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MODELLING DYNAMICS OF WATER CONFLICTS: THE CASE OF CARRACILLO REGION (SPAIN)

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"Queste donne pretendono che la metà del ruscello non basta per irrigare le loro terre. Esse vogliono più della metà, almeno così credo di interpretare i loro desideri. Esiste per ciò un solo accomodamento possibile. Bisogna lasciare al podestà i tre quarti dell'acqua del ruscello e i tre quarti dell'acqua che resta saranno per i Fontamaresi. Così gli uni e gli altri avranno tre quarti, cioè, un po' più della metà. Capisco." Aggiunse don Circostanza "che la mia proposta danneggia enormemente il podestà, ma io faccio appello al suo buon cuore di filantropo e di benefattore."

(Più tardi ci dissero che la perdita dell'acqua sarebbe durata 10 lustri e che questa proposta sarebbe stata avanzata in nostro favore da don Circostanza; ma nessuno di noi sapeva quanti mesi o quanti anni facessero 10 lustri.)

—Fontamara, Ignazio Silone

ABSTRACT

The present work lays on a preliminary analysis of existing relations between water harvesting and water conflicts. From this, the research area was extended to conflicts related to the mismanagement of water infrastructures. A case study was selected, regarding the ongoing conflict around the artificial aquifer recharge project in Carracillo region (Spain), located in the Duero basin. The recharge project has been implemented since 2000 and involves the derivation of water from Cega river, in order to recharge the quaternary aquifer in the Caracillo region, over exploited due to intensive horticulture activities. A third phase will be implemented. It involves lowering the minimum flow value to maintain downstream the derivation, while extending the derivation period. The published environmental impact assessment doesn't involve an analysis of the impacts that the third phase could have on the ecosystem services of Cega river. This perceived fallacy triggered a conflict between the stakeholders who live in close contact with the river, led by environmentalists, worried about the future of Cega river, and Caracillo farmers, who demand the water that was promised to them when the recharge project was promoted. For these reasons, the project represents an interesting insight into the consequences of different management choices. Objectives of the study is the analysis of the social dynamics underpinning the water-related conflict and the creation of a tool to support technical roles in participatory processes in water planning and management. Such a tool would ideally allow the involvement of ecosystem services in the design and planning of a recharge concession, and could be applied both in Carracillo region and in other cases. A first part of the study is dedicated to stakeholder analysis, fundamental in order to identify the main actors involved in the conflict and the dynamics that bind them. Moreover, it allows to establish the core points around which conflict develops. A second part is dedicated to conflict modelling. This was approached as a bargaining process between agricultural needs and natural necessities, embodied in Cega river ecosystem services. We defined the utility function for farmers as the relation between water actually available and agricultural water needs. Furthermore, we defined the utility function for ecosystem services through their quantification using Service Provision Index. After a thorough analysis of the hydrological and agronomic mechanisms involved in the scenario, a model was developed in order to investigate possible optima points and suggest concession rules for the recharge project, taking into account ecosystem services as well. In particular, optimum values for concession rules, in the form of minimum flow to be guaranteed downstream the derivation and maximum instantaneous intake were investigated. From the optimization process it emerged that an optimum value for the minimum flow to be guaranteed downstream the derivation is almost three times higher than the one prescribed by third-phase concession rules. Moreover, environmental flow values provided by the Confederacion Hidrografica del Duero for the hydrologic planning cycle 2015-2021, are less than 10% of average monthly flow, the threshold that, according to Tennant, defines the limit for a riverine ecosystem to be considered alive. Finally, optimization performed involving environmental flow values provided by Confederacion Hidrografica del Duero also shows higher results than values prescribed by the concession. These results suggest a need for a re-negotiation of concession rules related to the last phase of the recharge project.

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AN OVERVIEW OF THE THESIS

The present work is the result of three years of studies focused on the attempt of linking engineering disciplines with social ones, trying to provide new perspectives to the field of water-related conflict management.

The starting point is a preliminary analysis of existing relations between water harvesting and water conflicts. This led to the definition of a framework that identifies Anthropic factors as triggering factors of conflicts related to water harvesting practices. What emerged is that erroneous practices and myopic interventions may interfere with delicate structural conditions, thus leading to conflicts. Only an adequate and in-depth analysis of the social fabric, of water rules and rights traditionally in use can actually lead to lasting interventions, with real positive impacts on beneficiaries. On the contrary, a mere analysis of physical aspects can be empty, if not harmful.

Hence the need and curiosity arose to extend the research area. Conflicts related more generally to water management were then included; in particular, those related to the mismanagement of water infrastructures. To gain a better insight about the topic, a case study was selected. The ongoing conflict around an artificial aquifer recharge project in the Carracillo region (Spain), located in the Duero basin, was chosen. The project involves the derivation of water from a small river, Cega river, in order to recharge the quaternary aquifer in the Caracillo region (about 20 km from the river), over exploited due to intensive horticulture activities. The project's main objective is to provide water for agriculture. Cega river has an average annual flow of 2.07 m^3/s, and is characterized by an irregular flow pattern.

The project started in 2000 and the first two phases (implemented since 2000) were conducted without environmental impact assessment. The concession granted to the Comunidad the regantes (small farmers and large farms of the Carracillo region) for the irrigation of 3000 hectares establishes:

- a derivation period from January to April;
- a derivable flow rate of 1.37 m^3/s;
- a maximum volume derivable per year of 14.2 hm^3;
- a minimum river flow to maintain downstream the derivation of 6.9 m^3/s.

Difficulties in actually performing recharge, due to Cega river natural conditions, led the Comunidad de regantes to put pressure on the Confederacion Hidrografica del Duero in order to modify the concession.

A third phase is currently being implemented. The project is undergoing an environmental impact evaluation, and a report following environmental impact assessment has already been published. This phase will involve the derivation and storage of diverted water in a 3600 ha sandstone lens, covered by pine trees, in order to pump it during the irrigation period (from March to October). Moreover, the concession will undergo some modifications: the derivation period will be extended from December to May and the minimum river flow to maintain will go from 6.9 m^3/s to 0.6 m^3/s.

The published environmental impact assessment doesn't involve an analysis of the impacts that the third phase could have on the ecosystem services of Cega river. This perceived fallacy triggered a conflict between the stakeholders who live in close contact with the river, led by environmentalists, worried for the future of Cega river, and Caracillo farmers, who demand the water that was promised to them when the recharge project was promoted.

