. The EIA is based on the water concession flow rate and considers the environmental impacts to protected natural areas, such as Special Protection Areas or Special Areas of Conservation (SACs). Only if the EIA is positive is the water concession application accepted [34].

The only formal WAL that does not follow the administrative process described above is the "draw permit" (in Italian: *attingimento*), a temporary license related to contingent situations that allows the owner to withdraw surface water by means of mobile pumps. A *draw license* is granted for one year and can be renewed a maximum of 5 times. It may be revoked at any time on the basis of public interest, and without compensation for the license owner. In Piedmont, "draw license" also exist for the upper phreatic level. Piedmont and Lombardy have specific withdrawal limits for "draw license" (60 L/s nd 40 L/s, respectively, and no more than 300,000 cubic metres per year each). Emilia-Romagna, Veneto and Valle d'Aosta refer to art.56 of R.D. 1775/1933 [32], which states that "draw licenses" are the responsibility of lower institutions (the Technical River Authority, the Public Works Office and the regional public water management office, respectively) as long as: (i) the water withdrawn is less than 100 L/s; (ii) damage to the river bank is avoided; and (iii) there is no modification of river conditions or negative impact on environmental uses.

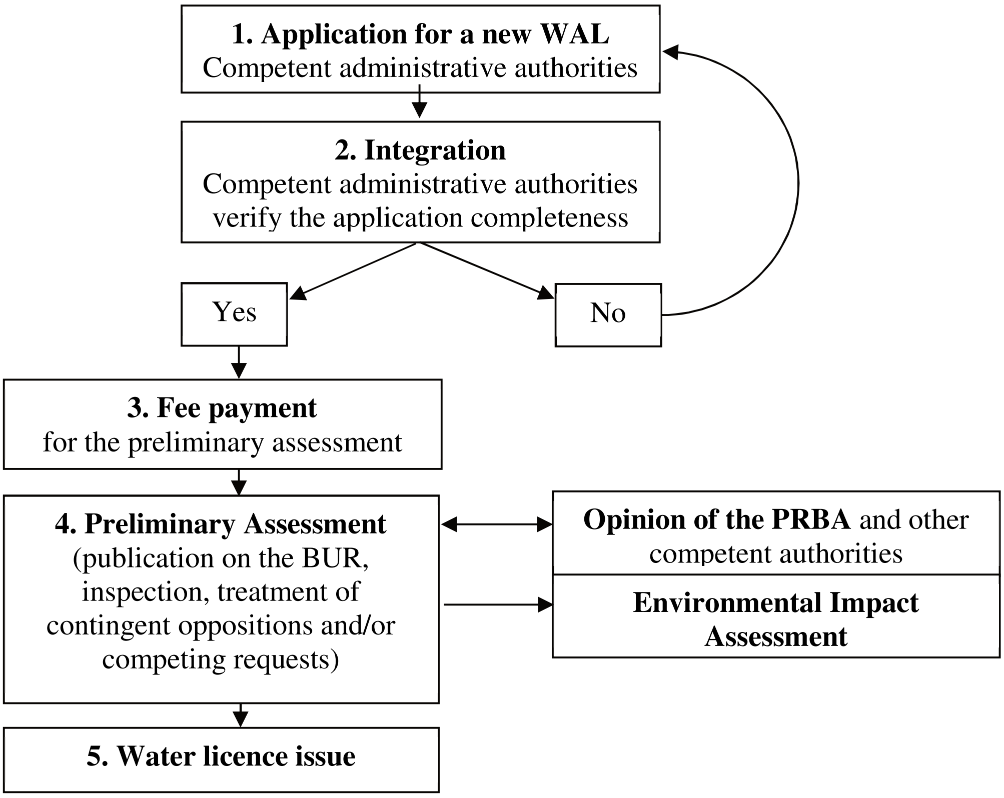


Figure 0.1 Administrative phases for LV and SV WAL across regions comprised in the PRBD. Source: *Own elaboration.*

The main water use categories are defined in the R.D. 1775/1933 [32] as civil, drinkable use; irrigation, energy production, industrial use; and health and sanitation use. The R.D. 1775/1933 [32] specifies a WAL duration of 40 years in the case of irrigation and 30 years for other uses, although regional laws may specify otherwise (Table 1.3).

Table 0.3 Terms of water uses for regions comprised regions included in the PRBD (source: own elaboration from [51–55]). Legend: * In the case of water rights allotted prior to 1956, Valle d'Aosta considers "no limitation" for Irrigation and Potable uses and 99 years for other uses.

Uses	Piedmont	Lombardy	Veneto	Emilia-Romagna	Valle d'Aosta *
Irrigation	40	40	40	40	40
Potable	30	30	30	30	30
Civil	30	30	30	30	30
Industrial	15	15	30	30	30
Fish Farming	30	40	30	40	30
Energy	30	30	30	40	30
Sanitation	30	30	30	40	30
Zootecnic	30	30	30	30	30
Others	30	30	30	30	30

The application for the WAL renewal must be submitted before the license expires, after the promulgation of a new regulation that specifies requiring renewal, or in case a substantial variation of water withdrawal is intended. Piedmont and Lombardy specify tighter time constraints for WAL renewal: Piedmont's regulation states that the renewal application has to be submitted at least one year before the license expires, while Lombardy accepts the application for renewal only if submitted no later than six months before the license expires. Otherwise, the WAL can be revoked in which case a new WAL procedure is necessary (Figure 1.1). In all regions, WAL renewal may be declined for reasons connected to public interest [51–55].

An existing WAL can be revoked as a result of the following omissions or negligence: (i) the (intended) water use differs from the one granted; (ii) the user does not respect the conditions and requirements associated with the license; (iii) failure to pay the abstraction charge for two consecutive years; (iv) end of term of the concession; (v) sub-licensing to third parties (e.g., trading); (vi) structural allocative inefficiencies that cannot be addressed through temporary or permanent limitations in the WAL; and (vii) an inadequate environmental flow (EF) [51–55]. It is worth noting that environmental standards for water flows in Italy focus on minimum environmental flows [34] instead of the ecological flows necessary to guarantee a "a hydrological regime consistent with achieving WFD environmental objectives in natural surface water bodies" [57]. The legislations of Piedmont and Lombardy also consider the following cases: (viii) no abstraction for three consecutive years; and (ix) a failure to install flow rate metering devices, mandatory for new WAL [34].

Different norms and procedures across the PRBD have created a fragmented WAL regime, managed by regions and numerous lower administrative authorities. This situation is aggravated by persistent bureaucratic tangles, poor coordination among regions and insufficient supervision. Besides lacking a unifying set of norms, the PRBD also lacks a coordinating entity with powers extending beyond the PRBA's advisory role. Differing water abstraction fees and the largely uncontrolled overall WAL census reflect this substandard regulatory context.

Water Concession Fees across the PRBD

Water in Italy is charged through water fees and tariffs. Water tariffs are charges imposed on water storage, treatment and/or supply, and contribute to financial cost recovery of these services [58]. Water tariffs include charges levied by *Land Reclamation and Irrigation Boards* (in Italian: *Consorzi di Bonifica e Irrigazione*, public institutions that control land reclamation and about 90% of water distribution in agriculture), and prices domestic users pay for water supply and sanitation services. Water Concession Fees (WCFs) are charges paid by WAL holders typically according to the volume of water withdrawal permitted. WCFs were established by art.35 of R.D. 1775/1933 [32] and at present are fixed and levied by the regions (Bassanini D. Lgs 112/98 [59]).

WCFs are detailed in Table 1.4 (prices are specified in harmonized units). WALs are typically specified in modules for all uses except for unmetered irrigation abstractions, where licenses are issued per ha, and hydropower, where licenses are issued per Kw. For all other uses, modules include the right to withdraw 100 L/s, except for industrial uses, where modules include a flow of 3 L/s in all regions but Lombardy (again 100 L/s) and Piedmont (1 L/s).

Where water is abstracted for different uses by the same WAL holder and the volumes abstracted cannot be split to account for different uses, the WCF corresponds to the water use for which the highest fee is due. If metering is available, the WCF is proportional to existing uses. In the particular case where a single water abstraction combines irrigation and hydroelectricity uses (a traditional practice in the PRBD known as *molinare*), the WCF corresponds to the use with the highest fee.

On top of the regular WCF, hydropower operators pay an additional fee to local authorities for grants and exploitation of public waters for producing electricity. There exist two supplementary fees: i) a Supplementary Fee for Riparian Authorities (in Italian: *Sovracanone Enti Rivieraschi*) is paid by plants with an installed capacity above 220 kW and amounts to 5.72 €/kW in case the capacity is below 3000 Kw, and 7.35 €/kW; otherwise, the revenues thus raised are divided among the regions, provinces and riverain municipalities on a predetermined basis. A Supplementary Fee for Mountain Basins (in Italian: *Sovracanone per bacini imbriferi Montani*) is collected by municipalities and paid by operators *located in mountainous areas* with an installed capacity greater than 220 kW, amounting to 22.88 €/kW in case the capacity is below 3000 Kw, and otherwise 30.40 €/kW.

The rationale behind the WCF is that of charging water users the costs stemming from the private use of a public good (art.35 of R.D. 1775/1933), making this instrument the apparent choice for the recovery of resource and environmental costs of water use [1]. Ministerial Decree 39/2015 developed guidelines for defining resource and environmental costs and identified WCFs as an adequate instrument for reducing (if water is *conserved*) or recovering them. Resource costs are defined as the best use foregone (e.g., opportunity cost); environmental costs are the expenses, interventions or commitments necessary to restore a good ecological status of water bodies or to limit or contain damage stemming from a specific use. Environmental and resource costs should account for both the quantity and quality of water and for seasonal variations [65]. In reality, though, there is insufficient data on the total revenues annually collected by regions through WCFs, and these are generally considered insufficient for the purpose of recovering environmental and opportunity costs [66]. This is aggravated by the WCFs actually declining charges, since the applied projected inflation rate used for updating WCFs falls far below the real inflation rate (initially introduced under the Galli Law 36/1994 [50], then replaced by each regional WAL). In addition, WCFs are calculated on the basis of the potential and not the actual volume of water withdrawn, a method that removes incentives for water saving/conservation. Metering is a prerequisite for any incentive charging policy [2] and its adoption has recently increased in the regions included in the PRBD in the wake of the EnC [34], which made it compulsory to install metering devices for new WALs [34]. However, the adoption of metering devices in agriculture is still insufficient for implementing volumetric charges that address region-wide or basin-wide quantitative challenges [67].

Table 0.4 Water abstraction fees (as in 2014) for the major water uses across the PRBD regions.Source: own elaboration from [60–64]. Legend: [1] abstraction with return; [2] abstraction > 3000 L/s; [3] large volume abstraction (>3000 kW); [4] small volume abstraction, installed capacity < 220 kW; [5] small volume abstraction, 220 kW < installed capacity < 3000 kW; [6] surface water; [7] groundwater.

	Unit	Lombardy	Piedmont	Emilia-Romagna	Veneto	Valle d'Aosta
Potable	€/L/s	22,51	22,22	20,43	43,06	20,49
Irrigation	Metered, €/L/s	0,53; 0,26[1]	0,53	0,48	1,01; 0,51[1]	0,48
	Unmetered, €/ha	0,53	1,16	0.44	0.919	0,45
Industrial	€/L/s	165,30; 333,22[2]	166,74	142,41	300,42	142,97; 71,49[1]
Hydropower	€/kW	15,35; 30,91[3]	28,24	13,93	29,38	18,54[4]; 22,66[5]; 25,76[3],
Civil	€/L/s	11,25	11,11	10,33	21,53	10,25
Fish Farming	€/L/s	3,75	3,74	3,41	3,76[6]; 7,18[7]	3,42
Sanitary	€/L/s	11,25	11,11	10,33	21,53	10,25
Zootecnic	€/L/s	11,25	56,72	10,33	21,53	10,25

There are also substantial equity issues related to WAL charging. WCF rates appear to be guided more by the user's ability to pay than by the activity's environmental and resource costs. For example, in Lombardy, where droughts are becoming an increasingly vital issue, industrial uses represent 5% of the WAL and 63% of the collected fees. WCFs also vary substantially across regions, a situation that cannot be explained solely by differing resource and environmental costs, but also by other economic and policy factors that affect equity among otherwise similar water uses across the basin.

The revenue raised through WCFs in the PRBD is not specifically addressed towards protecting and/or restoring vulnerable water ecosystems, –in contrast to existing regulations (article 119, comma 2-a of the EnC [34]). WCFs are typically incorporated the gross regional budgets instead of remaining a separate line item related to water management. An exception is the region of Piedmont, which allocates part of its WCF funds to specific (though mostly unrelated to water management) line items, namely, a fund for the economic support of mountain communities (30% of the revenues) and water monitoring (5%) in the context of the WPP.

WAL Census

Physical water balances (or budgets) are essential for a quantitative management of water resources [2,57]. Similarly, a census of abstraction licenses is critically important for understanding water demands within a river basin. Information on the number and characteristics of WALs in Italy is not publicly accessible. For our analysis we have collected disaggregated data from various regional and sub-regional authorities, except for Emilia-Romagna, for which we have only obtained data aggregated at the provincial level. The records are highly heterogeneous. We have reviewed and processed the data and compiled a database that is nearly equivalent to a census. It includes information concerning 70,000 abstraction licenses and contains detailed technical and administrative information on each of them. Table 1.5 summarizes water uses in the PRBD. The heterogeneous units of measurement were converted to m3/s to make them comparable.

The recorded characteristics typically include geographical coordinates of the withdrawal point, water source/body, type of permitted water use, status of license (active, expired or under review) and implied conditions, and time limit. The license is specified in absolute terms, either as average or (less frequently) maximum volume of flow that can be withdrawn. Piedmont, Lombardy and Valle d'Aosta specify both values. Where the maximum volume of flow that can be withdrawn is not specified, users have the opportunity to increase abstractions during drought events, precisely when it is a most valuable resource, and reduce its use during water abundant years so as to comply with average water use standards. Only some regions record return flows (Piedmont and Valle d'Aosta).

Withdrawal periods may be limited to irrigation seasons (April–September) but typically extend over the whole year. Some licenses, especially in the case of irrigation, do not define the abstraction volume. Therefore, our analysis is partly incomplete. As drought spells are becoming more frequent and intense, gaps in the WAL Census may become a critical issue [37]. In an effort to improve coordination among the different authorities in charge of managing WAL within the boundaries of the PRBD, the Piedmont region recently created an online WAL database called the *Water Resources Information System* (in Italian: *Servizio d'Informazione delle Risorse Idriche* (*SIRI*)) [73].

Table 0.5 WAL Census (source: own elaboration based on WAL data collected from regional authorities [68–72]).

Water Use	Nº of abstractions	Average water use		Maximum water use	
		% of abstractions with available info	m^3/s	%	m^3/s
Irrigation	21909	57.8%	1,653.6	17.2%	1,690.3
Potable	8180	75.5%	342.0	19.5%	79.0
Industrial	6864	76.7%	411.9	22.0%	49.5*
Fish-farming	706	75.2%	32.1	21.2%	10.6*
Energy	3430	85.4%	6,466.1	49.3%	7,531.5*
Sanitation	8639	82.6%	13.9	8.4%	3.6
Zootecnic	5798	83.4%	6.6	10.8%	113.9
Other uses	6773	56.2%	24.9	26.8%	22.1
Unspecified use	10190	0.3%	24.1	0.3%	34.9
Total	72489	59.8%	8,975.1	16.4%	9,535.4

Discussion and Conclusions

A more flexible WAL regime in Italy is to be recommended, on account of the observed and expected decline in water availability, amplified climate variability [36], population growth and economic development, and as a means of regulating minimum environmental flows. In this article we look at the case of the of the PRBD, the largest and economically most important river basin district in Italy. We assess the deficiencies of the current WAL regime and we argue these may compromise both the integrity of riverine and water dependent ecosystems and the economic uses of water. The lack of a central WAL register delays and in some cases impedes an environmental impact assessment for issuing new licenses or renewing existing ones and does not allow prioritizing applications according to their full economic value. It also does not allow taking the edge off the rising conflicts among the different water users during the times of temporary water shortages. The water pricing in place does not reflect the cost of water conveyance and use and does not encourage efficient water use. The regime is too rigid to permit formal or informal agreements among users, let alone the transfer (temporary or permanent) of existing permits. Finally, the current regime hinders the performance of bottom-up conflict resolution mechanisms such as the Drought Steering Committee. A reform should be inspired by international experience [13–16,74], while taking into account specific legal, institutional, economic and political conditions, in Italy in general and in the PRBD in particular. Based on our review we formulate the following recommendations that contribute to a greater water security in the district:

First, the WAL regime should specify the entitlements as shares of harvestable water resources and entitle shareholders to periodic allocations of water volumes that can be withdrawn for approved, site-specific purposes. Environmental outcomes should be managed by establishing minimum requirements in plans and perhaps by assigning shares to environmental trusts or their equivalents.

Second, transparency in governance and allocation arrangements should be granted by means of pre-established rules and procedures out stipulated in the river basin district plans. These rules should be reviewed periodically, say every ten years, and should clarify when, how and how much water will be allocated to each share-holder, and under what conditions unused allocations can be carried forward from one year to the next.

Third, the entitlements should check on the rate of return flow, so as to avoid harming the entitlements of downstream users.

Fourth, a single register of all water entitlements across the entire river basin district should be introduced and perhaps made publicly accessible.

Fifth, the river basin (district) authority should play a major role in controlling the environmental compatibility of the intended withdrawals, particularly for large volume abstractions. The WAL regime should respect the interconnection of and interaction between embedded ground/surface water systems, and between land (management) and the water cycle (run-off, infiltration and evapotranspiration). This, together with the register of entitlements, will favor the development of environmental-economic accounts [34].

Sixth, in the absence of or during the transition to genuine WAL trading schemes the water concession fees should be designed as incentives for (more) efficient water use and allocation [58]. The revenues collected by regions should cover operational costs of the WAL regime, including the monitoring, control, surveillance and enforcement costs. It is preferable to design the WCF as consisting of a fixed component and a variable component. Smart water meters should be installed for all abstraction licenses; not only for the new ones, but progressively for all existing abstraction permits.

Seventh, the potential efficiency achieved by making water entitlements transferable should be analyzed in depth. Properly designed water markets can both reveal the full economic value of water and facilitate its shift to highest value uses. The ample existing infrastructure favors physical water transfers and trading with licenses. However, in light of the manifested public opposition [75], it is not realistic to introduce a genuine trading scheme any time soon. If tradable permits are developed eventually, statutory plans need to anticipate potential market failures and define rules for determining whose shares and allocations can be traded.

Eighth, the length for which the WAL should be issued depends on whether or not introducing tradable permit schemes is envisaged in the long term. If there is an expectation of permission to trade with WAL in the future, then licenses should be released in perpetuity or, at least, with no time limits, in order to favor long-term investments and innovation. If not, licenses should be granted for durations that permit regular "back-end" adaptation to changing patterns of precipitation and river flow. Any changes in license durations should be managed by rules and procedures set forth in river basin district plans and/or regional water conservation plans.

These non-exhaustive principles and the complementary public debate have the potential to overcome the institutional "maze" which characterizes the current WAL regime. Our recommendations respond to allocation inefficiencies we have observed in the PRBD. They may have omitted relevant aspects that such a reform needs to tackle elsewhere. Still, our recommendations draw on EU and Italian policy guidelines [1,2,34,57], and build upon international standards [16] and experiences. We believe that this analysis offers helpful insights for water allocation reform elsewhere in Italy and in Europe, not least in river basin districts with similar characteristics. The new WAL regime should be robust yet flexible, and reliable yet sustainable. It should balance robustness at the user level with flexibility at the system level, and address trade-offs between efficiency and equity, while guaranteeing environmental sustainability and hydrological integrity.

It is clear that the proposed reform will not be unproblematic. While many recognize that the current license regime fails to allocate water sustainably and efficiently [76,77], there is a considerable divergence of opinions on how the regime should be reorganized [78,79]. It is not conceivable to design, let alone to implement, a reform of a such magnitude without extensive public consultation and scrutiny. Interest groups, even if small, are well-organized and influential, and thus are capable of hampering public policy dialogue and impeding transformative change [80]. A practicable way forward for Italy is a stepwise transition to a (more) resource efficient economy [81,82], an integral part of which is a modern water allocation regime that is consistent with the principles we have outlined.

This research highlights areas in which a concerted policy response is warranted. Although at present there is no plan or intention to embark in a similar policy debate, our contribution has shown that the topic of WAL is important and should be handled with a high priority. Future research should explore how to inform, open and strengthen the policy dialogue that could eventually lead to a new WAL regime and a greater water security in the PRBD and elsewhere in Italy. The analysis and recommendations above represent a first attempt which may help in this regard.

Acknowledgments

This research has received funding from the European Union under grant agreements No. 308438 (ENHANCE-Enhancing risk management partnerships for catastrophic natural disasters in Europe) and No. SEE/C/0001/2.2/X (ORIENTGATE—A structured network for integration of climate knowledge into policy and territorial planning).