For all these reasons, the project represents an interesting opportunity to study the consequences of management choices on different social and economic scenarios. Objective of the study is to create a tool for supporting participatory processes in water planning and management in the Carracillo region, by involving ecosystem services in the bargaining process. At the same time, this tool should strengthen mediation processes in water related conflict.

From here on, the dissertation focuses on the case study at hand. A first part of the study is dedicated to stakeholder analysis, fundamental in order to identify the main actors involved in the conflict and the dynamics that bind them. Moreover, it allows to establish the core points around which conflict develops.

A second part is dedicated to conflict modelling. This was approached as a bargaining process between agricultural needs and natural necessities, embodied in Cega river ecosystem services. We defined a utility function for farmers as the relation between water actually available and agricultural water needs. Furthermore, we defined a utility function for ecosystem services through their quantification using Service Provision Index (Korsgaard et al., 2008).

After a thorough analysis of the hydrological and agronomic mechanisms involved in the scenario, a model was developed in order to investigate possible optima points and suggest concession rules for the recharge project, taking into account ecosystem services as well.

The optimization, performed through Nelder-Mead algorithm implemented in Python, After a thorough analysis of the hydrological and agronomic mechanisms involved in the scenario, a model was developed in order to investigate possible optima points and suggest concession rules for the recharge project, taking into account ecosystem services as well. In particular, optimum values for concession rules, in the form of minimum flow to be guaranteed downstream the derivation and maximum instantaneous intake were investigated. From the optimization process it emerged that an optimum value for the minimum flow to be guaranteed downstream the derivation is almost three times higher than the one prescribed by third-phase concession rules. Moreover, environmental flow values provided by the Confederacion Hidrografica del Duero for the hydrologic planning cycle 2015-2021, are less than 10% of average monthly flow, the threshold that, according to Tennant, defines the limit for a riverine ecosystem to be considered alive. Finally, optimization performed involving environmental flow values provided by Confederacion Hidrografica del Duero also shows higher results than values prescribed by the concession. These results suggest a need for a re-negotiation of concession rules related to the last phase of the recharge project.

There's hope that this critical analysis and comparison may constitute a basis for sustaining participatory processes in water resources management in the Carracillo region, as well as a tool to mediate disputes about water allocation. Finally, further studies could lead to the application of the proposed methodology to different case studies.

It is possible to note that a variety of different topics related to different disciplines was deepened, thus requiring a work setup that is not conventional. The first part constitutes the starting point from which the current thesis developed. It is structured as a review paper, with its own material and methods, results and conclusions. The second part describes the study area related to the case study selected. From here, the work develops in parallel providing, on the one hand the stakeholder analysis (third part), on the other hand the optimization process (fourth part). Both third and fourth parts are structured as papers as well, each one with its specific material and methods and results. Finally, fifth part is dedicated to conclusions, meaning general conclusion on the whole thesis

OBJECTIVES OF THE THESIS

The use of Managed Aquifer Recharge techniques is spreading worldwide. Beyond the numerous beneficial effects, though, they can heavily impact not only the environment, but also the social context in which these structures are implemented. Little bibliography exists on the topic of conflicts related to MAR management. Thus, the main objective of this study is to deepen "the dark side" of Managed Aquifer Recharge, meaning to investigate those aspects that can lead to conflicts.

The controversial case of MAR in Carracillo region provides an interesting insight in the conflicting dynamics that can originate from different management strategies. Two crucial issues were considered approaching to this case. First of all, the actors who will suffer most from the negative impacts of the project were not involved in the planning phase nor in the management one. Moreover, ecological and economical benefits deriving from Cega river, concretized through the concept of Ecosystem services, were not considered in the design of the project. So that, they do not have the same dignity and weight as other actors and they can not be involved in the bargaining process for the allocation of water resource.

According to what emerged from the review on conflicts related to water harvesting, water conflicts are triggered by erroneous practices and myopic interventions that may interfere with delicate structural conditions, thus leading to conflicts. Starting from this assumption, the complex case study under analysis was deepened taking into consideration both social and technical dynamics, in order to analyze the conflict from different perspectives and to provide technical solutions without leaving aside an in-depth analysis of social dynamics.

Thus, objectives of this research work are:

- to create a tool for strengthening mediation processes in water related conflict;
- to create a tool that allows the involvement of ecosystem services in the design and planning of recharge concession.

These objectives were fulfilled through the work performed on the ongoing water conflict in the Carracillo region (Spain).

Part I

WATER CONFLICTS AND WATER HARVESTING

1 INTRODUCTION TO WATER HARVESTING AND CONFLICTS

Water harvesting (WH) is defined as the concentration, collection and storage of floodwater runoff or rainwater for multi-purpose use (Critchley and Siegert 1991)and it is a universally recognized mean to cope with water scarcity and to increase resilience and food security in arid and semi-arid areas of the world (Rockström and Falkenmark 2015). Moreover, it is recognized as having beneficial impacts on the environment, as it enables a lower exploitation of aquifers, rivers and lakes, leading to aquifer recharge (Mbilinyi et al. 2005; Mekdashi Studer and Liniger 2013; Ziadat et al. 2012). Runoff collection represents a measure of erosion control (Ziadat et al. 2012) and it has been proven that the intensification of water harvesting interventions may lead to a global increase in catchment ecosystem services (Dile et al. 2013).

Water conflicts are one of the most popular topics currently studied in the scientific environment and they are investigated from a range of different perspectives, not only from a social (Trottier 2003; Wolf 2007) but also from a geographic (Appert and Drozdz 2010) and engineering point of view (Zomorodian et al. 2017; Giordano et al. 2005). Furthermore, the concept of water wars has always been on the global agenda. After the quote of the former Vice President of World Bank Ismail Serageldin "if the wars of this century were fought over oil, the wars of the next century will be fought over water" (Serageldin 2009), pronounced on the occasion of a conference in Stockholm in 1995, the concept was pushed forward by international institutions as well as academia, leading in some cases to a misuse of the concept (Wolf, 1999). This does not mean that water conflicts do not occur, but it should be noticed how the research undertaken after the inflation of water wars concept showed that there are more cases of cooperation over shared water resources than conflicts over them (Wolf 1999; Kameri-Mbote 2007).

Many large-scale conflicts are related to water allocation and management of a shared source: such is the case of the collision between Sudan and Egypt related to upstream-downstream storage problems along the international river Nile; or the conflict between Armenia, Azerbaijan and Georgia, related to pollution issues (Basak and Campana 2008; Starr 1992; Kraak 2012).

WH, since it ensures water availability for domestic and agricultural use even in a scarcity of "common" sources, can sometimes act as a preventive or mitigating factor in water conflicts, if supported by a cooperative process of planning and management (Wolf et al. 2005). On the other hand, the construction of water harvesting structures like small dams or diversions changes the hydrological regime and, more specifically, it changes water allocation (Hay and Kitson 2013) and affects upstream-downstream dynamics (Seka et al. 2016). In this sense, it can be the cause of contentions between stakeholders referring to the same water source. A similarity can be found between alterations to the hydrological regime caused by WH infrastructures and water allocation changes typical of larger structures, which are often triggering factors for water conflicts.

However, water conflicts have been investigated above all in cases of international water conflicts (Freeman 2007; Trottier 2003; Warner 2012), often leaving out non-sensationalized local conflicts. Research about the relationship between water harvesting and occurrences of water conflicts is lacking.

Hence, the first part of the present work aims to analyse and clarify relations between WH and water conflicts, providing a conceptual framework to understand to what extent water harvesting can be considered a positive, mitigating factor and, on the other hand, to what extent it can act as triggering factor of water conflicts.

The first part of this study will be dedicated to an overview of the two topics we will investigate, that of water conflicts and that of water harvesting, providing some explanatory definitions of the first and the main existing classifications of the latter. The following sections will focus on a comparative analysis of the existing literature of case studies involving water harvesting and water conflicts. The analysis will develop in two steps: first putting water conflicts in relation with the two main water harvesting classes, then analyzing the role played by water harvesting as resistance mean in local and regional water conflicts. The discussion will subsequently clarify the major water conflict triggering factors related to water harvesting, while constructing a conceptual framework for the assessment of interactions between water harvesting and water conflicts. The presented study will constitute the theoretical base for a wider research, which main goal will be the creation of guidelines for conflict assessment in water harvesting interventions.

1.1 WATER CONFLICTS: DEFINITIONS

As Wolf states (Wolf et al. 2005), the Latin roots of the term rivalry mean "two people using the same river", intrinsically reflecting ancient origins of conflicts over water resources.

Anyway, it is possible to affirm that actual definitions of water conflicts do not exist, since they are rather based on what is meant by water conflict. Thus, first definitions of the more general concept of conflict will be provided, followed by those of water conflict.

Karamouz et al. (2006) define a conflict as "a disagreement among individuals or groups that differ in attitudes, beliefs, values or needs". Cadoret (2011) defines conflicts as a manifest opposition between two or more actors. Conflicts are distinguished from tensions due to a passage to the act, that can take different forms (threats, de facto, recourse to the courts, verbalization, mediatization, etc.). Considering water conflicts, Palmer et al. (1999) state that "conflicts occur when people disagree about how much water of a given quality should be used at a specific location for a specific purpose at a particular time".

Moreover, Mauelshagen (2006) defines water conflicts as "disputes between individuals or groups (institutions and states included) about the distribution and usage of freshwater and about the use of freshwater reservoirs (in the first instance: rivers and lakes)".

Sometimes it can be useful to integrate definitions with considerations on the extents at which water conflicts occur or on the triggering factors. Phelps (2007), for example, states that "water conflicts are really an issue of allocation and equitable sharing more than anything else" and that "Drought alone does not start conflicts. It is the lack of equitable allocation during droughts that creates conflict".

Finally, Ohlsson (2000) distinguishes between conflicts resulting from water scarcity itself and conflicts resulting from the application of social resource in order to deal with water scarcity (usually internal conflicts directed at the State).

1.2 WATER HARVESTING: CLASSIFICATIONS

The aim of water harvesting is to capture rainwater falling in a certain area at a certain time, reallocating it over time and within new scenarios (Critchley and Siegert 1991; Falkenmark et al. 2001). On the other hand, water harvesting classification has been widely discussed in the academic environment. Existent classifications are based on a particular distinctive aspect, for example the catchment type (FAO 1994) or the storage systems and strategies (Van Steenbergen and Tuinhof 2009; Tuinhof et al. 2012).

Critchley and Siegert (1991) simply distinguish between Rainwater harvesting and Floodwater harvesting. The first is comprehensive of those techniques that allow to harvest runoff from roofs or ground surfaces; the latter is constituted by those techniques that allow the diversion or spreading within channel bed of channel flows.

WOCAT (World Overview of Conservation Approaches and Technologies) guidelines (Mekdashi Studer and Liniger 2013)"Water harvesting, guidelines to good practice", claim that in general the terms water harvesting (WH) and rainwater harvesting (RWH) are used as interchangeable. Moreover, water harvesting is usually employed as a general term used to refer to those methods that allow the collection and management of floodwaters and runoff including rooftop water harvesting, runoff irrigation, spate irrigation and runoff farming.

These guidelines base their classification on catchment type, integrating the classifications used by Critchley and Siegert (1991), Oweis et al. (2012) and Tuinhof et al. (2012). It results in a four-group categorization: floodwater harvesting, macrocatchment systems, microcatchment systems, and rooftop and courtyard water harvesting. According to the definitions provided by WOCAT guidelines, Floodwater harvesting is "the collection and storage of ephemeral channel flow for irrigation of crops, fodder and trees, and for groundwater recharge". Macrocatchment WH comprehends systems that allow to harvest runoff water from a natural catchment. Microcatchment WH systems collect runoff "from small catchments of short length, so that rainwater is collected in confined areas where plants are grown". Finally, Rooftop and courtyard water harvesting allow to collect runoff water from rooftops or compacted, paved surfaces.

A controversial issue is that of Groundwater harvesting (Mekdashi Studer and Liniger 2013). Oweis (2016) argues that structures as Qanat, groundwater dams or horizontal wells, for example, are mistakenly considered water harvesting structures. In fact, rainwater harvesting is supposed to involve three constant processes: rainfall runoff, water storage, and water use for any target purpose. Within the framework of the present study, groundwater harvesting is not be considered as a form of water harvesting, since runoff does not occur, adopting Oweis' definition (2016).