References

1. European Commission. *Water Framework Directive 2000/60/EC*; European Commission: Brussels, Belgium, 2000.
2. European Commission. *A Blueprint to Safeguard Europe's Water Resources. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2012) 673 Final*; European Commission: Brussels, Belgium, 2012.
3. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Reinforcing Economic Policy Coordination. COM(2010) 250 Final*; European Commission: Brussels, Belgium, 2010.
4. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions An EU Strategy on Adaptation to Climate COM(2013) 216 Final Change*; European Commission: Brussels, Belgium, 2013.
5. Organisation for Economic Co-operation and Development. *Water Security for Better Lives*; Organisation for Economic Co-operation and Development: Paris, France, 2013.
6. European Commission. *Communication from the Commission to the European Parliament and the Council Addressing the Challenge of Water Scarcity and Droughts in the European Union. COM(2007) 414 Final*; European Commission: Brussels, Belgium, 2007.
7. Strosser, P.; Dworak, T.; Delvaux, P.G.A.; Berglund, M.; Schmidt, G.; Mysiak, J.; Kossida, M.; Iacovides, I.; Ashton, V. *Gap Analysis of the Water Scarcity and Droughts Policy in the EU; European Commisison Directorate General Environment, Final Report Tender ENV.D.1/SER/2010/0049*; European Commission: Brussels, Belgium, 2012.
8. European Parliament. *Report on Towards a Stronger European Disaster Response: The Role of Civil Protection and Humanitarian Assistance*; (2011/2023 INI)) A7-0283/2011; European Parliament: Bruxelles, Belgium, 2011.
9. European Environment Agency. *Water Resources in Europe in the Context of Vulnerability*; Report 12/2012; European Environment Agency: Copenhagen, Denmark, 2012.
10. European Environment Agency. *European Waters—Current Status and Future Challenges*; Report 9/2012; European Environment Agency: Copenhagen, Denmark, 2012.

11. Ciscar, J.-C.; Feyen, L.; Soria, A.; Lavalle, C.; Raes, F.; Perry, M.; Nemry, F.; Demirel, H.; Rozsai, M.; Dosio, A.; *et al. Climate Impacts in Europe—The JRC PESETA II Project, EUR–Scientific and Technical Research*; Joint Research Centre: Ispra, Italy, 2014.
12. United Nations. *The United Nations World Water Development Report 2014*; United Nations: New York, NY, USA, 2014.
13. Mysiak, J.; Vollaro, M.; Gómez, C.M.; Andersen, M.S.; Defrance, P.; Delvaux, P.A.G.; Green, C.; Dworak, T.; Davide, M.; Delacámara, G.; *et al. EPI-WATER Synthesis Report, Report of the EPI-WATER Project*; EPI-WATER: Venice, Italy, 2013.
14. Young, M. Environmental Effectiveness and Economic Efficiency of Water Use in Agriculture. In *OECD Studies on Water*; Organisation for Economic Co-operation and Development: Paris, France, 2010; pp. 1–33.
15. Young, M. *The Role of the Unbundling Water Rights in Australia's Southern Connected Murray Darling Basin, Report of the EPI-WATER Project*; EPI-WATER: Venice, Italy, 2011.
16. Organisation for Economic Co-operation and Development. *Water Resources Allocation: Sharing Risks and Opportunities*; Organisation for Economic Co-operation and Development: Paris, France, 2015.
17. Mysiak, J.; Carrera, L.; Massarutto, A. Servizio idrico e l'approvvigionamento di acqua nel contesto dei cambiamenti climatici. In *Qualità Dell'ambiente Urbano, IX Rapporto, Focus su Acque e Ambiente Urbano*; ISPRA; ISPRA–Istituto Superiore per la Protezione e la Ricerca Ambientale: Rome, Italy, 2013; pp. 113–120. (In Italian)
18. Parliament of the United Kingdom. Water Resources Act 1963. Available online: http://www.legislation. gov.uk/ukpga/1963/38/contents (accessed on 9 October 2015).
19. Environmental Agency and OFWAT. *The Case for Change–Reforming Water Abstraction in England*; Environmental Agency and OFWAT: Rotherham, UK, 2011.
20. Environmental Agency. *Abstraction and Flow Problem-Significant Water Management Issues*; Environmental Agency: Rotherham, UK, 2013; pp. 1–13.
21. Parliament of the United Kingdom. Water Resources Act 1991. Available on line: http://www.legislation. gov.uk/ukpga/1991/57/contents (accessed on 9 October 2015).
22. Environmental Agency. *Abstraction Charging Scheme*; Environmental Agency: Rotherham, UK, 2014.
23. Cave, M. *Independent Review of Competition and Innovation in Water Markets: Final Report*; Defra: London, UK, 2009.

24. Department for Environment, Food and Rural Affairs. *The Natural Choice: Securing the Value of Nature*; Defra: London, UK, 2011.

25. Department for Environment, Food and Rural Affairs. *Water for Life. Market Reform Proposals*; Defra: London, UK, 2011.

26. Department for Environment, Food and Rural Affairs. *Water for Life*; Defra: London, UK, 2011.

27. Boletín Oficial del Estado. *Ley 29/1985, de 2 de Agosto, de Aguas*; BOE: Madrid, Spain, 1985; Volume 189. (In Spanish)

28. Boletín Oficial del Estado. *Ley 46/1999 de 13 de Diciembre, de Modificación de la Ley 29/1985, de 2 de Agosto, de Aguas*; BOE: Madrid, Spain, 1999. (In Spanish)

29. Boletín Oficial del Estado. *Real Decreto-Ley 15/2005, de 16 de Diciembre, de Medidas Urgentes Para la Regulación de Las Transacciones de Derechos al Aprovechamiento de Agua (Vigente hasta el 30 de Noviembre de 2009)*; BOE: Madrid, Spain, 2005; Volume 15. (In Spanish)

30. Boletín Oficial del Estado. *Real Decreto-Ley 606/2003, de 23 de Mayo, por el que se Modifica el Real Decreto 849/1986, de 11 de Abril, por el que se Aprueba el Reglamento del Dominio Público Hidráulico, que Desarrolla los Títulos Preliminar, I, IV, V, VI y VIII de la Ley 29/1985, de*; BOE: Madrid, Spain, 2003; Volume 606. (In Spanish)

31. Organisation for Economic Co-operation and Development. OECD Environmental Performance Reviews: Italy 2013. Available online: http://dx.doi.org/10.1787/9789264186378-en (accessed on 10 September 2015).

32. Ministero dell'Ambiente e Della Tutela del Territorio e del Mare. Regio Decreto 11 Dicembre 1933, n. 1775-Testo Unico Delle Disposizioni di Legge Sulle Acque e Impianti Elettrici (G.U. 8 Gennaio 1934, n. 5). Available online: http://www.minambiente.it/sites/default/files/R.D._11-12-1933_n._1775.pdf (accessed on 9 October 2015). (In Italian).

33. Goria, A.; Lugaresi, N. *The Evolution of the National Water Regime in Italy*; Istituto per la Ricerca Sociale: Bologna, Italy, 2002.

34. Parliament of Italy. Testo Unico Ambientale 152/2006. Available online: http://www.camera.it/parlam/ leggi/deleghe/06152dl2.htm (accessed on 9 October 2015). (In Italian).

35. Coppola, E.; Giorgi, F. An assessment of temperature and precipitation change

projections over Italy from recent global and regional climate model simulations. *Int. J. Climatol.* 2010, *30*, 11–32.

36. Ministero dell'Ambiente e della Tutela del Territorio e del Mare. Rapporto Sullo Stato Delle Conoscenze Scientifiche su Impatti, Vulnerabilità ed Adattamento ai Cambiamenti Climati ci in Italia. Available online: http://www.minambiente.it/sites/default/files/archivio/allegati/clima/strategia_adattamentoCC.pdf (accessed on 9 October 2015). (In Italian).

37. Carrera, L.; Mysiak, J.; Crimi, J. Droughts in Northern Italy: Taken by Surprise, Again. Available online: http://www.feem.it/getpage.aspx?id=5594 (accessed on 10 September 2015).

38. Young, M. *Towards a Generic Framework for the Abstraction and Utilisation of Water in England and Wales*; Visiting

Fellowship Report 2012; UCL Environment Institute: London, UK, 2012.

39. Rey, L.; Calatrava, J.; Garrido, A. *Water Market Scenarios for Spain, Deliverable WP2 Water Cap and Trade*; IWRM-NET: Madrid, Spain, 2011.

40. EPI-WATER. *WP3 EX-POST Case Studies: Payment by the Drop: The Move to Water Metering in England and Wales*; EPI-WATER: Venice, Italy, 2011.

41. Massarutto, A.; Musolino, D. Po River Basin, Italy Drought management in a wide, densely populated and highly developed area. Available online: http://www.eu-drought.org/media/default.aspx/emma/ org/10815140/CS+Po_IT_flyer_1.pdf (accessed on 10 September 2015).

42. Autorità di Bacino del Fiume Po. *Sintesi Dell'analisi Economica Sull'utilizzo Idrico. Elaborato 6, Piano di Gestione*; Autorità di Bacino del Fiume Po: Parma, Italy, 2010.

43. Mysiak, J.; Carrera, L.; Massarutto, A. Sicurezza idrica nel contesto dei cambiamenti climatici. In *Qualità Dell'ambiente Urbano, IX Rapporto, Focus su Acque e Ambiente Urbano*; L'istituto Superiore per la protezione e la ricerca ambientale (ISPRA): Roma, Italy, 2013; pp. 113–120.

44. Calliari, E. *Ordinary and Extraordinary Tools for Managing Drought. The 2003 and 2006/2007 Events in the Po River Basin*; Bocconi University: Milan, Italy, 2011.

45. Civita, M.V. *Ground Water in the Southern Member States of the European Union: an Assessment of Current Knowledge and Future Prospects—Country Report for Italy*; European Academies Science Advisory Council: Halle, Germany, 2011.

46. California State Legislature. *California Water Code*; California State Legislature: Sacramento, CA, USA, 2013.

47. Hanak, E.; Lund, J.; Dinar, A.; Gray, B.; Howitt, R.; Mount, J.; Moyle, P.; Thompson, B. *Managing California's Water: From Conflict to Reconciliation*; Public Policy Institute of California: San Francisco, CA, USA, 2011.

48. Pérez-Blanco, C.D.; Gómez, C.M. Insuring water: A practical risk management option in water-scarce and drought-prone regions? *Water Policy* **2014**, *16*, 244–263.

49. European Commission. *Drought Management Plan Report*; Report 23; European Commission: Brussels, Belgium, 2008.

50. Parlamento Italiano. Legge Galli N.36, 1994 Disposizioni in Materia di Risorse Idriche. Available online: http://www.gazzettaufficiale.it/eli/id/1994/01/19/094G0049/sg (accessed on 9 October 2015). (In Italian).

51. Regione Emilia-Romagna. *Regolamento per le Disciplina del Procedimento di Concessione di Acqua Pubblica. Regolamento Regionale 20 Novembre 2001, n. 41*; Regione Emilia-Romagna: Bologna, Italy, 2001; pp. 1–17.

52. Regione Piemonte. *Regolamento Regionale 29 Luglio 2003, n.10/R, Disciplina dei Procedimenti di Concessione di Derivazione di Acqua Pubblica*; Regione Piemonte: Torino, Italy, 2003; pp. 1–42.

53. Regione Lombardia. *Regolamento Regionale 24 Marzo 2006, n. 2, Disciplina Dell'uso Delle Acque Superficiali e Sotterranee, Dell'utilizzo Delle Acque a uso Domestico, del Risparmio Idrico e del Riutilizzo Dell'acqua*; Regione Lombardia: Milano, Italy, 2006.

54. Regione Autonoma della Valle d'Aosta. *Legge Regionale 8 Novembre 1956, n. 4. Norme Procedurali per la Utilizzazione Delle Acque Pubbliche in Valle d'Aosta*; Regione Autonoma della Valle d'Aosta: Aosta, Italy, 1956.

55. Regione Veneto. *Deliberazione Della Giunta Regionale n. 1664 del 22 Giugno 2010: Disposizioni per la Presentazione e la Pubblicazione Delle Domande di Concessione di Derivazione D'acqua*; Regione Veneto: Venezia, Italy, 2010.

56. Regione Emilia-Romagna. *Deliberazione Della Giunta Regionale n. 1260 del 22 Luglio 2002: Rivisitazione Dell'assetto Delle Funzioni in Materia di Difesa del Suolo, dei Bacini Idrografici e Della Costa*; Regione Emilia-Romagna: Bologna, Italy, 2002. (In Italian)

57. European Commission. *Ecological Flows in the Implementation of the Water Framework Directive, Guidance Document No. 21*; Technical Report-2015-086; European Commission:

Brussels, Belgium, 2015.

58. European Environment Agency. *Assessment of Cost Recovery through Water Pricing*; No. 16; European Environment Agency: Copenhagen, Denmark, 2013.

59. Parlamento Italiano. *Decreto Legislativo 31 Marzo 1998, n. 112 Conferimento di Funzioni e Compiti Amministrativi Dello Stato Alle Regioni ed Agli Enti Locali, in Attuazione del Capo I Della Legge 15 Marzo 1997, n. 59*, Available online: http://www.parlamento.it/parlam/leggi/deleghe/98112dl.htm (accessed on 9 October 2015). (In Italian).

60. Regione Lombardia. *Canoni Acque Pubbliche 2016*, Available online: http://www.reti.regione.lombardia.it/ cs/Satellite?c=Redazionale_P&childpagename=DG_Reti/Detail&cid=1213550944051& pagename=DG_ RSSWrapper (accessed on 15 September 2015). (In Italian).

61. Regione Piemonte. *Canoni Per Uso Delle Acque Pubbliche*, Available online: http://www.regione.piemonte.it/ ambiente/acqua/atti_doc_adempimenti.htm (accessed on 15 September 2015). (In Italian).

62. Regione Emilia-Romagna. *Canoni Acque Pubbliche*, Available online: http://ambiente.regione.emilia- romagna.it/suolo-bacino/servizi/canoni/canoni-acque-pubbliche (accessed on 15 September 2015) . (In Italian).

63. Regione Autonoma della Valle d'Aosta. *Ufficio Gestione Demanio Idrico:Canoni Acque Pubbliche*; Regione Autonoma della Valle d'Aosta: Aosta, Italy, 2015. (In Italian)

64. Regione Veneto. *Ufficio regionale del Genio Civile: Canoni Acque Pubbliche*; Regione Veneto: Venezia, Italy, 2015. (In Italian)

65. Ministero dell'Ambiente e della tutela del territorio e del mare. *Decreto Ministeriale 24 Febbraio 2015, n. 39-Regolamento Recante i Criteri Per la Definizione Dei Costi Ambientali e Della Risorsa Per i Vari Settori D'impiego Dell'acqua*; Ministero dell'Ambiente e della tutela del territorio e del mare: Rome, Italy, 2015. (In Italian)

66. Autorità di Bacino fiume Po. *Piano di Gestione del Distretto Idrografico del Fiume Po. Studio di Fattibilità Analisi Economica Utilizzo Idrico Scala del Bacino del Po–Attività Integrative*; Autorità di Bacino fiume Po: Parma, Italy, 2010. (In Italian)

67. Istituto Nazionale di Economia Agraria. *Atlante Nazionale Dell'irrigazione, a Cura di Raffaella Zucaro*; INEA: Roma, Italy, 2011. (In Italian)

68. Regione Autonoma della Valle d'Aosta. *Ufficio Gestione Demanio Idrico: Database Delle*

Concessioni di Derivazione Dell'acqua Pubblica; Regione Autonoma della Valle d'Aosta: Aosta, Italy, 2015.

69. Regione Lombardia. *Unità Organizzativa Risorse Idriche: Database Delle Concessioni di Derivazione Dell'acqua Pubblica*; Regione Lombardia: Milano, Italy, 2015. (In Italian)

70. Regione Piemonte. *Settore Tutela Quantitativa e Qualitativa Delle Acque: Database Delle Concessioni di Derivazione Dell'acqua Pubblica*; Regione Piemonte: Torino, Italy, 2015. (In Italian)

71. Regione Veneto. *Ufficio regionale del Genio Civile della Provincia di Rovigo: Database delle concessioni di derivazione dell'acqua pubblica*; Regione Veneto: Venezia, Italy, 2015. (In Italian)

72. Regione Emilia Romagna. *Piano di Tutela delle Acque (PTA)*; Regione Emilia Romagna: Bologna, Italy 2005, 2015. (In Italian)

73. Regione Piemonte. SI Risorse Idriche (SIRI)/SI Bonifica e Irrigazione (SIBI). Available online: http://www.sistemapiemonte.it/cms/pa/ambiente/servizi/202-siri-si-risorse-idriche-sibi-si-bonifica-e- irrigazione. (accessed on 15 September 2015). (In Italian).

74. European Environment Agency. *Water Resources in Europe in the Context of Vulnerability-EEA 2012 State of*

Water Assessment; European Environment Agency: Copenhagen, Denmark, 2012.

75. Servizio Studi-Dipartimento ambiente della Camera dei Deputati. Il Servizio Idrico Integrato e il Referendum Abrogativo del 12-13 Giugno 2011. Available online: http://documenti.camera.it/leg16/dossier/Testi/ AM0232.htm (accessed on 15 September 2015). (In Italian).

76. Crase, L.; O'Keefe, S.; Dollery, B. Talk is cheap, or is it? The cost of consulting about uncertain reallocation of water in the Murray–Darling Basin, Australia. *Ecol. Econ.* **2013**, *88*, 206–213.

77. Young, M. Trading Into Trouble? Lessons from Australia's Mistakes in Water Policy Reform Sequencing. In *Water Markets for the 21st Century*; Springer: Berlin, Germany, 2014; pp. 50–61.

78. Garrick, D.; Whitten, S.; Coggan, A. Understanding the evolution and performance of water markets and allocation policy: A transaction costs analysis framework. *Ecol. Econ.* **2013**, *88*, 195–205.

79. Olson, M. *The Logic of Collective Action: Public Goods and the Theory of Groups*;

Harvard University Press:

Cambridge, MA, USA, 1965.

80. Pahl-Wostl, C. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Glob. Environ. Chang.* **2009**, *19*, 354–365.

81. McCann, L.; Colby, B.; Easter, K.W.; Kasterine, A.; Kuperan, K.V. Transaction cost measurement for evaluating environmental policies. *Ecol. Econ.* **2005**, *52*, 527–542.

82. Timmerman, J.G.; Langaas, S. Water information: What is it good for? The use of information in transboundary water management. *Reg. Environ. Chang.* **2005**, *5*, 177–187.

MEASURING TRANSACTION COSTS OF INFORMAL INSTITUTION FOR DROUGHT MANAGEMENT

Introduction

Water, an essential resource for life, is becoming increasingly scarce worldwide [1]. Global warming, population growth and economic development will lead water demand to outstrip supply by 40% in 2030, causing GDP to decline by as much as 6% in water scarce areas [2][2]. As global environmental and socioeconomic changes aggravate water scarcity problems, existing institutions may enshrine inflexible water governance arrangements that constrain capacity to take corrective action. This has led international institutions to dub the current water crisis as a "crisis of governance" [3], [4]. Now more than ever there is an urgent need to take stock of recent experiences, identify good practices and contribute to the policy-oriented debate for effective, fair and sustainable institutional management of water resources.

We define institutions as 'the rules of the game' within which political, social and economic realities operate [5]. At the water management level, two overarching institutional categories coexist: 1) *formal institutions*, which are established and communicated through channels that are widely accepted as official, such as laws and regulations enforced by authorities; and 2) *informal institutions*, where the social rules, customs, traditions or codes of conduct are part of the culture and ideology [6]. In both cases, institutions distribute power to differentially constrain and enable actors, and facilitate or limit the response(s) of individuals and communities to climate hazards such as drought [7].

When drought occurs, the negative supply-demand differential intensifies conflicts within different administrative units of management and economic sectors, which often have developed expectations for water availability based on previous periods of abundance and resource allocations [8]. Adverse conditions demonstrate the inherent limitations of existing institutions, and in the process of adapting to new supply-demand conditions allocation and conflict resolution mechanisms have to be either created or strengthened. Such changes that affect the evolution of institutions are one of the key premises in institutional economics and can be measured via transaction costs.

Transaction costs are defined as the costs of resources used to define, establish, maintain, administer and change institutions and organizations; as well as those needed to define the problems that these institutions and organizations are intended to solve [9]. In the larger context of institutional evolution, they are all the costs involved in human interaction over time. The arguments for measuring transaction costs represent an increasingly relevant feature in investigations of environmental or common property policy design and analysis, along with their budgets and benefits [10], [11].

The study of Transaction Costs

From an economic perspective, appropriate formal and informal institutional choices include options that minimise/lower all transaction and abatement costs [9]. In the context of complex multiscale problems, such as water management, the measurement of transaction costs usually focuses on markets and other formal institutions [12], [13], with little research being conducted on the transaction costs of informal institutions (see Landry and Amara [14] for a rare example). Yet, the latter are frequently used for water resource management in several areas worldwide, particularly to mitigate the adverse effects of droughts, e.g. through informal water markets [15], quota-based water reallocation [16] or risk sharing [17]. Reasons for reliance on informal institutions include trust, networking, shared norms and reciprocal arrangements; which may help minimise/lower total transaction costs [18].

Measuring transaction costs is challenging. Most water management institutions do not empirically quantify institutional transaction costs such that they can be easily distinguished from other cost categories. Researchers also report a number of difficulties related to the measurement of transaction costs, often suggesting that data is partial and indirect, and/or derived from limited cost typologies or proxies to represent transaction costs [19]. Further, there is no broad agreement on a standard terminology about the definition of transaction costs [20]. For this reason, it seems unclear how to identify the peculiarities of a transaction, and which expenses/investment should be regarded as transaction costs. All the above is even more challenging where informal institutions may amplify accounting data gaps. Finally, there are very few assessments of informal institutional transaction costs, especially empirical assessments, that can be used as a guidance to navigate the abovementioned challenges.