2 TOOLS USED FOR THE REVIEW

Initially, the framework for the review was based on univocal definition of water conflicts and classification of water harvesting. For what concerns the definition of water conflict used, in this study we will refer to the meaning emerging from Mauelshagen's statement (Mauelshagen, 2006), since it seems to us to be the simplest and at the same time the most exhaustive. Moreover, this study will provide more evidence of Phelps' argument (2007).

Regarding water harvesting classification, the study was performed starting from Critchley's classification of water harvesting, since a research based on WOCAT classification would have been too specific, limiting the spectrum of possible results. The literature review was performed on Scopus and Google Scholar using the following keywords combinations:

i "Water harvesting"+ Conflict

ii "Rainwater harvesting"+ Conflict

iii "Spate irrigation"+ Conflict.

The last keywords combination proved to be necessary since Spate irrigation papers are often classified only within the "irrigation" topic, without having direct links with WH, such as title, abstract or keywords. Only 21 papers were retrieved, testifying little literature about it.

The research led to the selection of twelve case studies, analysed and classified into three main chapters. The first two are related to the type of water harvesting involved: Floodwater harvesting and conflicts, Rainwater harvesting and conflicts. The third one considers the role of water harvesting as support tool in conflict situations. Finally, the comparison and the analysis of the case studies classified allowed to provide a theoretical framework that will be explained and discussed.

A visual configuration of the working scheme followed in this phase is provided in Figure 2.1

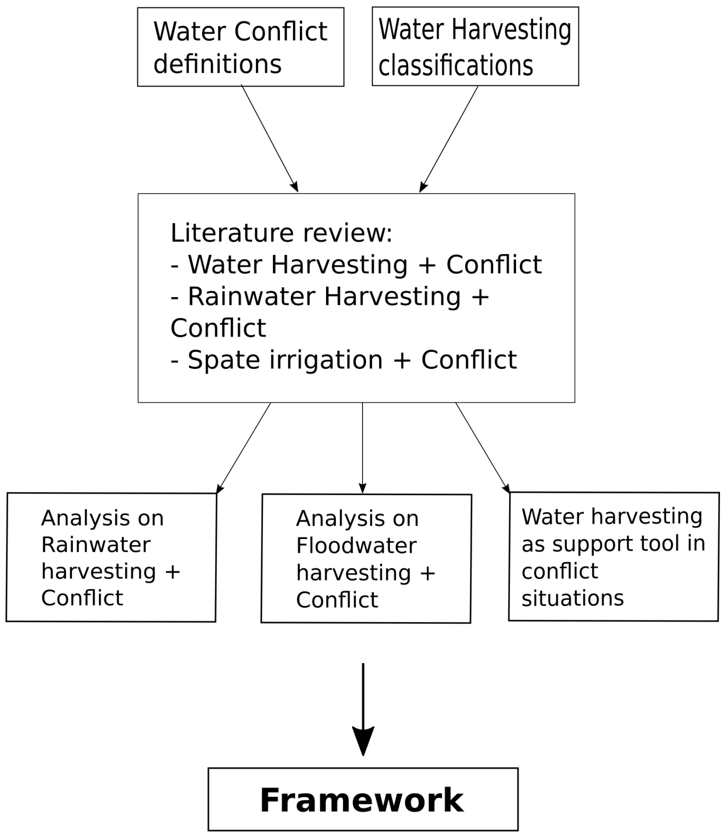


Figure 2.1: Visual configuration of the working scheme followed in the present study

3 OVERVIEW OF CASE STUDIES

By the analysis of the literature, 21 papers were retrieved within the literature database used. Therefore, the topic appears quite unexplored, despite the presence of relevant case studies. Twelve of them were identified and traced to three main chapters, performing a comparative analysis in the attempt of better explaining relations between water harvesting and conflicts (Table 3.1).

In the following section, the first two paragraphs discuss separately the nature and the dynamics of water conflicts identified for the two classes of WH defined, while the third one explores the concept of WH for supporting local population in conflicts against something else, with reference to water and environmental conflicts.

3.1 FLOODWATER HARVESTING AND CONFLICTS

Relations between floodwater harvesting and conflicts were analyzed considering and comparing different case studies focused on spate irrigation systems.

3.1.1 *The Wadi Laba spate system, Eritrea*

Conflicts generally occur between upstream and downstream communities within the same spate irrigation scheme. Mehari Haile et al. (2005a)present the case of the Wadi Laba spate irrigation scheme. Spate irrigation is a method for managing floodwater that, "from mountain catchments is diverted from ephemeral riverbeds (wadis-/koris) and spread over large areas, often in lowland plains, to irrigate crops" (Mekdashi Studer and Liniger 2013).

The Wadi Laba system is based on a fair and equal management of flood water, achieved through cooperation and active participation of both upstream and downstream farmers, located along the primary channel, in constant maintenance and reconstruction of spate structures, that were destroyed or partially washed away after floods. Internal rules establish that small and medium floods benefit upstream fields, while large floods will benefit downstream farmers.

Before each flood, the construction of the main diversion structure (jelwet), constituted by brushes, tree trunks, earth and stones, was agreed between the various farmers' group, according to the size and the location of the area to be irrigated, and to mentioned rules.

The system was modernized in 2001, with a concrete structure replacing the jelwet, with the aim of reducing the burden of the recon-

Table 3.1: Analysed case studies relating water conflicts to water harvesting practices.