However, a relatively common feature of transaction cost measurement is the distinction between ex-ante and ex-post costs – those occurring before and after the transaction. The sum of ex-ante and ex-post transaction costs yields total transaction costs. Total transaction costs can be further divided into: (1) administering, monitoring, contracting and enforcing current policy arrangements (termed static transaction costs), and; (2) periodically designing, enabling, implementing new and/or transitioning existing management arrangements to new systems (termed institutional transition costs). In addition to these costs, total transaction costs may be increased when subsequent adaptation requirements are triggered by policy shocks or surprises (termed institutional lock-in costs) [9]. Table 2.1 references typical transaction costs categories and examples, sub-divided between ex-ante and ex-post transaction costs.

Table 0.1: Categorisation examples of transaction costs, adapted from McCann, (2005) [21], Garrick (2015) [22] and Marshall (2013) [9].

Classes	**Sub-classes**	**Typology of transaction costs**	**Water market arrangement examples**
Ex-ante	Institutional transition costs	Research and information	River Basin development planning and closure (cap) Hydrologic and socio-economic studies
		Enactment or litigation	Water rights reform (adjudication, conflict resolution, rules)
		Design and implementation	Modification to storage and distribution, licensing systems, trading rules and registries Price discovery Water accounting systems
Ex-post	Static transaction costs	Support and administration	Transaction planning, identification of buyers and sellers, administrative reviews (injury analysis)
		Contracting	Water rights due diligence
		Monitoring and detection	Water use accounting
		Prosecution and enforcement	Compliance monitoring and enforcement Dispute resolution
	Institutional lock-in costs	Adaptation or replacement	Revised caps Adapted water rights and water user association rules Acquiring water rights for the environment if cap is revised downward
Source: Hanna (1995) [8]	Source: Marshall & Alexandra (2016) [23]	Sources: Marshall (2013); McCann (2005) [21] ; McCann and Easter (2004) [13];	Source: Garrick and Alyward (2011) [12]; McCann and Easter (2004) [13]

The contribution of this study

The goal of this paper is to explore a case study of informal drought management arrangements in northern Italy. We delineate the contours of institutional coordination and responses to droughts, measure associated transaction costs over time, and examine the water scarcity management outcomes of informal institutions. Given the importance of robust water governance and management institutions for dealing with broad water resource over-allocation and climate change impacts [7], and the marginal attention devoted so far to informal arrangements, this paper examines whether they can provide robust institutional outcomes. This will entail mapping the water governance institutions for Italy in general, and the Po River Basin (PRB) drought management systems in particular. The results provide a study of informal institutions in the context of watershed management, and their related transaction costs, which are both necessary for assembling a complete range of institutional options from which to choose and may be faster to implement that formal institutions (e.g. water property rights and market-based measures).

Background for the study

The Po River Basin (PRB) is mostly located in northern Italy, The PRB covers the territory of Liguria, Piedmont, Valle d'Aosta, Lombardy, Trentino, Veneto, Emilia-Romagna, Tuscany, Marche regions and also extends, with five per cent of its total area (~74,000km^2) to portions of French and Swiss territory (Figure 2.1b). In 2017 the Authority of the Po river basin district becomes operative, replacing the existing authority of the Po river basin and including the basins of the Reno, Fissero-Tartaro-CanalBianco, the Conca-Marecchia and the Romagnoli regional basins. The river basin authority presented in this study refers to the hydrographic limit of the Po river basin. In terms of average annual water discharge, the PRB is one of the largest in Europe with an outflow at the mouth of the Po River in Pontelagoscuro of 1,470m^3/s. Po River flow rates depend on water captured and stored in artificial reservoirs in the mountains, principally in five lakes located at the foot of the Alps: Lake Maggiore, Lake Como, Lake Iseo, Lake Idro and Lake Garda. Demand for water is high: the PRB supplies water for hydropower generation in upstream lakes and reservoirs, and potable water to some 3,700 urban municipalities within seven regions with a thriving industry that accounts for 40% of national GDP. The system also supplies irrigation water to Italy's largest contiguous agricultural region, which comprises 21.5% of total Italian agricultural land, contributes 30% of national agricultural value-added production [24], and represents around 80% of total water extractions [25]. Water is also needed in the lower reaches of the river to mitigate salinity intrusion during low flow or drought periods—as the area is located below sea-level—and to support fisheries and aquaculture demand.

Fig. 2.1b

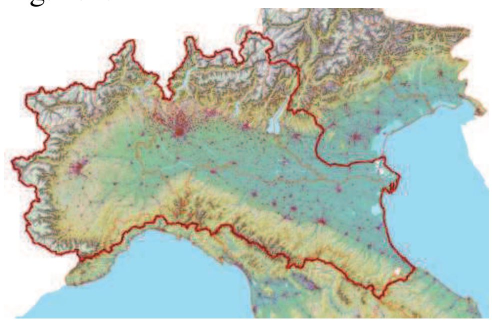


Fig. 2.1a

Fig. 2.1c

Figure 0.1a: The seven river basin districts in Italy; **Figure 2.1b:** The area of the Po River Basin; **Figure 2.1c:** The boundaries of Po River Basin District (red) and regions comprised (orange).

Average precipitation ranges from a maximum of 2,000mm in the Alpine regions of the PRB to less than 700mm on the eastern plains, with an annual average of 1,100mm. Under IPCC emission scenarios RCP4.5 and RCP8.5, temperatures will increase along with evapotranspiration demand, while summer precipitation levels will likely decrease [26]. Po River discharge is thus expected to decline during the summer months—when demand is typically at its peak—and shift to higher levels in the winter (Figures 2.2 and 2.3).

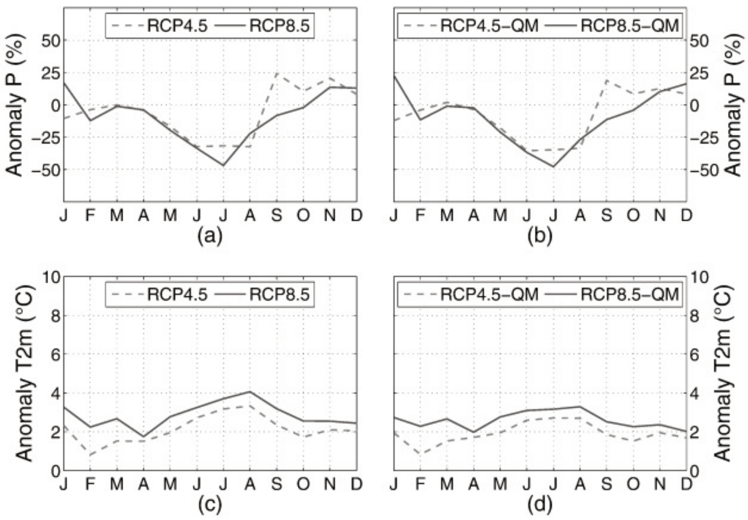


Figure 0.2: Anomalies in (a,b) seasonal precipitation in % and (c,d) two meter mean temperature in °C for the PRB, 2041–2070. Left side (a,c) refers to raw CMCC-CM/COSMO-CLM outputs, while the right side (b,d) indicates the bias-corrected climate projections [26].

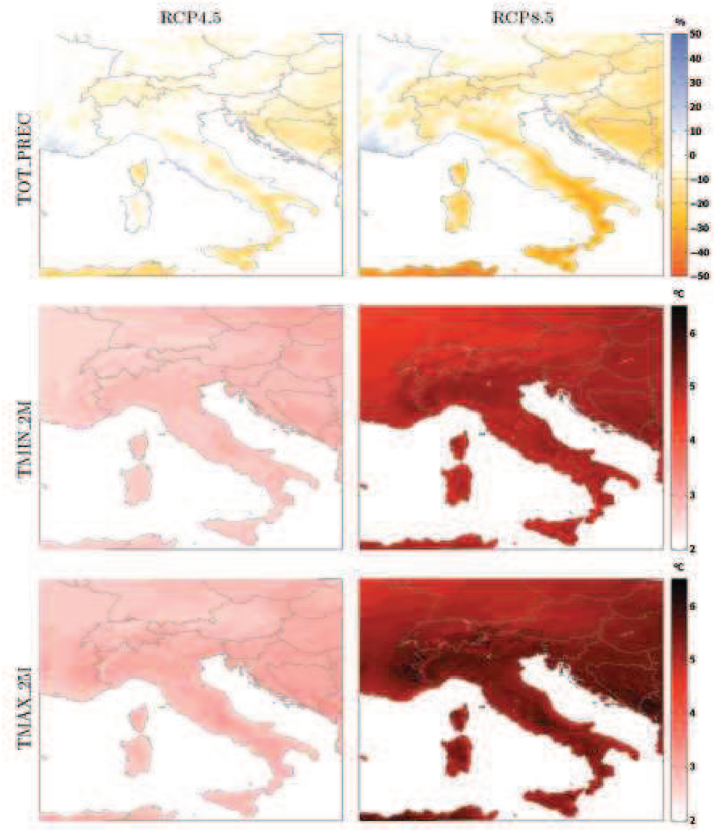


Figure 0.3: Climate change signal for the period 2071–2100 versus 1981–2010 for mean precipitation, maximum and minimum temperature [27].

As a result, the frequency and intensity of extreme events such as droughts are expected to increase, making current levels of water extraction in the basin unsustainable [28]. Evidence of these changes is already noticeable at regional and local levels, with recorded rainfall reductions and increased temperature variations of around one degree centigrade [29], [30]. Droughts also appear to be affecting the region more frequently, with a State of Emergency being declared in 2003, 2006, 2007 and 2017. Since 2000, these State of Emergency events have lasted 25 months in total, with an average duration of 6.25 months per declaration.

In response, a coordinated climate change adaptation strategy which identifies the main impacts of climate change for a number of socio-economic sectors in Italy was adopted in 2015, and followed by a National Adaptation Plan for Climate Change (in Italian: *Piano Nazionale di Adattamento ai Cambiamenti Climatici*, PNACC, [31]). The PNACC is meant to accelerate implementation of the National Adaptation Strategy to Climate Change (in Italian: *Strategia Nazionale di Adattamento ai Cambiamenti Climatici*, SNACC, [31]), and mitigate increased water scarcity impacts. The PNACC encourages institutions to identify effective ways to mainstream adaptation into existing plans and regulations at different levels of territorial government [16], [31]. Specifically, River Basin Authorities are responsible for identifying and coordinating drought adaptation actions and measures.

Water Abstraction Licenses regime in Italy: An obstacle to climate change adaptation

However, the current system of creating and managing water abstraction licenses (WAL) in Italy creates a significant obstacle to the effective implementation of these two adaptation strategies. Originally, Italian legislation viewed water as a plentiful resource, and this attitude has remained essentially unchanged since the 1930s. As a result, the volume of authorised WALs in the PRB now exceeds average water availability. For example, current hydroelectric and agricultural licenses amount to 1,840 m^3/s, against an average river flow of 1,470 m^3/s.

Although many of these licenses are dormant, over-allocation complicates managing water deficits during drought periods. For these reasons, both the PNACC and the SNACC proposed a revision of the WAL regime system [31], [32]. Recent legal definitions and laws now recognise the limits to national water use, and articulate collective uses of water resources in Italy with respect to protection of environmental water resource uses (Law 183/1989), integrated water resource management (Law 36/1994), and protection of water quality (Environmental Code 152/2000). Yet, over-allocation persists. In an attempt to address this obstacle, the Italian government sought to reorganise water services in the early 2000s, in what was then regarded as a first step towards the introduction of market and pricing reallocation mechanisms. However, in June 2011, a law favouring water privatisation and the possibility of water trading was repealed by referendum.[1] The law envisaged water supply managed exclusively by private companies; or mixed public-private enterprises where the private investor held at least a 40 per cent share. Proponents argued that privatisation would improve efficiency in the system, which at that time was losing on average 30 per cent of water withdrawals through leaks in the water pipe networks. Yet the prevailing view following the referendum was that access to water should be treated as a common resource and fundamental right, not subject to free market reallocation. The referendum outcome thus limits the use of formal market instruments such as water pricing, trading or buyback for drought management [33]. Alternative risk management arrangements such as applications of flexible, consistent and adaptive WAL quotas are also difficult to implement in Italy [34], [35] due to the fragmented nature of WALs, and the challenging interplay of Italian water institutions [36] where regional governments have been granted the power to regulate WAL matters. The capacity of river basin managers to coordinate parties and address climate change impacts and future population and economic growth, and/or to prioritise different water uses during drought is therefore compromised. Governance of water resources in Italy remains complex, emergency driven and focused on short-term problem-solving. This is particularly

[1] The Ronchi Decree was adopted in 2009 under the Berlusconi government. It was designed pave the way for the further privatization of the water services; particularly under the provision that shares in water companies held by the municipalities themselves must not exceed 30%, while making 70% available for private investors.

evident during drought events where reactive strategies may increase the negative impacts of water scarcity.

Formal drought management institutions

Drought management in Italy has traditionally focused on formal command and control mechanisms, where the state intervenes in the management of basin water resources as a last resort instrument (Law 225/1992) to enact water restrictions with sanctions for non-compliance [37]. In contrast, recent evidence of climate change and increased drought events from 2003 onwards have served to focus EU Member States' attention on alternative political and technical responses involving participatory approaches (Article 14 of the EU-WFD [38]) over prescriptive sanctions. A key document was the communication addressing the problem of water scarcity and droughts in the European Union [39], which presented an initial set of non-mandatory policy options at European, national and regional levels to address and mitigate the challenge posed by water scarcity and drought.

During the process of transposing the EU-WFD into national legislation, the PRB experienced a severe drought event in 2003 that presented a significant threat to urban, industrial and agricultural water supplies. The Italian government formally declared a State of Emergency, which enabled them to: i) centrally manage drought emergency interventions in the PRB for a period not exceeding 180 days (but which may be extended by another 180 days by the central government); and ii) allocate funding for initial drought management interventions, with the option for further interventions where recognised as necessary by the delegated Commissioners in charge of managing the emergency. This formal institutional arrangement was managed by the National Civil Protection Department (NCPD), anchored to the Presidency of the Council of Ministers, which supervised all activities.

Informal arrangements for drought management

In the 2003 drought event, the NCPD and Po River Basin Authority (PRBA) jointly sought to avoid last resort interventions by the central Italian government. Both organisations were concerned about the impact of the drought on energy supply, and the need to act more rapidly (and collectively) to address issues in line with EU best drought management practices. As a result, a Drought Steering Committee (DSC) was initiated, presided over by the PRBA, with the purpose of coordinating communication and voluntary responses to drought across a large number of organisational members.[2] In that regard, the DSC constituted an informal institution where decisions were made via agreement or consensus despite a lack of explicit legislative (formal) mandate in support of those

[2] These included the Po River Basin Authority, the Italian Registry of Dams, Emilia Romagna region, Liguria region, Lombardy region, Piedmont region, Valle D'Aosta region, Veneto region, Autonomous Province of Trento, Lake regulators, land reclamation boards, and the hydro-electric supply companies.

activities. In that regard, trust among the membership, networking and shared objectives should have served to reduce the total institutional transaction costs of drought management, as outlined below.

The mission of the DSC, sanctioned under a Memorandum of Interest (MoI), was to manage severe water deficits in a unified manner, and to delay or prevent critical water shortages. Two main objectives were included in the MoI: i) maintenance of minimum water withdrawal opportunities for downstream irrigators and Po River Delta water users (e.g. aquaculture); and ii) maintenance of hydroelectric outflows to guarantee maximum possible electricity production, as requested by the national transmission grid operator. Under these common objectives, the DSC initiated a network of information gathering aimed at measuring lake storage data, monitoring of PRB water flows in real time, and a summary of WAL water uses. These measures served to better assess and understand the negative impacts of the drought, contributed to an overall stabilisation of water flows and availability, and brought progressive increases in supply to WAL-holders during the drought. This initial success meant that, since 2003, the DSC has been convened again when necessary to deal with PRB drought events, and to limit (potentially costlier) state intervention. Drought management planning through the DSC is now enshrined in the Po River Basin District Plan [40], along with requirements for water-stress mapping, temporary restriction measures for intensive (e.g. back-to-back rotation) cropping, and early-warning systems based on basin modelling.

The success of the DSC has also become a reference point for the management of water crises in Italy more generally, given its capacity to aggregate and coordinate various stakeholders' interests considering regional differences. The DSC is therefore now recognised by the Italian government as an effective instrument for the fair and sustainable management of water withdrawals. In 2016, legislation provided for the mandatory activation of a DSC in each of the seven Italian basin districts, along with responsibility for coordinating different local water authorities. These DSCs are aimed at harmonising adaptation efforts under the larger Permanent Observatory (PO) institutional structure in Italy, which monitors climate dynamics and variability, climate hotspots, and natural environmental hazards from extreme weather events.

The success of the original PRB-DSC suggests that it may provide a useful model for jurisdictions beyond Italy, particularly in the EU. Incentives for a jurisdiction to participate in their own version of the DSC are twofold. First, the DSC represents an opportunity to coordinate with other water users before any drought declaration is made, after which centralised (distant and/or coercive) decision-making arrangements may dominate to reduce negotiation/adaptation opportunities. Second, the DSC is an opportunity to foster greater mutual understanding and trust among relevant organisations, increased information exchange, and collaboration between water users that may otherwise be hampered by administrative and political fragmentation. In light of this, the informal nature of the

DSC may lead to relatively inexpensive institutional arrangements that are more readily enacted (institutional transition costs) and administered (static transaction costs) by other watersheds with limited or poor water right structures. This paper seeks to shed light on these prospective benefits, and whether informal water governance arrangements may provide viable alternatives.

Methodology

Stakeholder map, interviews, document analyses, and assessment of governance arrangements

Our methodology included a stakeholder map that was useful to understand and explore relevant networks of institutions. The stakeholders are all of the interested parties who affect and influence drought governance decisions, as well as those who will be affected by those decisions. We therefore defined the domain of stakeholders involved in the DSC and different focus levels, ranging from identifying relevant institutions and key persons to finding the interactions and associated transaction costs.

The first part of the methodology involved three steps: i) delineating the water allocation governance framework in which the DSC operates; ii) understanding informal DSC institutions, and iii) mapping those arrangements within the larger national and PRB watershed governance frameworks. Initial meetings were held with senior members of the DSC to outline the objectives of the study, and to secure their support and engagement. This enabled the research team to identify key DSC personnel to target for interviews. Face to face and telephone interviews were then scheduled and conducted involving a total of 12 experts, with each interview lasting around two hours on average. The interviews enabled the research team to explore technical and organisational detail related to mapping the DSC within the broader PRB governance framework, and possible sources of transaction cost data. Document analyses of suggested reports, as well as relevant material identified in a larger literature review, were then undertaken.

Transaction costs data collection, categorisation and analysis

McCann (2005) [21] established a framework and typology for transaction costs measurement based on previous work from Thompson (1999), which we follow in our study. The data collection approach is similar to that detailed in Loch & Gregg (2018) [42]. The main function of the DSC is to coordinate stakeholder participation and consensus in the wake of significant drought event periods. Routine technical meetings during non-drought periods are also commonly arranged by regional authorities with the support of Environmental Protection Agencies (EPAs). In the study, DSC meetings were used to track stakeholder involvement, with salary cost rates (per hour) at each expert-level providing a proxy base value for transaction costs estimates. This data was obtained while also considering:

physical or virtual participation by experts in meetings; estimates of travel distances and/or costs from their origin (e.g. headquarters of the organization to which they belong) to the venue of the meeting; and the duration of the meeting. Information for the study was collected through interviews, and meetings minutes. For some meetings the minutes were not available, thus requiring additional interview data collection to fill information gaps. Further, in 28 out of 235 cases, mean salary cost values (~€70,000 per annum) had to be assigned when information was not publicly-available nor provided in the interviews. DSC meetings and related transaction costs were then classified based on their key focus. For example: meetings to agree memoranda of understanding involved ex-ante enactment costs; meetings to develop/test new hydrologic models for the basin involved ex-ante design and implementation costs; meetings to extend the modelling framework and thus enhance institutional capacity to monitor water use and compliance and limit illegal abstractions involved ex-post monitoring and detection costs; while meetings to incorporate the DSC institution within the PO arrangements for Italy as a whole provided some measure of lock-in transaction costs.

In addition, the DSC was provided with administrative support from the PRBA which enabled meeting organisation assistance, information collection and dissemination, and technical advice where necessary. Initially (2003-2008), this role was mainly accomplished with the administrative support of an external service provider and was subsequently transferred to the PRBA (2008-2016). Financial data from the PRBA provided transaction costs related to the collection of information in support of decision-making by the DSC, including the major hydrologic modelling costs. As an example, two external staff from the Regional Environmental Agency of the Emilia-Romagna Region worked almost full-time (~80%) on the development and management of the hydrological model to support DSC activities. It should be noted that the total transaction costs involved in the DSC process were thus absorbed by different organisations at different points of the original program life-cycle (2003-2016).

Finally, data for each expenditure were carefully collected and transformed into real values using 2017 as the base year. Transaction costs data estimates were individually categorised into the relevant institutional transition (ex-ante) and static transaction (ex-post) costs as per Table 2.1. Following the method adopted by Loch & Gregg (2018) [42] analyses were performed to identify: trends in each category over time, summed total transaction costs for the DSC, and comparisons between drought and non-drought periods. The results of the analyses are detailed in the following section.