Case study	Reference	Keywords
The Wadi Laba spate system, Eritrea	Mehari Haile et al., 2005a, 2005b.	Spate irrigation + conflict
Spate systems in Pakistan	Van Steenbergen, Frank, 1997; Mehari Haile et al., 2005.	Spate irrigation + conflict
Spate systems in Yemen	Al-Eryani, M. & Al-Amrani, M., 1998; Mehari Haile et al., 2005.	Spate irrigation + conflict
The Makanya spate system, Tanzania	Komakech, H.C. et al., 2011.	Spate irrigation + conflict
Rooftop water harvesting in India	Kumar, M.D., 2009.	Water harvesting + conflict
Rooftop water harvesting in the United States	Meehan, K.M. & Moore, A.W., 2014.	Rainwater harvesting + conflict
The case of usptream - downstream conflicts in North Ethiopian watersheds: Lake Tana and Raya Valley	Dile, Y.T. et al., 2016; Dile, Y.T. et al., 2013b; Castelli, G. et al., 2017	Rainwater harvesting + conflict
The case of Mekelle Plateu, Ethiopia	Aberra, Y., 2004	Rainwater harvesting + conflict
The case of Murcia Region, Spain	Castejòn-Porcel, G. et al., 2018.	Water harvesting + conflict
The case of Lerma-Chapala basin, Mexico	Scott, C.A. & Silva-ochoa, P., 2001.	Water harvesting + conflict
The case of Cochabamba, Bolivia	Coleman et al., 2012; Wilk, J. et al., 2017.	Water harvesting + conflict
The Palestinian case	Selby, 2007; Wessels 2015; Messerschmid 2007; Bashir & Winkelstein 2004.	

struction work to the farmers. This, de facto, transferred the system management to official gate operators (Mehari Haile et al. 2005b). In 2002, a large flood caused the complete destruction of the weir, due to unprepared gate operators. As a consequence of the damage, 7 consecutive large floods were lost for the whole system. After that, although it was illegal according to the system rules, the upstream farmers group unilaterally constructed a new structure to divert the water that was being lost, hindering other groups from receiving water. This decision caused conflict and a series of cascade effects. Moreover, farmers were not totally convinced of the newly implemented diversion weir could convey enough water to plots, and in 2003 one group of farmers used the scour sluice as an additional irrigation canal, while another one started to divert overflow water. These actions caused damage to downstream portions of the spate system, exacerbating conflicts and frictions among the farmers' community.

3.1.2 *Spate systems in Yemen*

In Yemen, the modernization of spate irrigation systems in three different wadi resulted in almost complete control on floodwater by upstream farmers (Al-Eryani and Al-Amrani 1998). Local Government that replaced Sultans and Sheikhs, that traditionally held power on local water rights and rules, was not able to adapt traditional rules and rights and to enable them to fit the new realities subsequent to structures' modernization. This led to a situation in which upstream farmers completely utilized floodwater, shifting to higher water demand and higher profitable crops. Downstream farmers often abandoned their fields and become daily labourers for upstream landlords.

3.1.3 *Spate systems in Pakistan*

The study performed by Steenbergen (1997) in Pakistan, highlights how the construction of a weir changed traditional water distribution system, causing conflicts between upstream and downstream farmers. At the end, the two communities upstream and downstream found a common agreement and pulled down the weir, returning to their traditional water rules and management.

3.1.4 *The Makanya spate system, Tanzania*

Komakech et al. (2011) analyzed the Makanya catchment spate irrigation system, in Tanzania. This complex systems' interconnection comprehends three main actors, that are: some water users placed upstream, but outside the spate system itself; the actual spate irrigation system; some livestock keepers that live downstream of the spate system.

Authors pointed out that there is no agreement between the spate irrigation farmers and the upstream users, even if spate irrigation system is based on exceeding water of upstream farmers. At the same time, spate irrigation's farmers use the amount of water they deem necessary, without taking into consideration livestock keepers placed downstream.

The lack of any sort of covenant or agreement between upstream and downstream users is leading to conflictual situations, due to the increasing water storage and use performed by upstream farmers and, at the same time, due to the inconsiderate water use by spate irrigation's farmers.

3.2 RAINWATER HARVESTING AND CONFLICTS

3.2.1 *Rooftop water harvesting in India*

The usefulness of rooftop water harvesting is proven by a large number of studies (Worm and Hattum 2006; Abdulla and Al-Shareef 2008; Melidis et al. 2007)and it constitutes almost the only source of water supply in many arid areas of the world (Bailey et al. 2017).

As stated by Kumar (2009) in his study "Roof water harvesting for domestic water security: who gains and who loses?", rooftop water harvesting seems not to be an effective mean to face the growing drinking water crisis in India. In fact, roof area per capita of low and middle income classes is quite limited. Furthermore, the economic role that rooftop water harvesting can play in ensuring domestic water security is poor in urban areas. Thus, the author states that low rates for domestic supplies and government subsidies proportional to available rooftop surfaces for water capturing will benefit high income groups, leading to even greater inequities in water access.

3.2.2 *Rooftop water harvesting in the United States*

In the study "Downspout politics, upstream conflict: formalizing rainwater harvesting in the United States" (Meehan and Moore 2014) authors analyze how water harvesting fits within United States' legislation. In particular, they focus on how rainwater is formalized, at institutional level and through market-based tools; furthermore they analyze how policies are implemented at different spatial scales. It emerges from the study that conflicts usually occur when "local norms contradict formal rules" or when local organizations contest State attempts to take control over public resources like spaces or water sources. There lacks a unique, shared and widely accepted legal medium that "*formalizes rain*", a feat made even more difficult by the fact that each State has its own jurisdiction over local water policy. In Colorado, for example, Senate Bill no.80 of 2009 allows to capture and store rainwater for beneficial use, but only over properties wich are not connected to the main water network; in contrast, Texas is increasingly encouraging the use of water harvesting practices.

3.2.3 *The case of North Ethiopian watersheds: Lake Tana and Raya Valley*

Dile et al. (2013, 2016), discuss the possibility of the occurrence of conflict related to the implementation of upstream Water Harvesting structures in upstream areas of Lake Tana Basin in Ethiopia. Their analysis encompass the use of the SWAT model, that however demonstrates a negligible environmental impacts on downstream areas. Authors consider only streamflow and sediment load modelling, warning about the possibility of indirect conflict given by the reduction of flows for irrigation.

Similar results emerged from the study conducted by Castelli et al. (2017) on two different wadi catchments of Raya Valley, Ethiopia. Authors stated that emerging conflicts were reported by both upstream and downstream communities as consequence of the increase of water management practices. The intensification of rainwater management and rainwater harvesting practices upstream improved economic activities and enhanced ecosystem services. On the other hand, the almost total abstraction of the gentle runoff by upstream communities for livestock and agricultural activities led to conflicts. Authors state that policies to regulate water allocation must be addressed to avoid worsening the delicate existing balances as well as future conflicts.