Table 0.2: Categorisation of transaction costs, adapted from McCann, (2005) [21], Garrick (2015) [22] and Marshall (2013) [9], including categorisations identified for the DSC case study.

Classes	**Sub-classes**	**Typology of transaction costs**	**Categorisation of transaction costs for the Drought Steering Committee**
Ex-ante	Institutional transition costs	Research and information	The meetings of the DSC (minutes)
		Enactment or litigation	Enactment: includes all the meetings for the signing of the memorandum of understanding for the DSC
		Design and implementation	Hydrologic studies and modelling of allocations supporting the decision of the DSC
Ex-post	Static transaction costs	Support and administration	The organisation of the meetings (design costs)
		Contracting	Not present
		Monitoring and detection	The meetings for the hydraulic modelling
		Prosecution and enforcement	The meetings of the Permanent Observatory
	Institutional lock-in costs	Adaptation or replacement	Meetings to include DSC arrangements within Permanent Observatory framework
Source: Hanna (1995) [8]	Source: Marshall & Alexandra (2016) [23]	Sources: Marshall (2013); McCann (2005) [21] ; McCann and Easter (2004) [13];	Source: Authors' elaboration

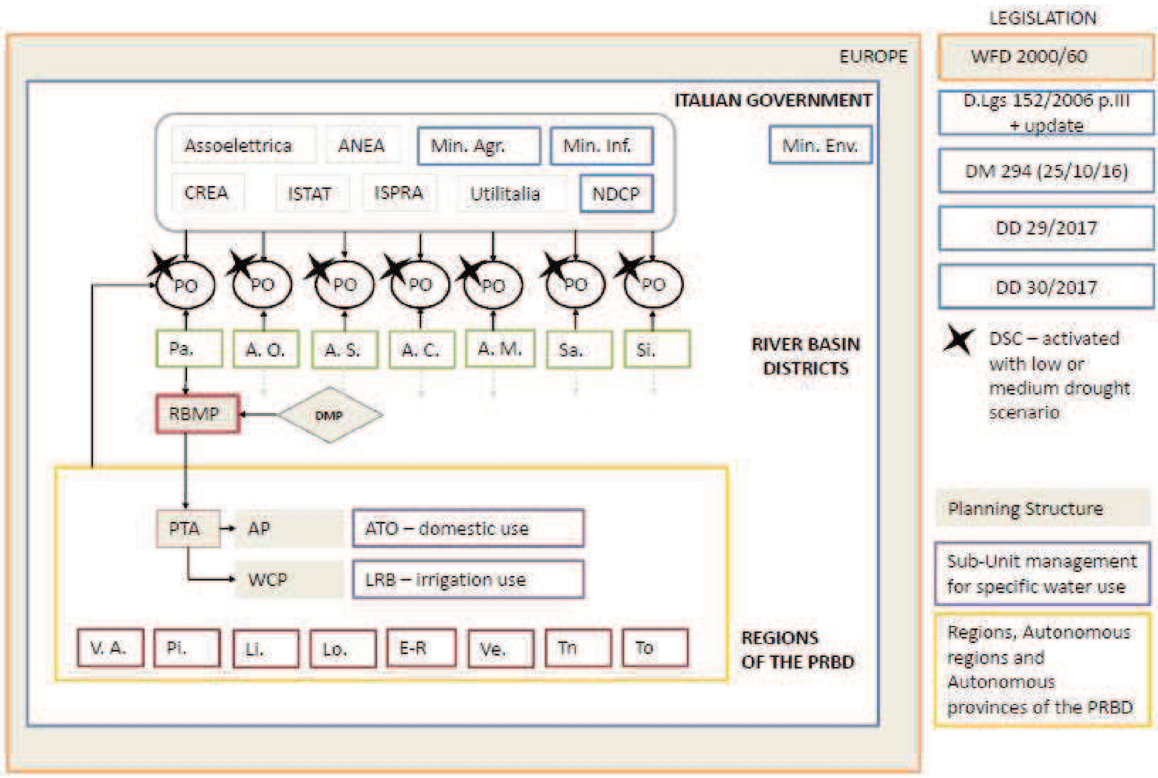
Results

Stakeholder map and assessment of governance arrangements

We begin with our detailed institutional maps of coordinated drought responses at the national and local levels. Current drought management systems in in the seven Italian river basin districts involve three authorities linked to River Basin Management Plans (RBMPs). These authorities include: the Italian national government and its related Ministries responsible for meeting European legislation and coordinating and monitoring the other authorities; the seven river-basin districts that prepare and pursue their individual RBMPs[3]; and the regions/autonomous regions/autonomous provinces within each river-basin district (Figure 2.4). These organisations are part of the Permanent Observatory and have to implement the RBMP through a Protection Plan (PTA, in Italian: "*Piano di tutela delle acque*") by addressing the qualitative and quantitative water resource management objectives.

Based on the objectives of the PTA, the Optimal Territorial Areas (in Italian: "*Ambito Territoriale Ottimale*", ATO, for the domestic use of water) and the Land Reclamation Boards (LRB, in Italian: "*Consorzi di Bonifica*" for the management of irrigation water) are in charge of preparing the Area Plan (AP, in Italian: *"Piani d'Ambito"*) and water conservation plans (WCP, in Italian: "Piani di conservazione delle Acque") respectively. During this process, drought is monitored through the relevant basin's Drought Management Plan (DMP), a subsidiary instrument to the RBMPs that assesses the basin status on a continuous basis using four stages (normal, pre-alert, alert, and emergency), and identifies appropriate measures to delay and/or mitigate drought impacts (e.g. information campaigns) [34]. Therefore, a variety of legislative requirements must be adhered to with respect to drought events.

[3] The 2nd River Basin Management Plans (RBMP, 2015-2021) were adopted by the Italian Government on 27 October 2016 and present an updated framework of the available knowledge for an integrated management of water resources. The RBMP identify the programs (which include the PO) created to achieve environmental quality objectives, also taking into account any measures envisaged by the first cycle of RBMP that are not yet realized.



Notes: critical Italian government institutions (from 2016 onwards) include the Department of National Civil Protection (NDCP), the Ministry of Agriculture (Min. Agr), the Ministry of Infrastructure (Min. Inf) and the Ministry of Environment (Min. Env.). The Permanent Observatories (POs) are now operating in each RBD: Pa=Padano (PRBD); A.O.=Alpi Orientali; A.S.= Appennino Settentrionale; A.C.= Appennino Centrale; A.M.=Appennino Meridionale; Sa.= Sardegna; Si=Sicilia. The Po River Basin District sub-regions are: V.A.=Autonomous Region of Valle d'Aosta; Pi.=Piedmont; Li.= Liguria; Lo.=Lombardy; E-R= Emilia-Romagna, Ve.=Veneto; Tn= Autonomous Province of Trento; To=Toscany.

Figure 0.4: Framework of drought management arrangements in Italy.

When a drought emergency is declared in the PRBD, the DSC is triggered. Naturally, this process requires coordination at a decentralised level. The PRBA is responsible for coordinating all DSC stakeholders (local and national), and their responses to the emergency drought status (Figure 2.5). The PRBA collects, updates and disseminates information on the availability and use of water resources across the relevant river basin organisations. These include: the Italian Ministries of Agriculture, Environment, Infrastructure, and Productive Activities; representatives from each of the five Lake Regulators; the Dam Management Agencies; the operator of the national transmission grid (*Gestore della Rete di Trasmissione Nazionale* – GRTN); the inter-regional agency for the Po river (*Agenzia Interregionale per il Po* - AIPO); the national Association of Land Reclamation Boards (*Associazione Nazionale bonifiche e Irrigazioni* - ANBI); the agencies responsible for energy supply (*Società di Produzione d'Energia elettrica* - SPE); representatives from regional drought committees responsible for managing these emergencies at the local level; and a representative from the autonomous province of Trento. The PRBA is responsible for notifying these stakeholders that a DSC has been convened, and calling on them to participate in the process and provide the latest technical synthesis reporting to describe current water resources through indicators, bulletins, reports etc. This technical information is supported by hydrologic modelling data and technical information provided by the Regional Environmental Agency of the Emilia-Romagna Region (*Agenzia Regionale della Protezione Ambientale* -ARPA-ER) and used to reach decisions on water reallocation via agreement or consensus.

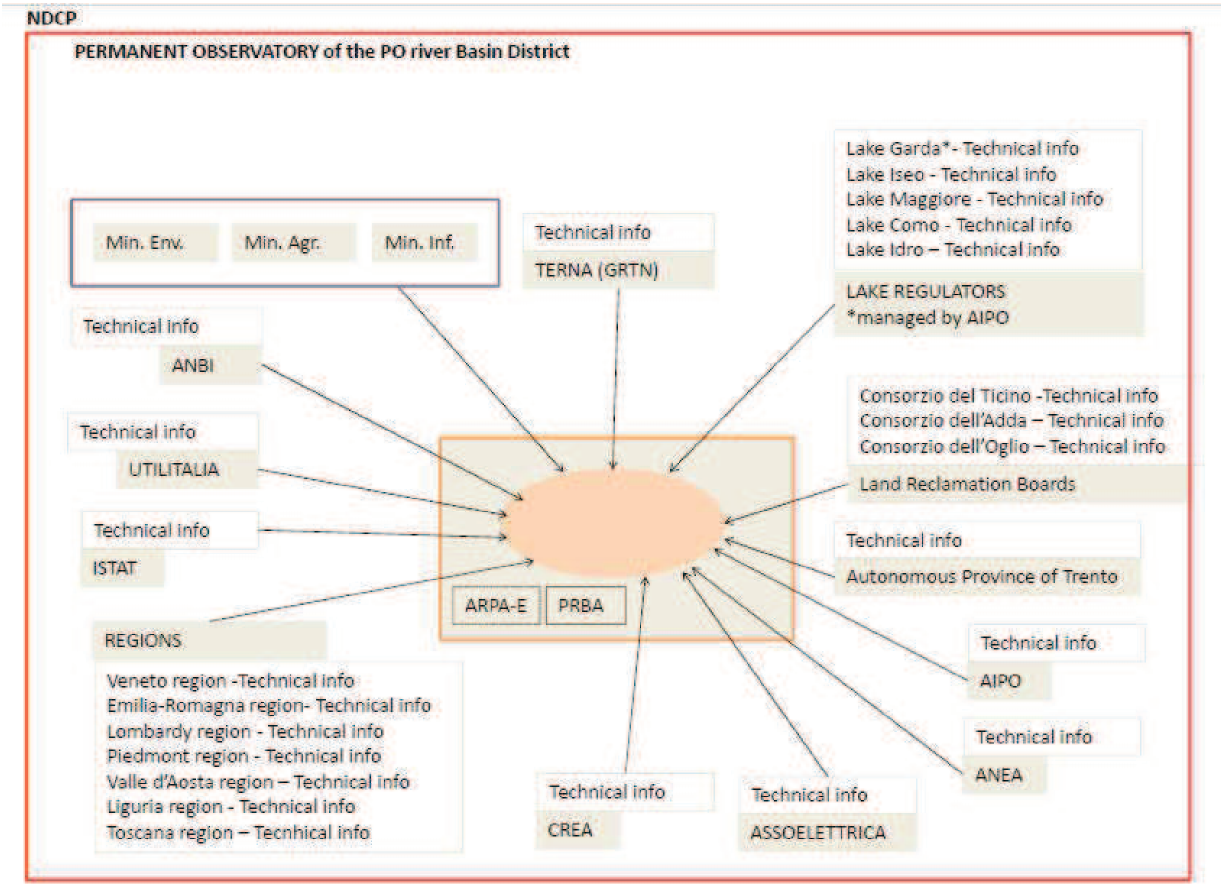


Figure 0.5: Participatory map of the Permanent Observatory of the PRBD stakeholders, 2016 – ongoing.

From the interview process it became clear that, when first implemented, the DSC was not trusted to deliver interventions on its own and needed the administrative support from one or more relevant authorities (i.e. the PRBA and other key institutional stakeholders). However, this is changing under new Permanent Observatory (PO) regulatory structures aimed at strengthening informal cooperation and dialogue between water governance organisations within each district and promoting the sustainable use of the water resources in line with the EU-WFD. These arrangements did not increase formal institutions though. The PO is a voluntary and subsidiary operational structure supporting integrated water governance to manage the collection, update and dissemination of data on the availability and use of water resources in the districts. The PO thus provides guidelines, rather than prescriptive arrangements, for the regulation of withdrawals, resource uses, and possible compensation to users. During droughts, the PO interacts with the DSC to ensure common objectives that include an adequate flow of information—necessary for the assessment of critical water scarcity levels, the evolution of that scarcity and current water withdrawals, and for implementing appropriate emergency actions to proactively manage the drought event. Public and private organisations at all levels of water governance can therefore participate in the decision-making to achieve these common strategic objectives during a drought.

The arrangements identified for the PRBD above thus offer a good example of informal water governance institutions for managing drought events. This is because: i) the DSC is not legally recognised, and stakeholders participate on a voluntary basis; ii) there is no capacity for sanctions in the case of non-compliance with decisions made at the meetings; and iii) in cases of conflict, the DSC cannot be sued and/or prosecuted because of its informal status. Yet the arrangements detailed above also have an increased potential to meet EU-WFD objectives over existing institutional approaches due to their integrated water resource management methods, coupled with processes aimed at avoiding political or legal interference (last-resort measures) during drought emergency response implementation. The DSC thus demonstrates capacity for coordinating actions on a voluntary basis and encompassing a wide range of stakeholder trust (democratic legitimacy), while achieving robust water governance institutions.

Transaction costs measurement and analysis

In order to test whether informal institutions within water governance arrangements can result in lower transaction costs over time, the average static transaction costs must reduce over time, and any periodic institutional transition costs associated with drought events must be short-lived. Our measurements of total transaction costs for the DSC involved in establishing, coordinating and managing the DSC are summarised in Figure 2.6, while the share of ex ante and ex post transaction costs is shown in Figure 2.7. A more detailed breakdown of the individual ex ante and ex post transaction cost categories is available in Appendix 1. The base-line is the 2003 drought event, when the DSC officially came into existence.

As shown, initial transaction costs were relatively significant in that year, consisting mainly of enactment and research/information gathering investments. Growth in total transaction costs was then experienced in response to three-consecutive drought events (2005-2007). This corresponded to investments in further information gathering, administrative costs for the DSC, and hydrological modelling to monitor water use across the relevant PRB sub-regions. Interview analysis revealed that a significant fraction of these costs involved identifying and agreeing upon common objectives for the DSC, consistent with informal network requirements and building trust between the stakeholders.

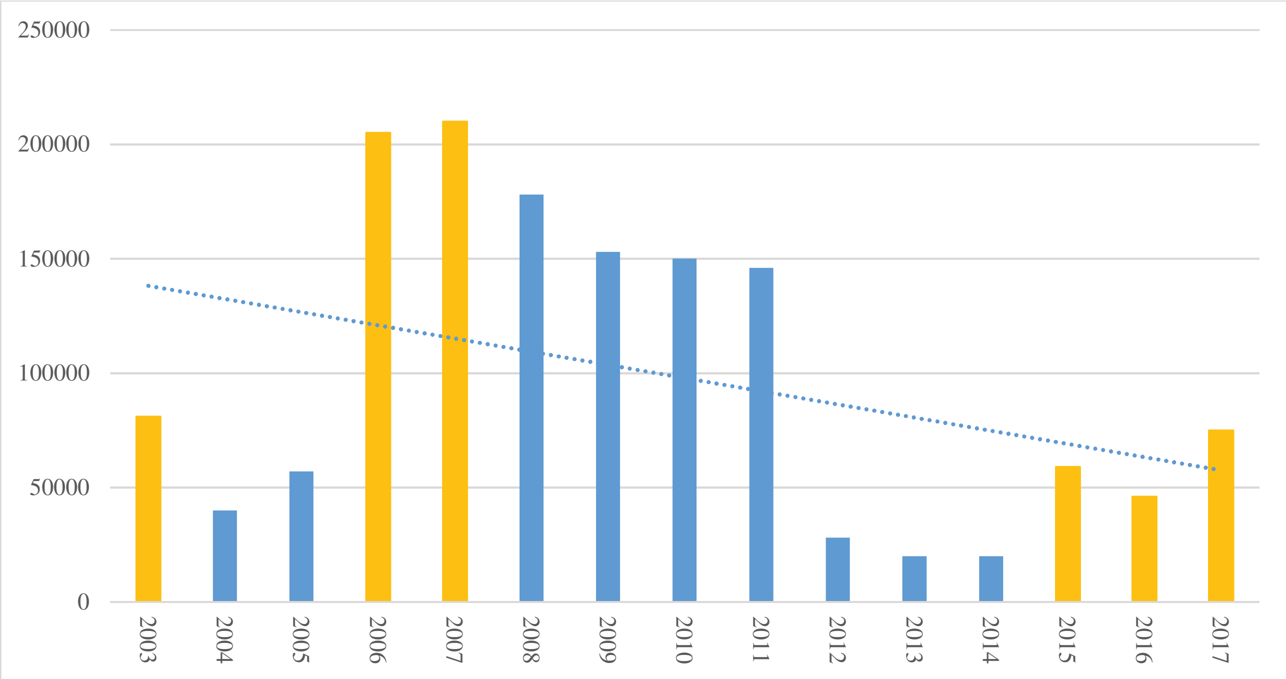


Figure 0.6: Total transaction costs (in Euros) for the DSC, 2003 to 2017 (years with droughts events are marked in orange).

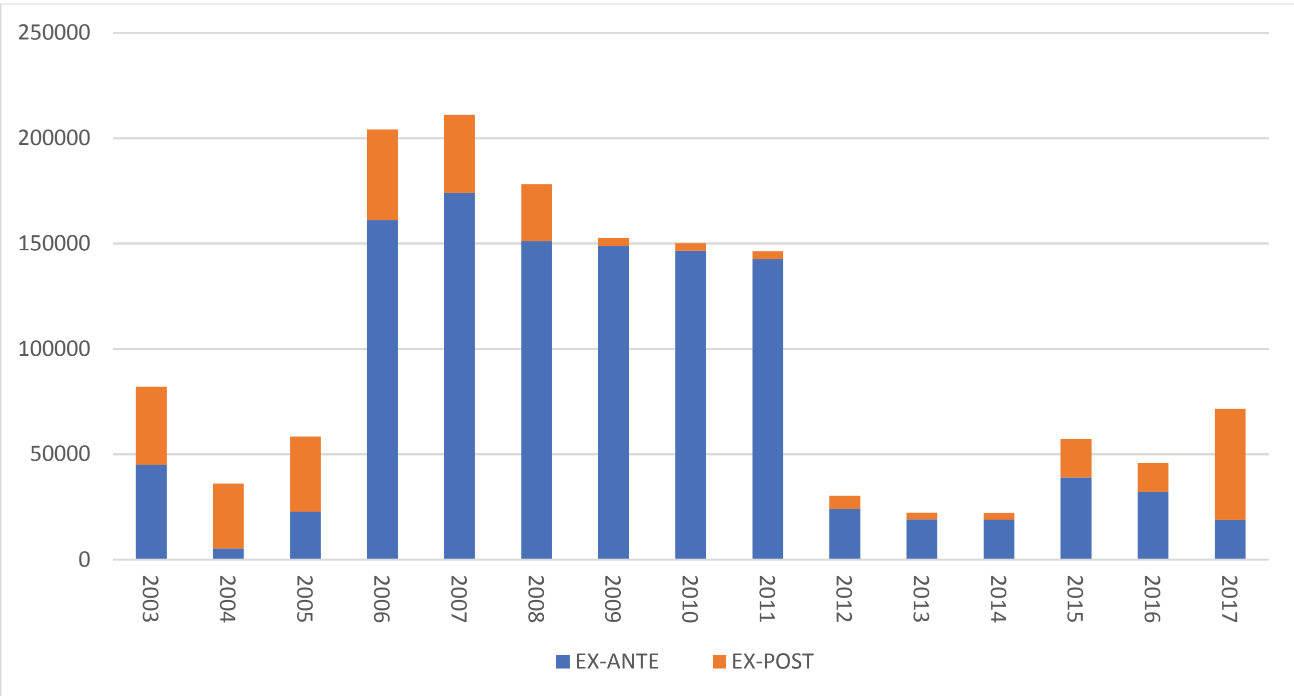


Figure 0.7: Ex-ante and Ex-post transaction costs (in Euros) for the DSC, 2003 to 2017. Droughts are in years 2003, 2006, 2007, 2015, 2016, 2017.

Post-2007, there are no drought emergency events occurring in the PRB. While investments in the hydrological modelling continued for a few years (2008-2011), the DSC total transaction costs generally fell as extraordinary meetings were not needed, and administration costs for routine management comprised the majority of required investment. However, in the period between 2015 to 2017 a series of consecutive drought emergency events occurred. This period also reflects the shift toward interaction with the PO arrangements, requiring some increased transaction costs. In response, transaction costs rose somewhat over that period due to increased administration and the enforcement of DSC requirements—but critically this increase is approximately one-third of the peak transaction costs of previous periods. Some of the lowering of transaction costs is due to an increased use of technology to support/conduct DSC meetings, as well as a lower degree of drought severity in the later events, relative to the period before 2010. Many of the meetings were now held at the PRBA using media such as Skype to allow stakeholders access to the meeting events and to share information updates/views. This lowered the requirement for travel and salary costs to attend meetings in person for many of the organisations, as well as the response and coordination times for managing drought emergencies.

With specific regard to individual transaction costs categories (Appendix 1), average static transaction costs decrease over the period considered, while short-lived institutional transition costs increases are observed during drought events (Figure 6). In total however, the trend is downward which suggests a lowering or minimisation of total costs across the life of the informal DSC governance arrangements. According to, such trends indicate robust institutional outcomes -i.e. institutions that are capable of taking corrective action through "relatively less transaction cost-intensive autonomous and planned adaptation" [43].

Discussion

The results from our analysis of the collected data offers a novel contribution to the transaction cost literature by: i) applying ex-ante and ex-post transaction cost measurement to informal institutions and ii) showing how informal institutions can underpin water governance/management arrangements that may lower transaction costs related to drought management in an EU context. The results from the informal management of drought events at river basin scale determined the following key points.

Drought management arrangements

Compared to other natural or anthropogenic disasters such as earthquakes and floods, drought has peculiar characteristics. Drought does not occur exclusively in the presence of specific geophysical, geographical conditions, hydrological or climatic, but it can indifferently affect either dry or wet regions with impacts that can last for a long period of time with damage that can be local or widespread. Thus, drought potentially requires a flexible management approach that is able to monitor the evolution of the event, to then respond within and across multiple governance levels. In comparison to formal arrangements available in Italy, the informal DSC approaches outlined above may be more flexible and adaptive with respect to drought management, which is also consistent with new EU water governance objectives. Shifting the management focus to a local level increases the appreciation of drought impacts and provides for more appropriate responses in shorter timeframes than that of monocentric models; although such shifts may also lead to local capture of, and rent-seeking in, the policy process.

Positive effects of the DSC also arise from improved information transmission among stakeholders, and a tangible capacity to lower drought impacts and increase adaptive capacity. Further, monitoring the availability of water resources (inflows, reservoirs, outflows) and their adjustment in real time has allowed the DSC to more quickly recognise and react to drought events via the use of short to medium term forecasting tools, drought indicators, and event evolution scenarios. These scenarios have also contributed to the construction of regional technical tools in support of managing water balances at the basin scale. Finally, the recent institutionalisation of DSCs and relevant stakeholder involvement across all (ordinary) periods of water management through the PO, rather than limiting their existence to drought periods, is an improvement upon the typically reactive (emergency) commencement of Italian management measures.

Without a measurement of the marginal centralised transaction costs in contrast to counterfactual institutional arrangements we cannot draw any formal conclusions about the value for money or total transaction cost differentials. However, the PRB DSC arrangements have now been extended across each of the seven River Basin Districts (RBDs) in Italy, formally established in May 2017[4]. According to interviewed stakeholders, the DSC arrangements were attractive to the Italian government because they did not require any additional funding to implement, while avoiding some negative impacts of drought events. Thus, it seems logical to conclude that the political value of these transaction costs and their institutional outcomes has been recognised. By favouring an informal institution like the DSC, the Italian government could potentially observe an increase in the effectiveness of water governance arrangements; although it will require further evidence over time to support this conclusively. This will be the focus of a future research project.

[4] The seven river basin districts were enacted by the Conferenza Istituzionale Permanente on May 23rd 2017, following the establishment of the Permanent Observatories by the Italian Ministry for the Environment in July 2016.

Transaction costs and policy performance analysis

Our findings are relevant for policy makers and other stakeholders beyond the PRB. The measurement and analysis of transaction costs undertaken here paves the way toward performance assessment of similar initiatives based on informal voluntary partnerships for water management in Italy and Europe. These include incipient river contracts, forums for dialogue and knowledge sharing between public/private stakeholders, and local communities in compliance with the EU's subsidiarity principle which are gaining momentum in Italy and elsewhere in Europe [44]. A constraint to any application of the findings reported here may arise from the non-conjunctive catchment characteristics of the PRB; that is, they do not share water resources with other basins. This is often not the case for the other river basin contexts in Italy or elsewhere in Europe, for whom the issues may be more challenging as a consequence and involve higher transaction costs.

Moreover, comparisons of the cost-effectiveness of alternative policy options to enhance flow rates during droughts must account for the total costs of the options relative to a baseline or status-quo scenario. These include the transaction costs of the reform measures, along with any abatement costs incurred by economic agents during the implementation of local adaptation strategies. Recent research focusing on the analysis of abatement costs in the PRB shows that the proportional rule used to reallocate water under the DSC approach—which relinquishes a fixed percentage of the initial allocation from users irrespective of the economic losses involved—underperforms other formal drought management arrangements such as water charges [45]. This gap will be further amplified via forward and backward linkages among economic sectors within the PRB, and with other Italian regions outside the basin. A complete policy performance assessment thus calls for empirical analyses that combine transaction and abatement costs estimates [46]. This too will be incorporated into future research work in the area.

Transaction costs and uncertainty analysis

Finally, water resource management is performed in a context of deep uncertainty, where it is often not feasible to identify all possible outcomes and/or assign a probability to each identified possible outcome. Future climate change and economic dynamics may change the outcomes reported in this study. Further research will be necessary to determine under what conditions this may happen, and any requirement to adjust or change policy accordingly [47].

As indicated above, our transaction cost measurement framework can provide initial information on the robustness of PRB institutional arrangements. However, conclusions about the robustness of these arrangements in response to future uncertainty would need to consider additional measures of adaptive efficiency Garrick (2015) [48] . To be complete, these measures would also have to include the lock-in cost impacts of institutional options to allow for a cost-effectiveness evaluation [9]. Similar to the work undertaken by Loch & Gregg (2018) [42] this would entail identifying and measuring three performance indicators over space and time: (1) how well the drought management objective(s) have been met; (2) the average transaction costs per unit of those met objective(s); and (3) total program budgets. For adaptively efficient institutions, these three performance indicators should be increasing, decreasing and sufficient respectively. Measures of these indicators are beyond the scope of this study, but remain an objective for the wider research program that is focused on identifying instruments best-suited to achieving water policy and management targets. The wider research focus of this work will examine maximised benefits per unit of transaction cost (alternative measure of cost effectiveness), as well as maximising the net public/private gains from transaction cost expenditure (social welfare). This broader assessment framework should enable a more comprehensive assessment of total policy or program benefit-cost outcomes.

Conclusion

Transaction costs matter for effective organisation and institutional management of scarce resources such as water. During times of drought, formal institutions may provide inflexible management arrangements that may increase total transaction cost requirements. This paper explores the transaction costs associated with informal drought management arrangements in the PRB of northern Italy. We measure and track these transaction costs with respect to drought periods in the basin to explore the total costs associated with this institutional approach, and note that the DSC arrangements have now been mandatorily adopted by the six other River Basin Districts in Italy—somewhat ironically as this has formalised what was originally an informal process. It remains to be seen whether the formalisation of drought management arrangements based on the PRBD DSC will ultimately increase total transaction costs, or further reduce the total transaction costs of drought management in Italy by following a participatory, consensus-based approach elsewhere. However, without a more detailed study of centralised costs it is impossible to draw more robust conclusions. That said, our study highlights the usefulness of transaction cost case studies, and the need for extensions to this approach that incorporate not only transaction and abatement cost minimisation evaluations, but also assessments of per unit private/public welfare benefits that accrue from policy and programs such that more comprehensive evaluations and uncertainty analyses may be achieved in future. We believe this to be a rich area of future research that may require the incorporation of climate, hydrological and economic modelling assessments to be successful.

Acknowledgements

Dr Loch’s involvement in this research was funded under an Australian Research Council DECRA grant (DE150100328) and the 2015-16 UNESCO Grants Program. The authors are thankful to Dr Graham Marshall and Dr David Adamson for useful comments and advice on earlier drafts of the paper, and to the experts from the Po River Basin District Authority and the Environment Agency of Emilia-Romagna for their valuable support in this research. The authors thank Mattia Amadio for drawing Fig. 1b.

References

[1] IPCC, "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change," Geneva, 2014.

[2] R. Damania *et al.*, *Uncharted Waters: The New Economics of Water Scarcity and Variability*. S.l.: World Bank Publications, 2017.

[3] OECD, *Water Resources Allocation: Sharing risks and opportunities*. OECD Publishing, 2015.

[4] World Bank, "High and Dry: Climate Change, Water, and the Economy," World Bank, Washington D.C. (US), Report, 2016.

[5] D. C. North, *Institutions, Institutional Change, and Economic Performance. , 1990*. Cambridge: Cambridge University Press, 1990.

[6] C. R. Williamson and C. B. Kerekes, "Securing Private Property: Formal versus Informal Institutions.," *J. Law Econ.*, no. 54, pp. 537–572, 2011.

[7] A. Agrawal, "The Role of Local Institutions in Adaptation to," *Soc. Dev.*, no. February, p. 65, 2008.

[8] S. Hanna, "Efficiencies of user participation in natural resource management," in *Property rights and the environment: Social and ecological issues*, Washington, 1995, pp. 59–67.

[9] G. R. Marshall, "Transaction costs, collective action and adaptation in managing complex social-ecological systems," *Ecol. Econ.*, vol. 88, pp. 185–194, 2013.

[10] K. Krutilla and R. Krause, "Transaction costs and environmental policy: an assessment framework and literature review.," *Int. Rev. Environ. Resour. Econ.*, no. 4, p. 261–354., 2011.

[11] L. McCann, "Transaction costs and environmental policy design.," *Ecol. Econ.*, no. 88, pp. 253–262, 2013.

[12] D. Garrick and B. Aylward, "Transaction costs and institutional performance in market-based environmental water allocation.," *Land Econ.*, no. 88, pp. 536–560, 2012.

[13] L. McCann and K. W. Easter, "A framework for estimating the transaction costs of alternative mechanisms for water exchange and allocation," *Water Resour. Res.*, vol. 40, no. 9, pp. 1–6, 2004.

[14] R. Landry and N. Amara, "The impact of transaction costs on the institutional structuration of collaborative academic research," *Res. Policy*, vol. 27, no. 9, pp. 901–913, 1998.

[15] N. Hernández-Mora and L. De Stefano, "Los mercados informales de aguas en España: una primera aproximación," in *Usos Del Agua: Concesiones, Autorizaciones y Mercados Del Agua.*, Embid Iruj., Cizur Menor (Spain): Thomson Reuters Aranzadi, 2013.

[16] S. Santato, J. Mysiak, and C. Pérez-Blanco, "The Water Abstraction License Regime in Italy: A Case for Reform?," *Water*, vol. 8, no. 3, p. 103, Mar. 2016.

[17] A. Mobarak, A. Mushfiq, and M. R. . Rosenzweig, "Informal Risk Sharing, Index Insurance, and Risk Taking in Developing Countries," *Am. Econ. Rev.*, vol. 103, no. 3, pp. 375–80, 2013.

[18] J. Sobels, A. Curtis, and S. Lockie, "The role of Landcare group networks in rural Australia: exploring the contribution of social capital.," *J. Rural Stud.*, vol. 17, pp. 265–276, 2001.

[19] N. Wang, “Measuring Transaction Costs: An Incomplete Survey,” *Conf. Trans. Costs*, vol. 2, p. 16, 2003.

[20] A. Benham and L. Benham, “The Costs of Exchange,” *Ronald Coase Inst. Work. Pap. Ser.*, pp. 1–14, 2001.

[21] L. McCann, B. Colby, K. W. Easter, A. Kasterine, and K. V. Kuperan, “Transaction cost measurement for evaluating environmental policies,” *Ecological Economics*, vol. 52, no. 4. pp. 527–542, Mar-2005.

[22] D. Garrick, “Water allocation in rivers under pressure.,” vol. Edward Elg, 2015.

[23] G. R. Marshall and J. Alexandra, “Institutional path dependence and environmental water recovery in Australia’s Murray-Darling Basin,” *Water Altern.*, vol. 9, no. 3, pp. 679–703, 2016.

[24] M. Amadio, J. Mysiak, L. Carrera, and E. Koks, “Improving flood damage assessment models in Italy,” *Nat. Hazards*, vol. 82, no. 3, pp. 2075–2088, 2016.

[25] ADBPO, “Caratteristiche del bacino del fiume Po e primo esame dell’impatto ambientale delle attività umane sulle risorse idriche. Autorità di Bacino del Fiume Po,” Parma, 2006.

[26] R. Vezzoli, P. Mercogliano, and S. Castellari, “Scenari di cambiamenti climatici nel periodo 2021-2050 : quale disponibilità idrica nel bacino del fiume Po ?,” *Ing. dell’Ambiente*, vol. 3, no. 1, pp. 44–52, 2016.

[27] A. L. Zollo, V. Rillo, E. Bucchignani, M. Montesarchio, and P. Mercogliano, “Extreme temperature and precipitation events over Italy: assessment of high-resolution simulations with COSMO-CLM and future scenarios.,” *Int. J. Climatol.*, vol. 36, pp. 987–1004, 2016.

[28] S. B. Guerreiro, R. J. Dawson, C. Kilsby, E. Lewis, and A. Ford, “Future heat-waves, droughts and floods in 571 European cities,” *Environ. Res. Lett.*, vol. 13, no. 3, 2018.

[29] ISPRA, “Adattamento ai cambiamenti climatici: strategie e piani in Europa,” 2009.

[30] S. Tibaldi, C. Cacciamani, and S. Pecora, “Il Po Nel Clima Che Cambia.,” *Biol. Ambient.*, vol. 24, pp. 21–28, 2010.

[31] MATTM, “Piano Nazionale di Adattamento ai Cambiamenti Climatici PNACC. Prima stesura per la consultazione pubblica Luglio 2017,” 2017.

[32] MATTM, “Strategia Nazionale di Adattamento ai Cambiamenti Climatici Indice (National Strategy of Adaptation to Climate Change),” 2014.

[33] C. M. Gomez, D. Pérez-Blanco, D. Adamson, and A. Loch, “Managing Water Scarcity at a River Basin Scale with Economic Instruments,” *Water Econ. Policy*, vol. 4, no. 1, p. 1750004, 2017.

[34] EC, “Drought Management Plan Report,” 2008.

[35] C. D. Pérez-Blanco and C. M. Gómez, “Insuring water: a practical risk management option in water-scarce and drought-prone regions?,” *Water Policy*, vol. 16, no. 2, pp. 244–263, Apr. 2014.

[36] OECD, “OECD Environmental Performance Reviews: Italy 2013.” Publishing. http://dx.doi.org/10.1787/9789264186378-en, 2013.

[37] GU, “Legge 5 Gennaio, N. 36 Disposizioni in Materia Di Risorse Idriche., Rome, Italy.,” 1994.

[38] EC, *Water Framework Directive 2000/60/EC*. 2000.

[39] EC, “Addressing the Challenge of Water Scarcity and Droughts in the European Union.,” no. European Commission, Brussels, Belgium. 2007.

[40] ADBPO, "Piano Stralcio del Bilancio Idrico del distretto idrografico padano. Piano per La Gestione Delle Siccità E Direttiva Magre.," Parma (Italy), 2016.

[41] D. B. Thompson, "Beyond benefit-cost analysis: Institutional transaction costs and regulation of water quality," *Nat. Resour. J.*, vol. 39, no. 3, pp. 517–541, 1999.

[42] A. Loch and D. Gregg, "Salinity management in the Murray-Darling Basin: a transaction cost study," *Water Resour. Res. An ANU J.*, 2018.

[43] D. Garrick, S. Whitten, and A. Coggan, "Understanding the evolution and performance of market-based water allocation reforms: a transaction costs analysis framework.," *Ecol. Econ.*, no. 88, pp. 185–205, 2013.

[44] M. L. Scaduto, *River Contracts and Integrated Water Management in Europe.* Germany.: Springer International Publishing, 2016.

[45] C. D. Pérez-Blanco, E. E. Koks, E. Calliari, and J. Mysiak, "Economic Impacts of Irrigation-Constrained Agriculture in the Lower Po Basin.," *Water Econ. Policy*, 2017.

[46] C. D. Pérez-Blanco, G. Standardi, J. Mysiak, R. Parrado, and C. Gutiérrez-Martín, "Incremental water charging in agriculture. A case study of the Regione Emilia Romagna in Italy.," *Environ. Model. Softw.*, no. 78, pp. 202–215, 2016.

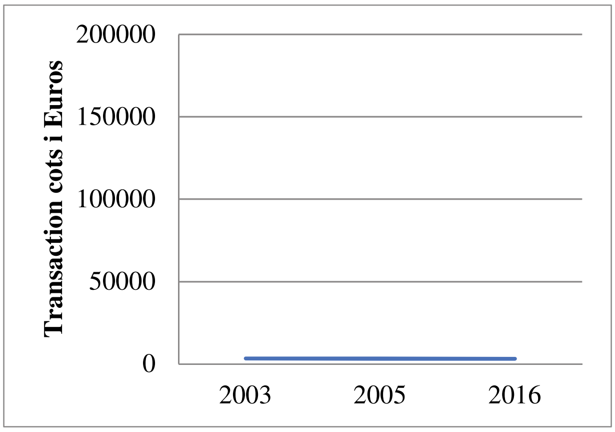
[47] M. Kandlikar, J. Risbey, and S. Dessai, "Representing and communicating deep uncertainty in climate-change assessments. Comptes Rendus Geoscience," no. 337, pp. 443–455, 2005.

[48] D. Garrick, *Water Allocation in Rivers under Pressure: Water Trading, Transaction Costs and Transboundary Governance in the Western US and Australia*. 2015.

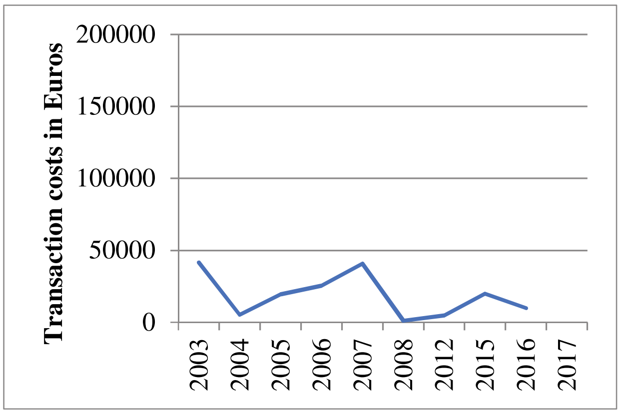
Appendix 1: Measures of DSC individual ex ante/ex post transaction cost categories over time

Ex ante transaction costs (in Euros):

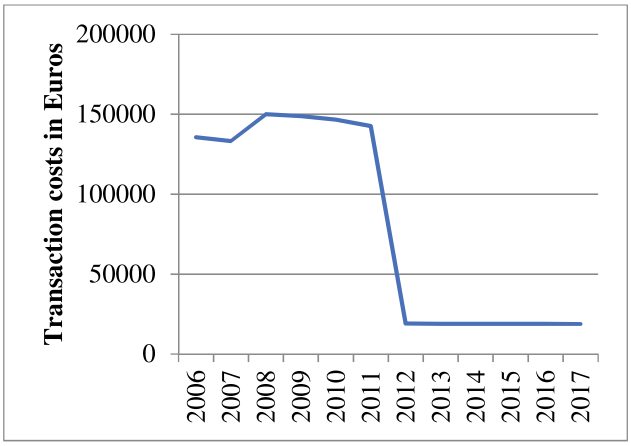
a. Enactment costs



a. Research and Information

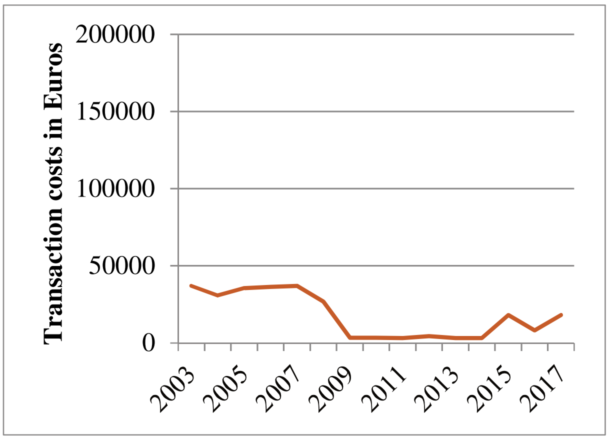


a. Hydrological model implementation

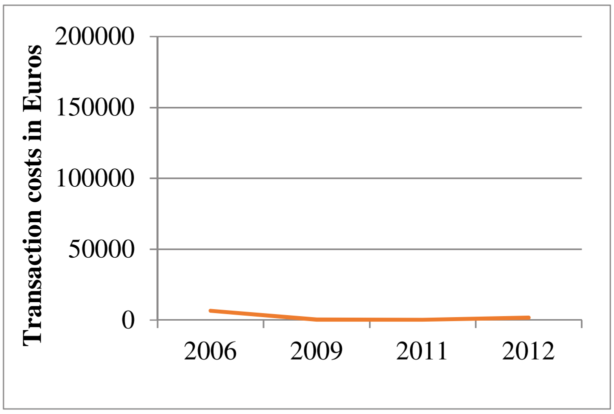


Ex post transaction costs (in Euros):

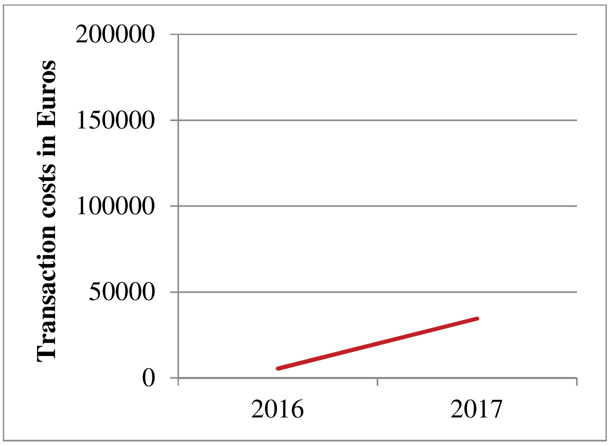
d. Meeting administration and coordination



e. DMP compliance monitoring



f. Enforcement of drought management planning



ECONOMIC INSTRUMENTS FOR GROUNDWATER MANAGEMENT: INSIGHTS FROM FORESTED INFILTRATION AREAS IN ITALY

Introduction

Groundwater is an essential source of water supply around the world as well as an important contribution in terms of base flows of rivers, acting as a buffer during the dry periods [1]. Balancing and properly managing such flow is of vital importance both for human activities and natural ecosystems. Water abstraction for drinking water supply and irrigation purposes represents the main cause for failure in reaching a good quantitative status. In Europe, more than 50 % [2], [3] of drinking water and over 40 % [1] of irrigation water is taken from aquifers. The regulative frameworks define the management of the resource and influence the behaviour of underground water users [4]. Yet, when water is cost-free for the user and in the absence of intervention, the resource is misallocated causing an unsustainable water abstraction. In many countries, such as Italy, the regulatory frameworks are variable, and are often split into self-contained sets of regulations dealing with water, industry and agriculture — a situation that is not particularly helpful to local policy-makers. Recent drought episodes demonstrate that the institutional and legislative national framework on water management is not flexible enough to cope with growing demand and projected climate changes [5] causing an increasing deficit and negative impacts on environmental flows [6].