3.2.4 *The case of Makelle Plateau, Ethiopia*

Conflicts, however, arose in the similar case of the Mekelle Plateau, Ethiopia (Aberra 2004). This study shows that attempts of interventions to improve small-scale irrigation systems, like for example the construction of runoff harvesting micro-dams, led to small conflicts between farmers and SAERT (Commission for Sustainable Agriculture and Environmental Rehabilitation for Tigray, a regional government agency) personnel, due to the non-inclusion of farmers in planning and design phases.

3.2.5 *The case of Murcia Region, Spain*

In the Region of Murcia, Spain, a research performed in order to demonstrate the potential of runoff water as resource (Castejòn-Porcel et al. 2018),underlined how new water collection infrastructures led to the outbreak of conflicts. Indeed, in this region rainwater harvesting technologies, used since ancient times, have been replaced by new technologies like transfer of foreign flows, underground exploitation and desalinization. These new structures allowed an extraordinary agricultural and touristic expansion, at the same time introducing a new exploitation model and heavily threatening social and environmental fabric.

3.2.6 *The case of Lerma-Chapala basin, Mexico*

The study "Collective action for water harvesting irrigation in the Lerma-Chapala Basin, Mexico" (Scott and Silva-ochoa 2001) analyses and compares two water harvesting irrigation systems within the same basin, the Lerma-Chapada.

In 1930, the Cardenas agrarian reform established the ejidos, legal bodies of the reform communities, to which land was titled and that collectively managed land and water resources based on shared rights and rules. The modification of article 27 of the Mexican Constitution (that led to permission to sell ejido land) and increasingly implementation of the North America Free Trade Agreement (NAFTA) greatly threatened collective land and water management accomplished by ejidos. The two analyzed WH systems, in Trojes and Napoles watersheds, are both based on the ejido model. In Trojes, WH system is constituted by a 1300000 m^3 reservoir, serving 53 users. Water is allocated per unit land, not per user, meaning a non-equal distribution among users. Napoles' system is constituted by diverting structures with inter-community allocation and by a 50000 m3 storage reservoir that serves 51 users and that it is shared with a private land-owner. Water allocation is there based on 4 hour rotational turns, without considering parcels' size or necessary flow. Unlike Trojes, in which water allocation system led to low variation in the irrigation depth and a consequent ability to deal with water scarcity, Napoles water allocation system resulted in a high variation in the measured irrigated area, with a consequent total crop failure during water scarce years.

This competition upon resources requires solidarity within the community and this can be achieved only through an equal access to water for all users.

3.2.7 *The case of Cochabamba, Bolivia*

In 2000 Cochabamba was the scene of a violent conflict over water. People in Cochabamba were used to practicing rooftop water harvesting as alternative additional source of water supply to deal with the scarce system of potable water services (Coleman 2012). Neoliberal policies led to the privatization of state-owned companies and the transferring of concessions from the public sector to the private one. In particular, the concession for the provision of water in Cochabamba region was sold to Aguas del Tunari's, a Bolivian subsidiary of the Bechtel Corporation, a private construction and engineering company based in San Francisco. The concession resulted in a further deterioration of an already scarce system of potable water services and in an increase of the rates. Moreover, the definitive triggering factor was the prohibition of the use of rooftop water harvesting systems people created as alternative water supply and the cancellation of those traditional rules for water allocation and rights that people developed on their own based on the consideration of water as a public good (Wilk et al. 2017).

3.3 RESISTING FROM BELOW: WATER HARVESTING AS A SUPPORT TOOL IN CONFLICTING REALITIES

If assessed in the right way, starting from below through a bottom-up approach (Stewart et al., 2015) and cooperatively constructing and managing the structures, water harvesting can positively act as support tool in conflictual situations as well as in resistance actions.

It is a fact that water harvesting has played the role of support mean in counter-hegemony strategies (Zeitoun and Warner 2006). Furthermore, as stated by Cascao (2009), "the unilateral construction of infrastructures" is a commonly used leverage mechanism in counter-hegemonic actions. But, more in general, it is interesting to underline that technologies for rainwater harvesting can play a further positive role, by sustaining people that face struggle situations. Some explanatory examples can be found in Palestine and in the already mentioned case of Cochabamba in Bolivia.

The conditions in the Palestinian territories occupied by Israel are getting worse and worse. The faint light of hope ignited by the Oslo Agreements signed in 1993 turned off drastically as soon as it became clear that the Accords not only favored the Israeli position but also legitimized those manoeuvres imposed through illegal measures and military orders (Selby 2007).

Palestinians are every day more dependent on the costly, unfair and uncertain water supply provided by Israel, that exploits Palestinian water sources located in the West Bank and Gaza to sell back to Palestinians living in these areas (Wessels 2015). Around 60 litres daily are allocated to each Palestinian in the West Bank for domestic consumption, while an average of 220 litres per day are allocated for each Israeli (Messerschmid 2007). Moreover, drilling permits are quite impossible to obtain, also within the eastern aquifer that has no connections with Israel.

In this drastic situation, Palestinians rely heavily on rainwater harvesting. Rainfall is collected from rooftops and directly used for domestic consumption or stored in cisterns and sub-surface tanks as water supply for the driest months (Bashir and Winkelstein 2004).

Water harvesting structures, far from being an alternative able to completely fill the gap created by the lack of an adequate system of water supply, can still represent a valid form of support. Yet, the collection of rainwater can just act as sustaining mean, relieving a situation whose gravity has its roots in a merely politic design that made inequality a structural problem.

Another representative case is that of the already mentioned conflict of Cochabamba. There, people recognized water harvesting as part of their cultural identity, as an alternative water supply source supported by traditional water laws and allocation criteria, based on a fair and equitable distribution of water resources. The prohibition to do water harvesting deeply affected the identity of the community, that felt deprived of a fundamental pillar. Thus popular insurrection, supported by appropriate legal actions, led to the annulment of Agua del Tuanari's contract.

4 ANALYSIS AND DISCUSSION

4.1 POTENTIAL RISK FACTORS AND TRIGGERING FACTORS: THEORETICAL FRAMEWORK

Potential risk factors are potential causative agents of conflicts, meaning all aspects that can constitute the fuse for water conflicts. They are correlational factors, thus not necessarily causal, and relate to both floodwater and rainwater harvesting. A simple classification in two classes is proposed: Structural and Anthropic.