In the last decades economists started to focus in the theoretical application of economic tools in the area of groundwater resources, understanding the challenges and opportunities for its management [7], [8]. The use of economic instruments allows to consider environmental or social costs into the prices of goods, services or activities that give rise to them [9]. Induced by price signals, the users reduce inefficiency in using the resource seeking for optimal allocation. The economic instruments are significant for the application of the "polluter and user pays principle" because they call into question the polluter to pay for damages, rather than the whole community. With this regard, the EU Water Framework Directive (WFD) [10] and the EU Groundwater Directive (GW) [11] provide a solid legislative basis for long-term integrated water management in the EU. The implementation of Article 9 of the WFD (which requires Member States to take account of the principle of recovery of the costs of water services, including environmental and resource costs) is important for strengthening water efficiency. Indeed, it has been acknowledged that water pricing and non-pricing measures have a high potential to provide an incentive for more efficient water use and thus help to achieve the environmental objectives under the Directive. Equally, the Roadmap to a resource-efficient Europe under the Flagship Initiatives of the European 2020 Strategy [12] identifies resource pricing as a key issue to be tackled, recognizing that, in some cases, market and prices, taxes and subsidies do not reflect the real costs of resource use, locking the economy into an unsustainable path. The policy orientation and course of action indicated by the Roadmap focuses on water efficiency, efficiency targets and better demand management through economic instruments.

Decision makers, water resource managers and water users in Italy have started to explore alternative measures for enhancing resilience to droughts and reliability of water supply for domestic, industrial, livestock watering and irrigation, which include underground storage [13], [14]. Among these, Managed Aquifer Recharge (MAR) involves building infrastructure and/or modifying landscapes to promote groundwater recharge. Over the past two centuries, MAR has been successfully implemented worldwide at different scales and for different purposes (i.e. maximize natural storage; water quality management; physical aquifer treatment; ecological benefits), often proving to be more sustainable and cost-effective in expanding the supply base as compared to other engineering-based solutions such as dams or saltwater desalination [15], [16]. At present, more than 1200 case studies from over 50 countries have been implemented [17], and MAR has reached an estimated 10 km^3 /year, ~2.4% of groundwater extraction in countries reporting MAR (or ~1.0% of global groundwater extraction). MAR is likely to exceed 10% of global extraction, based on experience where is more advanced [18]. At a EU level, MAR has played an important role in expanding the supply base, particularly for drinking-water [11]. Irrigation is also a relevant user of MAR, with 35 % of MAR resources being used to sustain agriculture in most Member States [19]. There currently are 224 active MAR sites reported [15] in 23 European countries. In Italy, the bulk of the MAR pilots are located in the northern area in the Veneto and Friuli-Venezia Giulia regions.

As far as MAR schemes are concerned, relevant EU Directives establish they may be adopted and implemented by Member States as long as an authorization or permit, control and monitoring regime is established within their jurisdictions [20]. In Italy, legislation concerning groundwater has often been neglected in comparison to the attention given to surface water and there is no ad hoc legislation on MAR. However, steps ahead have been accomplished with the transposition of the “polluter pays principle” from the WFD into the Decree DM 39/2015 [21] which also introduced an estimation method of the environmental and resource costs (ERC) associated with different water uses. Other relevant provisions on water management may be found in the so-called ‘Environmental Code’ 152/2006 (EnC [22]). Articles 104 and 105 aims at protecting the quality level of water sources and establishing specific measures to manage the discharge to superficial water and groundwater.

Traditional studies on MAR have been devoted to better understand the technical aspects/engineering behind groundwater recharge (i.e. runoff and discharge, hydrogeological characteristics, etc.), to develop methods for identifying optimal locations and suitability for MAR [23]–[25] based on attributes including water availability (ideally a river close to the MAR site), geology of the aquifer and topography, among others. On the other hand, the establishment of management rules of underground resources is essential for MAR, particularly where groundwater is considered as an open access good. A recent study from Dillon et al., 2018 [18] reported advances worldwide in MAR in the last 60 years and shows that their uptake depends both on technical and non-technical aspects. This calls for the design and/or reform of the institutional framework for water allocation and for the promotion of the use of economic instruments with an aim to support decision makers and promote efficient use of the resource.

This paper aims at contributing to a growing body of scientific research, by enquiring into the role of economic instruments for the governance of aquifers and their employment to enhance wider and effective MAR uptake. Our work focuses on Forested Infiltration Areas (FIA) in Italy, a pioneering MAR method ideated by Veneto Agricoltura to recharge groundwater aquifers. The FIA methodology implies that surface water is channelled during times of excess into designated areas that have been planted with various species of trees and/or shrubs. Since 2007, FIA has been implemented through 8 pilot studies in the upper plain of the Veneto region (Northern Italy) with the aim to address water scarcity challenges and/or to achieve environmental benefits over the long term.

Past, present and future challenges for underground water management in the Veneto region

The natural recharge of the aquifer is originated from the net infiltration of the rain, the water discharge dispersed and drained by rivers, and by irrigation channels and fields; the outflows are originated from water discharges from the springs and from the water fluxes springing from (or pumped out by) a large number of private and public wells operating in the area. The notable water abundance in the area and the shallow water table have resulted in uncontrolled—and until recently unregulated—drilling of a large number of private wells, many of which are still not metered. For the last 40 years, this has resulted in massive land use changes and growing groundwater use [26]. On the other side, climate change is directly affecting availability and dependency on groundwater [27], [28], especially in spring and summer. Changes in precipitation regime and more intense and prolonged droughts are likely to occur more frequently and with higher intensity in Italy [29]. A comprehensive assessment on the effects of climate change on groundwater resources in Veneto region has been carried out as a part of the Life+ TRUST project [30], [31]. Climate change scenario simulations (2071–2100) refer to the end of the irrigation period which corresponds to the summer when demand for water is high. Main results show that the groundwater recharge decreased by more than 70% with respect to the reference period. During winter, the 2071–2100 mean precipitation appears to be about 20% higher than in the control period (1971–2000). In contrast, rainfall tends to decrease during the other seasons and especially in summer, when precipitation appears to be 15%

weaker. This variability may affect groundwater initially and primarily through changes in water demand, in addition to changes in recharge and discharge [14] posing risk of aquifer depletion. Indeed, the monitoring of several public and private wells shows a negative trend of the groundwater piezometric head characterized by a loss of 1,20 meter in 40 years (-3 cm/year). This is a clear signal that the water extraction in the area exceeds the overall recharge rates, resulting in a continuous decrease of groundwater levels and contributing to the disappear of the springs [32]. A census carried out by the Brenta Land Reclamation Board (BLRB) shows that in the right bank of the river Brenta 25 springs out of 66 are extinguished and in the remaining 41 the recharge capacity has been reduced by 28% [33]. Another spring census conducted by the province of Vicenza in the context of AQUOR Life project reports around 16% of extinct resurgences [34]. Such situation limited the reserve of water and the recharge capacity of groundwater to the aquifers, damaging also the wetland ecosystem [35]. In 2017 the territory of Northern Italy was hit by a severe drought and spring water flow reached the historical minimum of 1 m3/s.

A possible measure designed to mitigate hydrologic impacts of groundwater over-exploitation and restore the groundwater balance in the long term is MAR. Forested Infiltration Areas (FIA) is a type of MAR scheme, conceived and developed in 2007 by Veneto Agricoltura, (the Veneto region authority responsible for aspects related to agricultural, forestry and agri-food development) involving an increasing number of stakeholders (see Annex 1). Stakeholder engagement and new local partnership ranging from consideration of alternatives to monitoring, and multi-disciplinary analyses to support decision-making demonstrated to be of high value and key for the development and implementation of FIA.

Forested Infiltration Areas in the Veneto region

Aquifers are connected with other natural systems (e.g. surface water) and allow the interaction with a large diversity of actors which interplay at different levels. Characterized by a high-permeability, the Upper Plain of the Veneto Region is strategic for recharging aquifer systems that constitute the local primary potable water resource, used also for irrigation and industrial purposes [36]. It contains a single unconfined aquifer that stretches from the Upper Plain to a transition zone 2–5 km wide (called “spring line”, in Italian: *linea delle risorgive*) where characteristic springs emerge (Fig. 3.1). Springs are a groundwater system’s connection to the surface and provide a constant source of water to the landscape throughout the year. They played an important role in the history of human settlements and provide valuable ecological refuges.

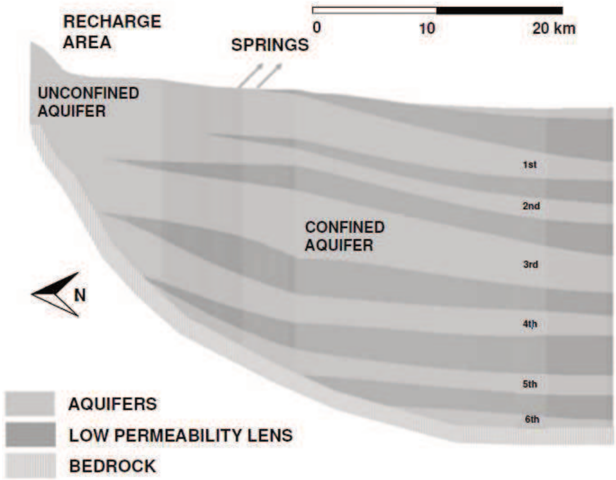


Fig. 3.1

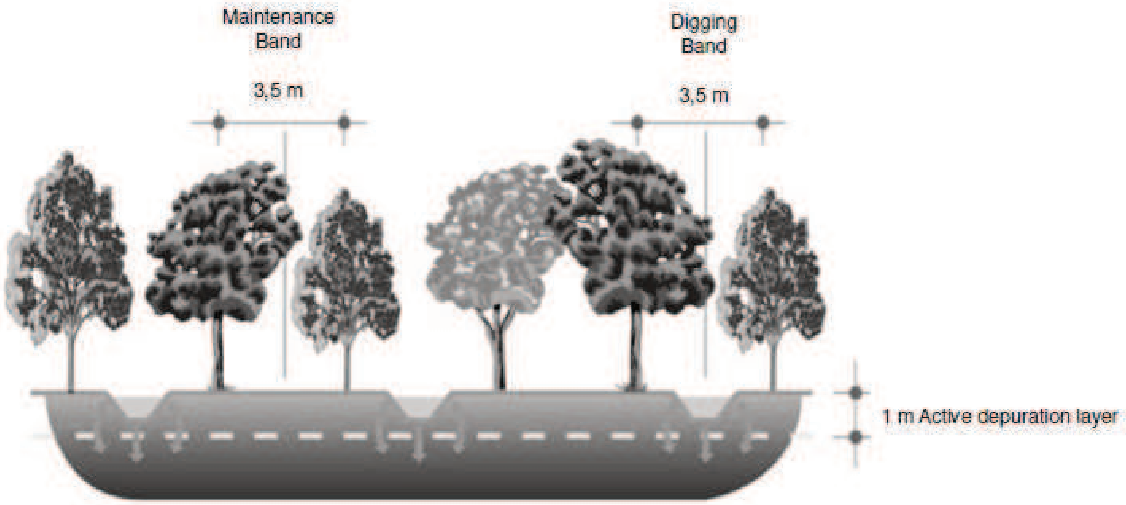


Fig. 3.2

Figure 3.1 Hydrologic scheme of high and med Veneto plain. The unconfined aquifer changes from high plain southwards to multi-layered confined or semi-confined aquifers (adapted from Passadore et al., 2012 [37] and its estimated thickness is around 250–300 m [38]). **Figure 0.2** Section of a Forested Infiltration Area (adapted from Mezzalira, Gusmaroli, and Niceforo 2014 [36])

FIA, the innovative method ideated by Veneto Agricoltura, consists in positively exploiting the high infiltration rate of the soils above the spring line for 200 days per year, allocating surface water to the cultivation of a short rotation forested area (provided that is possible to derive water from river without affecting the minimum water runoff). A FIA typically requires at least 0.5 ha [35] and a first pilot study has been implemented with the support of the province of Vicenza and by BLRB which acquired an area of 1 ha in the municipality of Schiavon (VI) [40] with the aim to determine the hydrologic performance of FIA over time and the possibility to export such technique to other identified suitable areas of the Brenta megafan (namely large landforms results from the tectonic setting). The FIA of Schiavon allowed to empirically demonstrate a water infiltration capacity of hundreds of thousands of cubic meters of water per year per hectare of area (approximately 0.8 Mm3 ha-1 year-1) opening the door for a possible replication of FIA in other areas of the Brenta megafan that suffer from groundwater resources depletion [41].

Following the inception pilot studies experience in 2007, the BLRB, together with other local authorities and with the collaboration of privates, created 8 FIA in its territory (Table 1), converting a total area of about 10 ha to recharge groundwater aquifers scope, and other 5 FIA with a total area of 7 ha are going to be implemented in the Municipality of Rosà (VI) by the end of 2018.

Some of these areas were implemented in the context of European LIFE Projects [42]. Particularly, two FIAs were partly financed by TRUST Project (Tool or regional-scale assessment of groundwater storage improvement in adaptation to climate change, LIFE07 ENV/IT/000475); and four received funding from AQUOR Project (implementation of a water saving, and artificial recharging participated strategy for the quantitative groundwater layer rebalance of the upper Vicenza's plain, LIFE 2010 ENV/IT/380).

Table 0.1 Dissemination of FIA in Veneto region from 2007 to 2018.

Year	N.	Where	Project	Scope
2007	1 FIA 1,2 ha	Schiavon (VI)	**Schiavon** – Democrito project, financed by BLRB	Determine the hydrologic performance of FIA over time
2008	1 FIA 1 ha	Schiavon (VI)	**Schiavon 2** -financed by Province of Vicenza and implemented with BLRB and Veneto Agricoltura	Study on different wood species and mechanical harvesting of FIA
2010	2 FIA 0,65 ha 0,67 ha	Pozzoleone (VI); Marostica (VI)	**LIFE TRUST** – with Alto Adriatico river basin authority, CMCC and Studio Galli	Nominated by EU "Best of the best" Life projects in 2012. FIA and climate change
2010	1 FIA 1,7 ha	Tezze sul Brenta (VI)	**RiduCaReflui** – coordinated by Veneto Agricoltura, in collaboration with BLRB and Universities	Management and technical solution to reduce nitrogen from livestock farming
2011	2 FIA 2,5 ha 1,2 ha	Carmignano di Brenta (PD); Schiavon (VI)	**LIFE AQUOR** – coordinated by province of Vicenza, in collaboration with BLRB and Veneto Agricoltura	Comparison between different types of MAR; opening of information office; study on economic benefits of FIA
2012	1 FIA 2 ha	Tezze sul Brenta (VI)	**RedAFI** – financed by Veneto region, coordinated by Veneto Agricoltura, in collaboration with ARPAV, BLRB and Universities	Follow-up on nitrogen reduction and biomass production
2018	5 FIA 7 ha	Rosà (VI)	BLRB	Replication of FIA in the territory of BLRB

FIA requires a relatively large quantity of water to supply the recharge of the aquifer. Artificial watercourses are preferred to natural ones, since the latter contains too many suspended solids during high flow and moderate flow periods that can block the porosity of the substrates and prevent the system from being effective. Notwithstanding, the infrastructure for irrigation supply managed by Land Reclamation Boards is present in the territory of Italy since centuries and is well developed in the plain area of Italy. A site that is located near an irrigation ditch of this type offers a decided advantage in terms of suitability for groundwater recharge systems. Another factor that make FIA successful is the quality of water. Donor water bodies that have chemical, physical and microbiological properties that will not have any negative impact on the aquifers. Projects results demonstrated also the benefits that FIA provide in terms of quality restoration. In the worst case, 1 ha of FIA can infiltrate 5.600 m3/ha/year with average concentration of nitrate around 20-25 mg/l: on average, the groundwater presents a value of 6 mg/l, confirming the depuration capacity of FIA [43].

On the quantity side, the measured data lead to infiltration capacity values in the range of 20 - 50 $l*s^{-1}$ per hectare, depending on soil permeability [44], posing FIA as a promising measure for the restoration of the groundwater balance. At the same time FIA improves the quality of groundwater, contributes to reduce heatwaves, mitigates CO2 emissions and enhances other ecosystems functions (e.g. aesthetic value), all this at a relatively low maintenance cost of the natural capital used [43]. Such positive effects are difficult to find in other type of MAR systems, which typically show a significant decline in the infiltration capacity over time due to progressive clogging [45] calling for expensive maintenance not required by FIA [41].

Economic instruments for groundwater management with FIA

Drought and water scarcity events are posing challenges to water demand management strategies in all Mediterranean countries, including Italy, recently experiencing overexploitation of groundwater resources [46]. As the resource becomes more scarce, challenges in protection and utilization arise. When groundwater use reaches a defined level of availability, an underground water-right system cab become a method to control over-abstraction. Such system could entitle users to take the resource in at a specific pint in time or in a given period of time. In the case users are not identified and if is not clear how much water they are entitled to use, the users themselves have no incentive to use the water efficiently because they are not aware how much water they can save today to abstract in the future. Moreover, if water rights exchanged among users are not clearly defined, thus there is no information about who would lose and who could gain including the sanctions in the event of non-compliance with the environmental objective. In Italy, the water abstraction licence information is incomplete or missing [5]. During prolonged droughts the water responsible institutions can enact temporary limitations to water withdrawals.

When water rights are clearly defined, economic instruments can support the decision-making process and encourage more efficient use of the underground water resource.

However, the design of economic instruments for FIA cannot be limited only to economic efficiency and the transparency of water rights. There are other aspects to consider that include the interplay between stakeholders and water/forest ecosystems to be efficient in achieving the environmental objective. Aquifers provide multiple benefits ranging from water supply and irrigation to sustaining ecosystems and are also essential for building resilience into our economic and social systems and adapting to climate change. Under the WFD, Member States are obliged to implement adequate incentives to use water resources efficiently, discouraging over-abstraction and misallocation. In many countries, water pricing and metering, together with water saving measures, have been highly effective in changing consumer behaviour.

Differently from surface water, groundwater has some peculiarities that need to be taken into account when designing economic instruments for its management [47]. First of all, groundwater is costly to assess due to high infrastructure and operation costs. Then legal entitlements are subject to zoning restrictions and availability causing increase costs for monitoring activities. Finally, some aquifers are more vulnerable than others, so the time-lags could vary differently.

Based on international literature on the economics of water management [9], [47]–[51] we identify the strengths of, barriers to and unintended consequences of major economic instruments (see Table 3.2) for managing groundwater extraction and pollution considering the case study of FIA in the Veneto region: 1) Subsidies; 2) Payment for ecosystem services; 3) Water Charges; 4) Water Markets; 5) Insurance.

Table. 3.2 Economic instruments for groundwater management. Adapted from Rey (2018) [46], Delacàmara (2013) and [9] Kraemer (2013) [51].

Economic Instrument	**Groundwater management**	**Pros**	**Cons**
Subsidies	Subsidies for groundwater management could be directed to (a) encourage the use of more efficient irrigation technologies to achieve real water savings, (b) encourage water saving measures, (c) for industries and municipalities to implement appropriate water treatment technology.	Popular with recipients; promote desirable activities rather than prohibiting undesirable ones	Require funding, may lead to economic inefficiencies, may encourage rent-seeking behaviour

Payment for Ecosystem services	This instrument is applicable to aquifers, but some intrinsic characteristics of groundwater have to be taken into account, notably the time-lag of impacts, the persistence of some groundwater contaminants, and the potential cost of some pollution episodes. Buyback can serve to compensate farmers for not pumping water from aquifers. Based on the contexts, economic incentives can enforce PES for instance industry and water utilities to invest in adequate wastewater treatment and recycling.	Increase the revenue of land owners by securing or increasing the production of environmental services; contribute to reinforce the political voice and legitimacy of stakeholders during negotiation process; increase the provision of target environment services and complementary ones.	Inefficiency or even failures due to lack of adequate performance monitoring; free riding associated to the nature and functioning of ecosystem services.
Water charges	This instrument requires to put in place a registry of groundwater users and rights to determine the feasibility of direct abstraction metering or an alternative technique to determine groundwater use. Indirect charging for groundwater abstraction via energy pricing also needs to be analysed in relation to its potential effect on the poorer groups in society and compensatory measures defined and implemented.	Adjustment of price signals to reflect actual resource costs; encourage new technologies; flexibility; generation of revenue that can be used for water management activities	Low charges/prices have a minimal on user/polluter behaviour and can lead to resource over-utilization
Water Markets	Water markets are not legal in Italy. The water market is a set of arrangements that permit water to be traded. Specific prerequisites need to be achieved as (a) the prevailing hydrogeological regime, (b) the previous history of informal trading and/or rights, (c) the types and numbers of groundwater rights holders and users and (d) the physical arrangements for moving water between users.	Creating incentives for water saving and conservation; allocate water more efficiently; showing water users the opportunity costs	Reinforcing social disparities and reducing spatial cohesion as water is re-allocated to more valuable uses; leading to speculation with water rights when they are accumulated and not used; worsening overexploitation and scarcity trends if water use rights do not match available water resources.

Insurance	Groundwater stocks have the important function of insuring farmers. Drought insurance can act as an adaptation instrument but if an aquifer has a below/average recharge, thus the groundwater can no longer act as insurance for farmers. It may be necessary to limit the depletion or inform farmers about the imminent depletion. Insurance has therefore to be considered coupled with other economic instruments, as subsidies	Alternative way to stabilize farmers' income during dry periods; create conditions for collective control of aquifers	Insuring farmers but not discouraging over-abstractions; transferring risks from individual users to the government and adding to fiscal imbalance

Subsidies

A subsidy is a reward for meeting a certain groundwater level, which is higher than the desired standard. Can be explicit (price supports, subsidized loans, direct payments) or implicit (reduced regulation, tax/charges relief). Explicit subsidies are common in Europe, especially in the agricultural sector [52]. Here, subsidized loans were frequently introduced to involve farmers in irrigation modernization programmes. The most important one was implemented in Spain showing that the significant investment has not reduced pressures on water bodies [53]. Implicit subsidies are typically applied through insufficient cost recovery at different levels (water works, environmental and resource costs), with loose monitoring and enforcement of allocations. In particular, cost recovery of water resource and opportunity costs is reported to be inadequate, representing also an 'environmentally-harmful subsidy' in all EU member states [54].

Payments for ecosystem services

Payment for ecosystem services (PES) are conditional payments offered to land users in exchange for the voluntary provision of some sort of ecological service as water infiltration. An agricultural area converted into FIA produces two important environmental services (recharging the aquifer, defense of water from nitrate pollution, CO2 compensations supported by sponsors) and an agricultural commodity (wood chips for energy production). Through PES scheme beneficiaries or users of the ecosystem service(s) compensate the provider or manager of those services, directly or indirectly, by internalizing the positive externalities attached to the conserved resources and related by-products [55]. The service provider (private and communal landholders) and beneficiaries agree on the terms and conditions of the PES and usually enter into a formal agreement. PES could be a cost-effective solution for groundwater-based natural infrastructure as well.

The case of Kumamoto in Japan [56] is an example in how PES scheme had reverse groundwater depletion. The programme has facilitated the restoration of groundwater levels and demonstrated how such schemes can provide effective incentives for groundwater recharge while providing greater security of supply for groundwater users. However, in the case of FIA, the major challenge for establishing a PES is the uncertainty related to hydrogeological conditions and the fate of recharged water. Due to the open access peculiarity of groundwater resource the real challenge is to define a boundary condition (i.e., which users within a certain area are entitled to the additional water), which is important as a basis for determining a cost-benefit sharing mechanism for the PES.

In the case of Bosco Limite in Carmignano di Brenta (PD), the largest FIA in Veneto region, the landowner is exempted to pay the Land Reclamation Board Tax (required to all the citizens benefitting the Land Reclamation Board activities for supporting the maintenance, management and monitoring costs of the territory) and at the same time receives a payment of 1200€/ha/year from the Brenta Land Reclamation Board (BLRB) for the aquifer recharge service provided under a 10-years agreement started in 2011. The municipalities surroundings the area of "Bosco Limite" (Carmignano di Brenta, Pozzoleone, Tezze and Vicenza) recognize the positive social and environmental impacts that the FIA provides to the community by supporting the recreational activities with a yearly payment of 640€/ha. Moreover, for the same area, the landowner earns income also from selling firewood obtained by the ordinary maintenance activities of the forest, and by the presence of truffle-production trees.

The feasibility of PESs depends on its cost-effectiveness compared to alternative mechanisms (e.g., strict regulatory enforcement, or artificial provision of that service), and in low transaction costs. Typically, PESs can be useful where relatively little additional incentive can stimulate buyer-desired changes. For them to be effective, proper monitoring is needed, as well as enforcement of sanctions for contractual non-compliance on the part of the provider. The legal framework is crucial for the introduction of a PES scheme. Despite the increasing attention on water related challenges, the Italian regulative framework still represents a emblematic case where the implementation of economic tools such as PES is inhibited by the presence of a complex regulatory and institutional framework [57].

Agricultural food and trade policies

The major share of groundwater is consumed by irrigation, where agricultural policies have a major impact. For this reason, agricultural and food trade policies could be considered as an indirect economic instrument for groundwater management. From an economic perspective, however, the allocation of groundwater to this type of consumptive use is not very efficient, and agricultural policy should better reflect the scarcity of groundwater resources.

The conversion of a crop intensive land to a FIA could be financially supported by the Common Agricultural Policy (CAP), which allow the landowner to make the initiative economically sustainable. An important recognition about the FIA is the recent inclusion of this methodology in the Veneto Region's Rural Development Plan (RDP) 2014 – 2020 [58] together with other thematic programmes. Such initiative will provide loans for landowners interested in creating and managing aquifers (Intervention 4.4.2 "introduction of green infrastructures" and measure O33 "Experimentation and application of interventions that contribute to reducing nutrient release").

Environmental Agreements

Another option that can support economic instruments for groundwater management is voluntary agreements between farmers and government organizations. Participation in such control programs is encouraged by means of positive incentives (a restitution of taxes). Such programs try to convince farmers (through education) of the advantages of fine-tuned groundwater control. Voluntary agreements on controlling groundwater use are efficient, since they rely on specialized knowledge of participants about local conditions. During the years, many workshops, stakeholders meetings and conferences have been organized in the area of aquifer recharge in the Veneto region in order to share the knowledge of FIA with the experts and the community. A crucial aspect that emerged since the early beginning of the spreading of FIA was the availability of the land for the installation of the recharge systems. Farmers demonstrated to be key actors in the decision process of a FIA and their participation in planning and decision-making at the local level is increasing and becoming more common. With the aim of identifying areas and owners that could host the new FIA and explore innovative funding mechanisms, the Brenta operational group (GO Brenta 2020, in Italian:"Gruppo Operativo Brenta 2020) was recently established by Etra SpA (a water utilities company), Coldiretti Veneto (trade union agriculture organization), Etifor Srl (Padua University spin-off for ecosystem evaluation) and interested farmers, financed by Misura 16.1 of the Rural Development Program 2014-2020 [58].

Water charges

Many countries apply charges or taxes on water abstraction to manage water quantity issues. This economic instrument is defined as levies on water use related to conveyance and storage services and the opportunity cost of the resource. They can be earmarked (tariff) or not (tax) and are applied in the majority of European Member States [51].

Tax

Theoretically, a tax can be used to restrain farmers from lowering the groundwater level below a certain standard but in practice, as for instance in the Dutch experience [59], it was found that is far too low to provide any real incentive to reduce groundwater extraction.

The effectiveness of a tax depends on the right estimation of the marginal tax level and on how risk averse farmers are with respect to damage from reduced water availability (both in quality and in quantity terms). A differentiated tax level has to be created, because of local differences in both the monetary value of reserves and vulnerability of the environment to changes in the groundwater level. An advantage of a tax is that it improves both economic and technical efficiency. Administrative costs are high, since a differentiated tax is not easy to control and monitor. The financial impact on affected parties depends on the restitution of revenues, which affects tax acceptability. Finally, there are practical implementation problems. It is hard to define a good basis for a tax. A volumetric tax on extraction is complicated, since it involves high monitoring costs. A tax on a change in the groundwater level is also complicated, because external and stochastic factors affect the level of groundwater, which is not uniform across any given aquifer. Charging water boards for lowering surface water levels will not influence an individual farmer's behaviour, but it will affect strategy of groups of farmers represented in the governing body of water boards.

Tariffs

In Italy, the Decree 39/2015 [21] allows the water utilities to include within water tariffs of costs related to sustainable catchment management interventions, such as FIA. Recently, Etifor Srl, in the context of GO Brenta 2020, submitted a feasibility study of a tariff to the water utilities (Veneto Acque and Etra Spa) with the aim to recover the cost of FIA and other types of MAR. According to the Decree 39/2015, the water service works according to the investment logic: the envisaged interventions, such as FIA, are included in an investment plan and then in the water tariff. In case of a positive answer, expected by the beginning of 2019, this will be the second case of reinvestment in watershed management. The pioneer in Italy is Acque Spa, a water utility from Emilia Romagna that in 1988 started to allocate 2% of its revenues (later increased to 3% in 2008 and then 4% in 2012) to the mountain towns where its treatment plants are located in order to indirectly support watershed protection. Romagna Acque Spa is currently working with nearby universities to demonstrate a science-based approach to calculating environmental and resource costs for setting water tariffs [60].

Water markets

Another prescription economists offer in the face of demand–supply imbalances is the introduction of water markets which demonstrate to have the capacity to rationalize water scarcity, both qualitatively and quantitatively. In the context of groundwater resources, a market is an arrangement in which holders of groundwater rights trade in them or with outside parties.

Tradable rights improve economic and technical efficiency, since the market determines the price of the right in a dynamic way. The high demand for administrative institutions is a major disadvantage. The financial impact on affected parties and related acceptability depends on the initial allocation of rights. The use of tradable rights for groundwater seems to be complicated in practice, since the impact of changes in the groundwater level on agricultural production and nature depends on location-specific circumstances. Examples of tradable permit markets are rare in Europe but water markets and water banking have been developed in the United States over the last decades in order to address water allocation problems. In particular, water bank serves as an institutional mechanism designed to respond to climate variability (droughts) [61]. A considerable potential for application of water banking in FIA case studies is represented by the Arizona experience which settled a legislatively-authorized and advanced groundwater program. Similar water banking approach could be implemented in other areas if a groundwater entitlement system is prepared for a water banking investment [62].

In Europe, the Blueprint to Safeguard Europe's Water Resources [54] take into consideration water markets for the improvement of water-use efficiency on condition that a cap on water use was implemented and enforced.

In Italy water markets are not legally possible and the current regulative water system in place in not flexible enough for introducing this type of mechanism. However, there are different sort of water bank that can be considered for managing FIA even in a non-water market context as the Italian one.

Insurance

Insurance is the most commonly used instrument for financial protection addressing drought risk by covering the loss of or damage to crops caused by insufficient rainfall. Insurance firms or programs cover the farmers that regularly contribute to pay a risk premium. Agents in the pool are entitled to receive full or partial financial compensation in case a drought is officially declared, based upon observable drought indices such as the reduction of water stored in dams and aquifers or of river flows below a predetermined threshold, and contingent reductions in water supply come into force.

Crop insurance is not an economic instrument for water management but could be fundamental in addressing the incentives for aquifer over-exploitation during droughts [48]. The drought insurance scheme in Italy, compensates drought-related losses in irrigated agriculture and could therefore act as an adaptation instrument. However, FIA itself could be considered an insurance itself instead of financial one to compensate the farmer. Indeed, FIA is about using natural capital (water stored into the aquifer) for the purpose of protecting from drought and could therefore act as an insurance tool itself. For this reason FIA has the potentiality to complement already existing drought insurance scheme in Italy if properly designed, making insurance more affordable and sustainable.

Conclusion

FIA provide a whole range of services that are still unrecognized in economic accounts, but vital to human welfare: regulating water flows, flood control, decontamination, and carbon sequestration, as well as providing nursery grounds for many species and products on which human communities depend. FIA demonstrated offering the owners the potential to receive greater remuneration compared to common crop management, such as maize or soy, because can generate multiple sources of income. Moreover, compared with other type of MAR, FIA results more attractive in monetary investment terms.

Pioneering pilot projects in the Veneto Region demonstrate that FIA can be effectively applied to expand the supply base during drought events and improve water quality while enhancing overall environmental health and strengthen community and stakeholder engagement. FIA are therefore strategic as local measures to adapt to climate change. Although there is general acceptance of FIA as an effective way to expand the supply base during droughts, a number of enabling factors are required to get beyond “FIA pilot-projects” and support the introduction of economic instruments.

This study first reviewed the main economic instruments largely applied for water allocation and report about their implementation, if available, considering the Forested Infiltration Area case study in Veneto region showing the pros and cons economic instruments. General recommendations have to consider that the introduction of economic instruments for FIA management will depend on current hydrologic, economic, social and political conditions in the area of implementation. A correct quantification of the abstraction volumes, but also the study of the infiltration dynamics and possible factors that can limit the operation over time (for example, tied to the problem of clogging), are therefore priorities aspects to be investigated. A feasibility analysis could be helpful to support policy making decisions by including an assessment of costs and benefits of each economic instrument and possible combinations. It should also take into account long-term recurrent costs and institutional capacity (for administration, monitoring, enforcement) and the transaction costs involved to set up systems. The expected costs and benefits would also influence the trade-off between the use of economic instruments and other groundwater management tools. Any of these measures or strategies, however, must be based on solid scientific knowledge, in order to avoid unwanted side effects or mal-adaptation. Research on the dynamics and interdependencies of the biophysical and socio-economic components of water systems across scales, as well as on multi-level and nested institutional responses, needs to support the management and governance of global water resources towards water security, equity and sustainability.

References

[1] S. Siebert *et al.*, “Groundwater use for irrigation - A global inventory,” *Hydrol. Earth Syst. Sci.*, vol. 14, no. 10, pp. 1863–1880, 2010.

[2] FAO, “AQUASTAT,” 2018. [Online]. Available: http://www.fao.org/nr/water/aquastat/main/index.stm. [Accessed: 05-Dec-2018].

[3] EEA, “European waters Assessment of status and pressures 2018,” 2018.

[4] K. Mechlem, “Groundwater governance: The role of legal frameworks at the local and national level-established practice and emerging trends,” *Water (Switzerland)*, vol. 8, no. 8, 2016.

[5] S. Santato, J. Mysiak, and C. Pérez-Blanco, “The Water Abstraction License Regime in Italy: A Case for Reform?,” *Water*, vol. 8, no. 3, p. 103, Mar. 2016.

[6] MATTM, “Strategia Nazionale di Adattamento ai Cambiamenti Climatici Indice (National Strategy of Adaptation to Climate Change),” 2014.

[7] P. Koundouri, “Current issues in the economics of groundwater resource management,” *J. Econ. Surv.*, vol. 18, no. 5, pp. 703–740, 2004.

[8] S. Kumar Das, “The Economics of Groundwater Resource Management,” *Int. J. Ecosyst.*, vol. 5, no. 3A, pp. 65–68, 2015.

[9] G. Delacámara *et al.*, “Guidance. Design and development of economic policy instruments in European water policy,” no. December, 2013.

[10] EC, *Water Framework Directive 2000/60/EC*. 2000.

[11] EC, *Directive 2006/118/EC on the Protection of groundwater against pollution and deterioration*, vol. 2006, no. 1463. 2006.

[12] EC, *Roadmap to a Resource Efficient Europe. COM(2011) 571*. 2011.

[13] C. Clifton, R. Evans, S. Hayes, R. Hirji, G. Puz, and C. Pizarro, “Water and Climate Change: impaCts on groundWater resourCes and adaptation options,” *Assessment*, no. 25, pp. 1–76, 2010.

[14] R. G. Taylor *et al.*, “Ground water and climate change,” *Nat. Clim. Chang.*, vol. 3, no. 4, pp. 322–329, 2013.

[15] C. Sprenger *et al.*, “Inventory of managed aquifer recharge sites in Europe: historical development, current situation and perspectives,” *Hydrogeol. J.*, vol. 25, no. 6, pp. 1909–1922, 2017.

[16] P. Dillon, P. Pavelic, D. Page, H. Beringen, and J. Ward, *Managed aquifer recharge : An Introduction*, Waterlines., no. 13. 2009.

[17] C. Stefan and N. Ansems, “Web-based global inventory of managed aquifer recharge applications,” *Sustain. Water Resour. Manag.*, vol. 4, no. 2, pp. 153–162, 2017.

[18] P. Dillon *et al.*, “Sixty years of global progress in managed aquifer recharge,” 2018.

[19] Eurostat, “Agri-environmental indicator - commitments,” no. March 2016, pp. 1–17, 2017.

[20] T. Wintgens, R. Hochstrat, C. Kazner, P. Jeffrey, B. Jefferson, and T. Melin, “Managed Aquifer Recharge as a component of sustainable water strategies, Chapter 8,” in *IWA Publishing*, 2006.

[21] MATTM, “DECRETO 24 febbraio 2015, n. 39. Regolamento recante i criteri per la definizione del costo ambientale e del costo della risorsa per i vari settori d’impiego dell’acqua.,” *Gazz. della Repubb. Ital.*, pp. 2–5, 2015.

[22] MATTM, *Decreto Legislativo 3 aprile 2006, n. 152 “Norme in materia ambientale” pubblicato nella Gazzetta Ufficiale n. 88 del 14 aprile 2006 - Supplemento Ordinario n. 96*. 2006.

[23] P. Rodríguez-Escales *et al.*, “A risk assessment methodology to evaluate the risk failure of managed aquifer recharge in the Mediterranean Basin,” *Hydrol. Earth Syst. Sci.*, vol. 22, no. 6, pp. 3213–3227, 2018.

[24] C. Stefan *et al.*, “Free web-based modelling platform for managed aquifer recharge (MAR) applications,” no. April, 2017.

[25] P. Tsangaratos *et al.*, “Bulletin of the Geological Society of Greece facilities SUPPORT SYSTEM (DSS) COUPLED WITH GIS FOR IDENTIFYING OPTIMAL LOCATIONS FOR SOIL AQUIFER,” vol. 47, pp. 789–800, 2013.

[26] P. Fabbri, L. Piccinini, E. Marcolongo, M. Pola, E. Conchetto, and P. Zangheri, “Does a change of irrigation technique impact on groundwater resources? A case study in Northeastern Italy,” *Environ. Sci. Policy*, vol. 63, pp. 63–75, 2016.

[27] J. Spinoni, J. V. Vogt, G. Naumann, P. Barbosa, and A. Dosio, “Will drought events become more frequent and severe in Europe?,” *Int. J. Climatol.*, vol. 38, no. 4, pp. 1718–1736, 2018.

[28] L. Gudmundsson and S. I. Seneviratne, “Observation-based gridded runoff estimates for Europe (E-RUN version 1.1),” *Earth Syst. Sci. Data*, vol. 8, no. 2, pp. 279–295, 2016.

[29] IPCC, “Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III

to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change," Geneva, 2014.

[30] S. Pasini, S. Torresan, J. Rizzi, A. Zabeo, A. Critto, and A. Marcomini, "Climate change impact assessment in Veneto and Friuli Plain groundwater. Part II: A spatially resolved regional risk assessment," *Sci. Total Environ.*, vol. 440, pp. 219–235, 2012.

[31] F. Baruffi *et al.*, "Climate change impact assessment on Veneto and Friuli plain groundwater. Part I: An integrated modeling approach for hazard scenario construction," *Sci. Total Environ.*, vol. 440, pp. 154–166, 2012.

[32] A. Mayer *et al.*, "A multi-tracer study of groundwater origin and transit-time in the aquifers of the Venice region (Italy)," *Appl. Geochemistry*, vol. 50, pp. 177–198, 2014.

[33] Consorzio di Bonifica Brenta, "Le risorgive," 2015. .

[34] S. Bertoldo, L. Rigato, and A. Sottani, "CENSIMENTO DELLE RISORGIVE IN PROVINCIA DI VICENZA (AZIONE D4 – PROGETTO LIFE+10/ENV/IT/000380 AQUOR): INDAGINI GEOLOGICHE, IDROGEOLOGICHE ED AMBIENTALI. Relazione Tecnica," Vicenza, 2015.

[35] L. Agostinetto, F. Dalla Venezia, and G. Gusmaroli, "Managed Aquifer Recharge (MAR) demonstrative techniques for the quantitative restoration of the groundwater balance in the Vicenza Upper Plain," 2013.

[36] G. Mezzalira, G. Gusmaroli, and U. Niceforo, "Aree forestali di infiltrazione (AFI): principi, esperienze, prospettive," *Acque Sotter. J. Groundw.*, no. 3/137, pp. 055–060, Sep. 2014.

[37] G. Passadore, M. Monego, L. Altissimo, A. Sottani, M. Putti, and A. Rinaldo, "Alternative conceptual models and the robustness of groundwater management scenarios in the multi-aquifer system of the Central Veneto Basin, Italy," *Hydrogeol. J.*, vol. 20, no. 3, pp. 419–433, 2012.