Structural risk factors are concrete, rooted into the environmental characteristics of a territory or a basin, or to the effects of a water harvesting system. They constitute a potential risk factor as they represent structural inequities, and it is proven that inequities are generally fertile ground for conflicts eruptions (Cramer 2005). In this category fall (Figure 4.1):

- The upstream-downstream nature of floodwater distribution in spate systems, as in the case of the Makanya catchment in Tanzania (Komakech et al. 2011), the presence of head-enders and tail-enders irrigators, as in the case of the Wadi Laba in Eritrea (Mehari Haile, Schultz, et al. 2005a), and the spate systems in Yemen and Pakistan (Van Steenbergen 1997), concerning upstream and downstream communities. The existence of upstream and downstream communities or of head-enders and tail-enders is linked to the natural, environmental pattern and is an inevitable problem of diversion interventions.
- Pre-existent inequities in available collecting surfaces (as in the reviewed case study in India (Kumar 2009)) or in storage capabilities.

Anthropic risk factors are forms or consequences of human activity. Examples from the cited case studies include:

- The construction of new water harvesting structures, like the introduction of a new form of water harvesting with small dams in the Mekelle Plateu in Ethiopia (Aberra 2004), the intensification of water harvesting performed by head-enders in the Lake Tana basin in Ethiopia (Dile et al. 2016; Castelli et al., 2017)and by upstream community in the Makanya catchment in Tanzania, or the introduction of new water collection infrastructures in Campo de Cartagena in Spain (Castejòn-Porcel et al. 2018). The construction of new, modern diversion structures in Yemen and

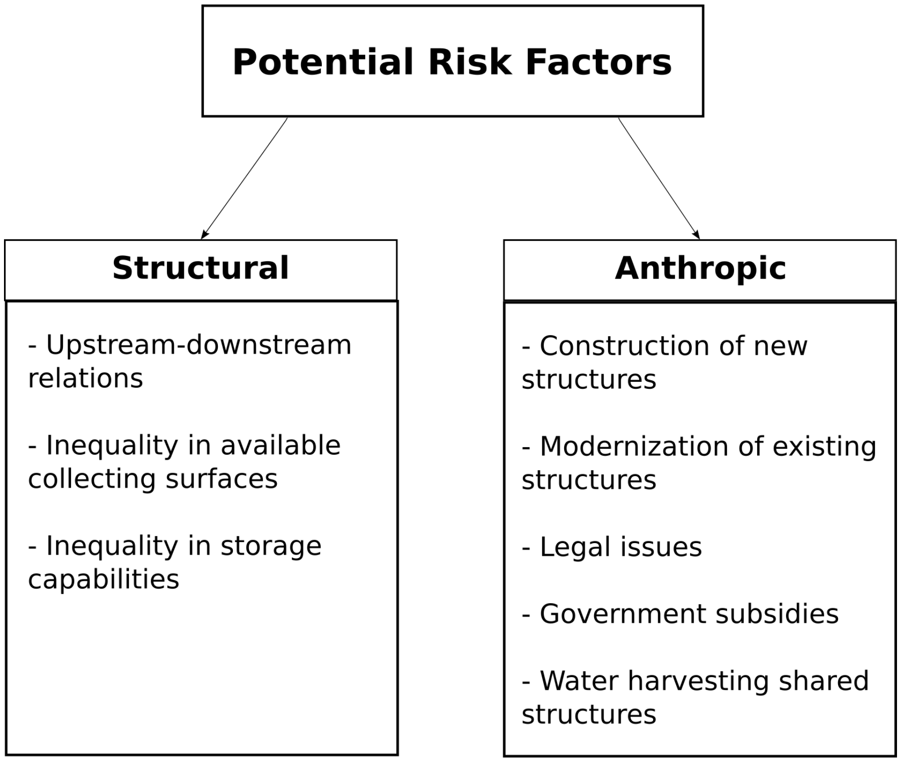


Figure 4.1: Potential risk factors related to water harvesting.

Pakistan is a further example (Mehari Haile, Steenbergen, et al. 2005).

- The modernization of existing structures, like in the case of the Wadi Laba spate irrigation scheme in Eritrea.
- Political and juridical aspects, as is the case of the presented case studies in India, Yemen, Cochabamba and the United States.
- Sharing policies, as highlighted in the case of Mexico.

Once the original triggering factor has been identified, it can be classified as an Actual Triggering factor, as such belonging to a subset of Potential risk factors. Actual Triggering factors can be recognized via a critical analysis of the presented case studies, and the thesis of the present research is that, for what concerns water harvesting, they are uniquely and solely constituted by Anthropic factors, as Structural factors have always been present and, if well managed, do not lead to conflicts.

Table 4.1 puts each case study in relation with corresponding Potential risk factors and effective Triggering factors.

The proposed study allowed to define a theoretical framework for the assessment of the obtained results. The framework is presented in Figure 4.2.

Water harvesting interventions can be thought of as they were constituted by some necessary steps, meaning the Design phase; the

Table 4.1: Potential risk factors and effective Triggering factors in the analysed case studies.

Case study	**Potential risk factor**	**Triggering factor**
The Wadi Laba spate system, Eritrea	Upstream-downstream relations	Modernization of existing structures (=>Introduction of new forms of water management)
Spate systems in Yemen	Upstream-downstream relations	Construction of new structures (=>Introduction of new forms of water management); Legal issues
Spate systems in Pakistan	Upstream-downstream relations	Construction of new structures (=>Introduction of new forms of water management)
The Makanya spate system, Tanzania	Upstream-downstream relations	Construction of new structures
Rooftop water harvesting in India	Inequality in available collecting surfaces	Government subsidies
Rooftop water harvesting in the United States	Legal issues	Legal issues
The case of usptream - downstream conflicts in North Ethiopian watersheds: Lake Tana and Raya Valley	Upstream-downstream relations	Construction of new structures
The case of Mekelle Plateau, Ethiopia	Upstream-downstream relations	Construction of new structures
The case of Murcia Region, Spain	Construction of new structures	Construction of new structures
The case of Lerma-Chapala basin, Mexico	Upstream-downstream relations	Shared water harvesting structures
The case of Cochabamba, Bolivia	Legal issues	Legal issues