[38] P. A. Vorlicek, R. Antonelli, P. Fabbri, and R. Rausch, "Quantitative hydrogeological studies of the Treviso alluvial plain, NE Italy," *Q. J. Eng. Geol. Hydrogeol.*, vol. 37, no. 1, pp. 23–29, 2004.

[39] Regione Veneto and Veneto agricoltura, "Forested Infiltration Areas to recharge aquifer," Legnaro (PD), 2012.

[40] Consorzio di Bonifica Brenta, "Iniziativa sperimentale di ricarica della falda a Schiavon," 2008. .

[41] A. Dal Prà, G. Mezzalira, and U. Niceforo, "Esperienze di ricarica della falda con aree forestali

di infiltrazione," *Acque Sotterranee-Italian Journal of Groundwater*, 2010.

[42] R. Rossetto and E. Bonari, "Il futuro della ricarica delle falde in condizioni controllate in Italia: il progetto europeo FPVII MARSOL e la EIP on Water MAR to MARKET," *Acque Sotter. J. Groundw.*, no. 3/137, pp. 009-012, Sep. 2014.

[43] Veneto Agricoltura, "Le aree forestali di infiltrazione - progetto Riducareflui," 2012.

[44] U. Niceforo, "I boschi di ricarica," 2016. .

[45] M. Mastrocicco, N. Colombani, E. Salemi, B. Boz, and B. Gumiero, "Managed aquifer recharge via infiltration ditches in short rotation afforested areas," *Ecohydrology*, vol. 9, no. 1, pp. 167–178, 2016.

[46] B. W. T. A. R. Collins, *Towards efficient use of water resources in Europe (EEA Report No 1/2012)*, no. 1. 2012.

[47] K. Kemper, S. Foster, Hector Garduno, M. Nanni, and A. Tuinhof, "Sustainable Groundwater Management. Concepts & Tools. Economic Instruments for Groundwater Management: using incentives to improve sustainability.," *GW Mate, World Bank*, no. 7, p. 8, 2004.

[48] D. Rey, C. D. Pérez-Blanco, A. Escriva-Bou, C. Girard, and T. I. E. Veldkamp, "Role of economic instruments in water allocation reform: lessons from Europe," *Int. J. Water Resour. Dev.*, vol. 0627, pp. 1–34, 2018.

[49] C. M. Gomez, D. Pérez-Blanco, D. Adamson, and A. Loch, "Managing Water Scarcity at a River Basin Scale with Economic Instruments," *Water Econ. Policy*, vol. 4, no. 1, p. 1750004, 2017.

[50] R. Damania *et al.*, *Uncharted Waters: The New Economics of Water Scarcity and Variability*. S.l.: World Bank Publications, 2017.

[51] R. A. Kraemer, Authors, Z. Guzmán Castro, R. Seroa da Motta, and C. Russell, "Economic Instruments for Water Management: Experiences from Europe and Implications for Latin America and the Caribbean," *Integration and Regional Programs Department Sustainable Development Department*, no. November. 2003.

[52] EC, "COUNCIL REGULATION (EC) No 1782/2003 of 29 September 2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers and amending Regulations (EEC) No 2019/93, (EC) No 145," *Off. J. Eur. Union*, vol. L, no. 270, pp. 1–69, 2003.

[53] J. Berbel and L. Mateos, "Does investment in irrigation technology necessarily generate rebound effects? A simulation analysis based on an agro-economic model," *Agric. Syst.*, vol.

128, pp. 25–34, 2014.

[54] EC, *Blueprint to safeguard Europes water resources. COM(2012) 673 final COMMUNICATION*. 2012.

[55] S. Engel, S. Pagiola, and S. Wunder, "Designing payments for environmental services in theory and practice: An overview of the issues," *Ecol. Econ.*, vol. 65, no. 4, pp. 663–674, 2008.

[56] K. Kato and H. K. Province, "Groundwater Conservation and Tap Water Management : Experience of Kumamoto City , Japan Policies for Groundwater Conservation Maintaining groundwater recharge." pp. 1–10, 2015.

[57] D. Pettenella, E. Vidale, P. Gatto, and L. Secco, "Paying for water-related forest services: A survey on Italian payment mechanisms," *iForest - Biogeosciences For.*, vol. 5, no. 4, pp. 210–215, 2012.

[58] P. e F.-R. del V. Direzione AdG FEASR, "Italy - Rural Development Programme (Regional) - Veneto. Version 7.1 (last update 17/09/2018)," 2018.

[59] M. Schuerhoff, H. P. Weikard, and D. Zetland, "The life and death of the Dutch groundwater tax," *Water Policy*, vol. 15, no. 6, pp. 1064–1077, 2013.

[60] G. Bennett and A. Leonardi, "State of European markets 2017. Watershed Investments," *ECOSTAR Proj.*, p. 43, 2017.

[61] N. M. Montilla-López, C. Gutiérrez-Martín, and J. A. Gómez-Limón, "Water banks: What have we learnt from the international experience?," *Water (Switzerland)*, vol. 8, no. 10, 2016.

[62] S. B. Megdal, P. Dillon, and K. Seasholes, "Water banks: Using managed aquifer recharge to meet water policy objectives," *Water (Switzerland)*, vol. 6, no. 6, pp. 1500–1514, 2014.

Appendix 1 : Stakeholders engaged in the FIA in Veneto region, their role and involvement in the Brenta Groundwater Contract and in the Brenta Operational Group. Based on interviews.

	Type of stakeholder	**FIA stakeholder in Veneto (main)**	**Role**	**Stakeholder network for environmental agreement**	
				Brenta Groundwater contract	Brenta Operational Group
1	Consultancy	Etifor srl: universities	Provide studies on the full value of the products and services provided by nature		X
2	Agriculture Organization	Veneto Agricoltura	Applied research and dissemination of technological and organizational innovations	X	
3	Water utility	Veneto Acque Spa	Design, execution and management of infrastructural networks and structures related to the integrated water service		
4	Land Reclamation Board	Brenta Land Reclamation Board, Alta Pianura Veneta Land Reclamation Board	Manage the irrigation network and contribute to realize and manage FIA with farmers	X	
5	Farmer	Bosco Limite, Agriflor srl, Moresco Adelia	Make available land for FIA; implement and manage the drain system		X
6	Trade union organization	Coldiretti Veneto	Represents people and businesses operating in agriculture		X
7	Water utilities company	ETRA Spa, Viacqua Spa	Management of the integrated water and waste service	X	X
8	Optimal Territorial Areas	Consiglio di Bacino Brenta	Territorial group of municipalities that coordinate drinkable use of water		
9	Municipalities	Schiavon (VI); Carmignano (PD); ecc	Recognize and include FIA into local planning tools		

10	Region	Veneto Region	Recognize and finance the FIA with the use of plans and programmes		
11	Province	Province of Vicenza	Favored and promote FIA into territorial planning	X	

CONCLUSION

Water is the common denominator through which climate change leverage human and natural ecosystems. Projected average higher temperatures and variability in precipitation and temperature extremes are already affecting the availability and quality of water resources.

The thesis offers methodologies and insights to the actual discussion of strategies and measures for adapting water policy, management practices and existing institutions to better respond to the emerging water challenges posed by climate change. The thesis is structured in three contributions that fall under the umbrella of water resources management and climate change adaptation considering the case study of the Po River basin in Italy.

Adaptation to climate change is urgent and it’s a matter of improving water management and enhancing water security. The main barriers that preclude the adoption of the adaptive responses are linked to institutional inertia, technological lock-in and decision support systems that favour the adoption of traditional responses. Fundamental changes considered in the thesis are on legislations and institutions following three urgent needs. First, national policy responses and relative legislative frameworks that have to quickly adapt to projected droughts and availability of water resources. Second, adaptation requires an effective and measurable strategy for institutional transition. Third, innovative technologies and integrated solutions are needed in order to prevent local impacts during the adaptation transition.

The first chapter refers to a key institutional precondition for an efficient management and allocation of water at national level through a documented analysis of the deficiencies of water use rights definition and allocation in Italy. Results are put in perspective by comparing water use rights systems for water allocation in Italy, Spain, Australia and other water stressed and drought prone areas. Once the deficiencies of the water allocation licences is presented, the first chapter introduces a blueprint for its reform that, besides the Po river basin itself, might be relevant for other areas with similar problems that obstacle adaptation which include but are not limited to: i) the lack of a central water abstraction licence register which delays and in some cases impedes an environmental impact assessment for issuing new licenses or renewing existing ones, and does not allow prioritizing applications according to their full economic value; ii) lack of monitoring and enforcement, iii) inadequate pricing mechanisms that does not reflect the cost of water conveyance and use, and does not encourage efficient water allocation, iv) need to make property rights contingent to the state of water resources and to protect environmental flows and convenience to make right permits tradable under conditions that protect collective interest and environmental targets.

The second chapter addresses the institutional transition by introducing the measurement of transaction costs at river basin level. During times of drought, formal institutions may provide inflexible and more costly management arrangements that may increase total transaction costs. Conversely, informal institutions may be less likely to deliver robust and enforceable water management and reallocation outcomes during stressful periods of low supply. This chapter presents the recent developments and challenges in drought management in Italy and explores the transaction costs associated with informal arrangements in the Po River Basin District. This study measure and track transaction costs with respect to drought periods and identify a loose downward trend over the course of several recent drought events. Informal drought management planning is now enshrined in the Po River Basin District Plan, and that basin's Drought Steering Committee model has also been mandatorily adopted by the six other River Basin Districts in Italy. This informal institutional model is an example of potential alternative drought management arrangements beyond formal (less flexible) planning approaches. This method can be applied beyond the case study area of the Po River Basin and have important implications for the current management of drought events elsewhere in Europe.

The third chapter is of a practical kind. It illustrates the type of technical options that, different from heavily engineered traditional responses. might come into play as relevant alternatives to build water security at local level. With the aim to provide useful insights for improving the management of underground water resources, the chapter describes the current stage of implementation of managed aquifer recharge through Forested Infiltration Areas (FIA) in Italy and explores potentialities and limitations for the use of economic instruments. FIA is a type of nature-based solution that leverages on ecological functions usually performed by ecosystems (such as forested areas) to restore aquatic systems (such as groundwater) in order to increase water security at the local level in the face of the uncertain consequences of climate change. Showing the promising role of these alternatives for water resources management and climate change adaptation the third part of the thesis shows the pros and cons of major economic instruments for underground water management. The main barriers for the introduction of economic instruments for FIA management depend on current hydrologic, economic, social and political conditions in the area of implementation.

Further water management research steps of the thesis are likely to extend the analysis to the particular mechanisms that might be used to reach the objectives of the blueprint introduced in the first chapter considering, for instance, the water use licence buybacks, spot markets, smart pricing that could also directly support the replicability potential of Forested Infiltration Areas in Italy.

An additional contribution might provide further insights for the resilience of groundwater management to drought impacts by modelling different scenarios of income from farmers (normal;

normal with droughts; FIA; FIA with droughts). Such contribution would aim to track how FIA respond to alternative states of water availability (drought and normal).

Another hypothesis to be explored further is whether informal arrangements are spontaneous social adaptations to water scarcity and droughts. This may reveal lower transaction costs adaptation paths from which governments can learn to figure out the best way to facilitate transformational change in water resources management in the face of climate change.

ABOUT THE AUTHOR

Silvia is graduated in Planning and Environmental Policies at the IUAV University of Venice.

Since 2013 she is a researcher in the RAAS division of CMCC and since 2017 she is the thematic expert in disaster risk reduction for the Climate-Adapt platform.

Her research interests focus on the Mediterranean area and the Po river basin and mainly concern analysis and evaluation on non-structural adaptation measures (regulations, institutions and planning) to climate change in the water resources sector.

During her academic studies, she carried out research experiences on water resource planning and management in Sweden, Denmark, Spain, Germany and Australia. She organized and coordinated summer schools and workshops in Sudan, Algeria and Italy in the context of projects and collaborations, maturing an extensive experience in stakeholders and decision makers engagement. Silvia has been the project manager of Climathon, Cost-ADAPT and PLACES projects, funded by Climate-Kic.

She contributed to the National Adaptation Strategy (special chapter on the Po river basin district) and to the National Adaptation Plan (chapter on water resources).

LIST OF PUBLICATIONS

Santato S., Loch A., Peréz Blanco C. D., Mysiak J.: "Measuring transaction costs of informal institution for drought management", Journal of Water Resource Management, *(submitted)*

Marzi, S., Mysiak, J., **Santato, S.,** (2018). "Comparing Adaptive Capacity Index across scales: the case of Italy" Journal of Environment Management 1023–1036. doi:https://doi.org/10.1016/j.jenvman.2018.06.060

Santato S., Mysiak, J., Pérez-Blanco, C.D., (2016). The Water Abstraction License Regime in Italy: A Case for Reform? Water 8, 1–15. doi:https://doi.org/10.3390/w8030103

Santato S., Mysiak J. and Pérez-Blanco C. D.: 'The Water Abstraction License Regime in Italy: A Case for Reform?' Publication in Note di Lavoro FEEM, 2016.029

Santato S. 'Prelievi idrici in un clima che cambia: elementi di riflessione verso una riforma delle concessioni di derivazione dell'acqua". OFFICINA* N. 17, ISSN 2532-1218

Santato S., 'Verso una legge sul consumo di suolo'. OFFICINA* N. 20, ISSN 2532-1218

Contribution to the Chapter "Po River Basin District" of the Italian National Adaptation Startegy (SNACC) (2017)

Contribution to the Chapter "water resources" of the Italian National Adaptation Plan (PNACC) (2014)

Contribution to the 'Enabling the Business of Agriculture (2017), World Bank. doi: 10.1596/978-1-4648-1021-3

Mysiak J., De Salvo M**., Santato S.,** Amadio M. "Economic impacts of drought on agriculture" (2015) CMCC Research Paper No. 206

Santato, S., Bender, S. & Schaller, M. (2013): The European Floods Directive and Opportunities offered by Land Use Planning. CSC Report 12, Climate Service Center, Germany

49

Università Ca'Foscari Venezia

DEPOSITO ELETTRONICO DELLA TESI DI DOTTORATO

DICHIARAZIONE SOSTITUTIVA DELL'ATTO DI NOTORIETA'

(Art. 47 D.P.R. 445 del 28/12/2000 e relative modifiche)

Io sottoscritto Silvia Santato

nata a Monselice (prov. PD) il 26/09/1982

residente a Venezia in Cannaregio n. 5284

Matricola (se posseduta) 956249 Autore della tesi di dottorato dal titolo:

Reforming Water Resource Allocation: Climate Change Adaptation in Water Management

Dottorato di ricerca in Scienza e Gestione dei Cambiamenti Climatici

(in cotutela con ……………………………………………………………)

Ciclo XXXI

Anno di conseguimento del titolo 2019

DICHIARO

di essere a conoscenza:

1) del fatto che in caso di dichiarazioni mendaci, oltre alle sanzioni previste dal codice penale e dalle Leggi speciali per l'ipotesi di falsità in atti ed uso di atti falsi, decado fin dall'inizio e senza necessità di nessuna formalità dai benefici conseguenti al provvedimento emanato sulla base di tali dichiarazioni;
2) dell'obbligo per l'Università di provvedere, per via telematica, al deposito di legge delle tesi di dottorato presso le Biblioteche Nazionali Centrali di Roma e di Firenze al fine di assicurarne la conservazione e la consultabilità da parte di terzi;
3) che l'Università si riserva i diritti di riproduzione per scopi didattici, con citazione della fonte;
4) del fatto che il testo integrale della tesi di dottorato di cui alla presente dichiarazione viene archiviato e reso consultabile via internet attraverso l'Archivio Istituzionale ad Accesso Aperto dell'Università Ca' Foscari, oltre che attraverso i cataloghi delle Biblioteche Nazionali Centrali di Roma e Firenze;
5) del fatto che, ai sensi e per gli effetti di cui al D.Lgs. n. 196/2003, i dati personali raccolti saranno trattati, anche con strumenti informatici, esclusivamente nell'ambito del procedimento per il quale la presentazione viene resa;
6) del fatto che la copia della tesi in formato elettronico depositato nell'Archivio Istituzionale ad Accesso Aperto è del tutto corrispondente alla tesi in formato cartaceo, controfirmata dal tutor, consegnata presso la segreteria didattica del dipartimento di riferimento del corso di dottorato ai fini del deposito presso l'Archivio di Ateneo, e che di conseguenza va esclusa qualsiasi responsabilità dell'Ateneo stesso per quanto riguarda eventuali errori, imprecisioni o omissioni nei contenuti della tesi;
7) del fatto che la copia consegnata in formato cartaceo, controfirmata dal tutor, depositata nell'Archivio di Ateneo, è l'unica alla quale farà riferimento l'Università per rilasciare, a richiesta, la dichiarazione di conformità di eventuali copie.

Data 12/12/2018 **Firma** [signature]

AUTORIZZO

- l'Università a riprodurre ai fini dell'immissione in rete e a comunicare al pubblico tramite servizio on line entro l'Archivio Istituzionale ad Accesso Aperto il testo integrale della tesi depositata;
- l'Università a consentire:
  - la riproduzione a fini personali e di ricerca, escludendo ogni utilizzo di carattere commerciale;
  - la citazione purché completa di tutti i dati bibliografici (nome e cognome dell'autore, titolo della tesi, relatore e correlatore, l'università, l'anno accademico e il numero delle pagine citate).

DICHIARO

1) che il contenuto e l'organizzazione della tesi è opera originale da me realizzata e non infrange in alcun modo il diritto d'autore né gli obblighi connessi alla salvaguardia di diritti morali od economici di altri autori o di altri aventi diritto, sia per testi, immagini, foto, tabelle, o altre parti di cui la tesi è composta, né compromette in alcun modo i diritti di terzi relativi alla sicurezza dei dati personali;
2) che la tesi di dottorato non è il risultato di attività rientranti nella normativa sulla proprietà industriale, non è stata prodotta nell'ambito di progetti finanziati da soggetti pubblici o privati con vincoli alla divulgazione dei risultati, non è oggetto di eventuali registrazione di tipo brevettuale o di tutela;
3) che pertanto l'Università è in ogni caso esente da responsabilità di qualsivoglia natura civile, amministrativa o penale e sarà tenuta indenne a qualsiasi richiesta o rivendicazione da parte di terzi.

A tal fine:
- dichiaro di aver autoarchiviato la copia integrale della tesi in formato elettronico nell'Archivio Istituzionale ad Accesso Aperto dell'Università Ca' Foscari;
- consegno la copia integrale della tesi in formato cartaceo presso la segreteria didattica del dipartimento di riferimento del corso di dottorato ai fini del deposito presso l'Archivio di Ateneo.

Data 12/12/2018 **Firma** ______________________________

La presente dichiarazione è sottoscritta dall'interessato in presenza del dipendente addetto, ovvero sottoscritta e inviata, unitamente a copia fotostatica non autenticata di un documento di identità del dichiarante, all'ufficio competente via fax, ovvero tramite un incaricato, oppure a mezzo posta

Firma del dipendente addetto ....

Estratto per riassunto della tesi di dottorato

L'estratto (max. 1000 battute) deve essere redatto sia in lingua italiana che in lingua inglese e nella lingua straniera eventualmente indicata dal Collegio dei docenti.
L'estratto va firmato e rilegato come ultimo foglio della tesi.

Studente: Silvia Santato ______________________________ matricola: 956249

Dottorato: Science and Management of Climate Change

Ciclo: XXXI

Titolo della tesi[1] : Reforming water resource allocation: climate change adaptation in water management

Abstract:

Italy has recently experienced a series of drought events which caused relevant economic impacts. Upward trend water demand projections, due to population growth and changing distributions of wealth, and downward trend water supply projections, due to climate change, suggest that the frequency and intensity of droughts and their socioeconomic impacts will aggravate in the future. This context has prompted a series of water governance and water resources management initiatives characterized by an emergency-driven approach.

The thesis analyses non-structural adaptation options in Italy that include economic, institutional and legal aspect of water allocation and sharing in Italy. The results will inform future policy water reform and offers adaptation insights for policy-makers involved in the management of the water resource. Based on the comparison between water abstraction licence databases collected from the regions comprised in the Po and review of the current legislative framework, the first part of the research (Ch. 1) reveals that the water abstraction licences system in place is widely fragmented to cope with drought management at river basin scale, therefore hampering bottom-up conflict resolution, such as the Drought Steering Committee. Although Italy is far from starting a discussion about a new water reform, the turn of drought events which affected the Northern part of the country started the Drought Steering Committee of the Po River Basin District, an informal institution which proven to be effective in managing water scarcity in the period 2003-2016. The second part of the research (Ch. 1) identifies, categorizes and analyses transaction costs and their influence on effective organisation and informal institutional management of scarce resources, showing a loose downward trend over the course of several recent drought events. When the framework on water management is not flexible to cope with drought conditions and informal institutions such as the DSC may not reach an agreement in time for limiting drought impacts, local

[1] Il titolo deve essere quello definitivo, uguale a quello che risulta stampato sulla copertina dell'elaborato consegnato.

solutions are required to manage challenges such as water scarcity at a catchment level. In Italy an effective and efficient management of aquifers move to the center stage of the contemporary policy debate. With the aim to provide useful insights for the improvement of management of underground water resources and local drought risk management in Italy, the third part (Ch. 3) describes the current stage of implementation of managed aquifer recharge in Italy and possible economic instruments for ground water management considering the case study of Forested Infiltration Areas in the Veneto region.

Firma dello studente