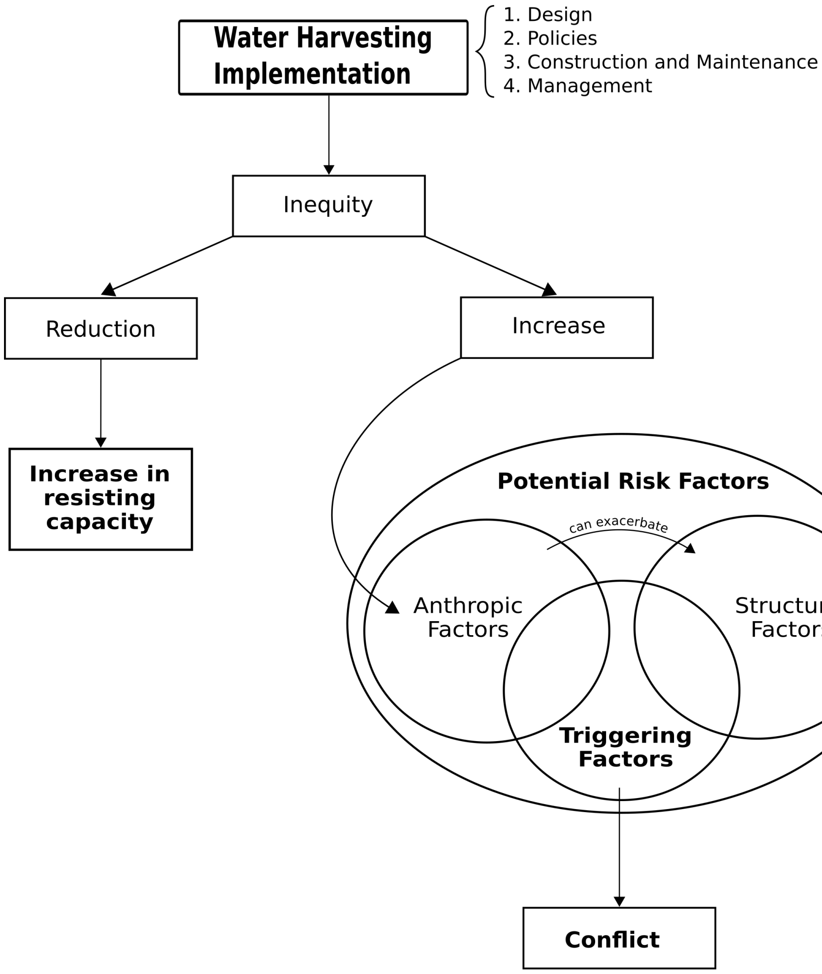


Figure 4.2: Theoretical framework for the assessment of studies relating water harvesting interventions to water conflicts.

underlying legal fabric interventions, constituted by the Policies related to water management; the Construction and Maintenance phase; the Management phase.

Water harvesting implementation impacts on existent inequities. Each one of these steps can increase or reduce them. Where interventions are designed in a participatory way, horizontally approaching construction, maintenance as well as management of the structures, water harvesting can reduce inequities, as the case in which it represents a support tool in conflict situations.

On the other hand, even if only one of these steps is inappropriately conducted, consequent Potential Risk Factors are generated.

In some cases, a subset of Potential Risk Factors actually cause a conflict situation, thus becoming effective Triggering Factors. In the proposed framework, following the given definition of Potential Risk Factors, the authors decided to consider negative downfalls of water harvesting interventions as being exclusively Anthropic Risk Factors.

4.2 ANTHROPIC RISK FACTORS AS TRIGGERING FACTORS: DISCUSSION

The comparative analysis on the selected case studies allowed to highlight that the final causative agents of water conflicts are constituted by Anthropic Risk Factors. Where not careful design and mismanagement of structures, and short-sighted interventions, both technical and legal occur, conflicts can be triggered. At the same time, Anthropic Risk Factors can threaten the weak physical aequilibrium: eventual Structural Risk Factors are pre-existent and can be exacerbated by human intervention.

The studies performed in the Mekelle Plateu, Lake Tana basin (Dile et al. 2016)and Tigray Region in Ethiopia are emblematic, since they evince that the construction of new structures and an intensification of WH practices can lead to side effects. In fact, from one side modeling shows good results. From the other side, conflicts occurring during practical implementation highlight the crucial role played by man in the whole process (Aberra, 2004; Castelli et al., 2017).

Moreover, the construction of new structures and the modernization of existent ones require new forms of water management, like in the case of Eritrea, Yemen and Pakistan, that can cause conflicts if done wrong. In this prospective, it makes sense to compare the three spate irrigation interventions in Eritrea, Pakistan and Yemen (Mehari Haile, Steenbergen, et al. 2005). The three communities involved reacted in different ways to changes in the water management systems, due to the different mechanisms of water redistribution. The worst reaction, where the hardest conflicts arose, is the one of Yemen, where the heterogeneity of population in terms of power and richness, as well as the detention of the power on water management by Sultans and Sheikhs, resulted in an unstable social system. The Local Government, after the decommissioning of Sultans and Sheikhs, wasn't able to manage the unstable situation that, left to itself, opened the way to conflicts. On the other hand, communities in Pakistan and Eritrea profited from a fairer water redistribution: in Pakistan, upstream and downstream communities have equal socio-economical powers and upstream farmers did not try to exploit a situation that was advantageous for them; in Eritrea the presence of a homogeneous society, strongly believing in the righteousness of a fair distribution of water, as well as the existence of democratically elected leaders and village elders supporting in dealing with social disputes, enabled communities to better cope with external stresses and face modernization cohesively (e.g.: getting involved in the management and maintenance of new structures) (Mehari Haile et al., 2005).

Furthermore, water harvesting structures affect social structures and existing traditional laws. When the interventions are performed without taking into consideration communities traditionally living in the area, with their own rights and rules, they trigger conflicts due to a complete exclusion of local farmers and communities from both the design and the management phases (Aberra 2004; Mehari Haile, Schultz, et al. 2005A). Their exclusion from the benefits deriving from the construction or modernization of the structures, from rights of using their land and water, and in general changes in traditional water management and social pattern are also sources of conflict (Al-Eryani and Al-Amrani 1998; Van Steenbergen 1997).

In the same way, government subsidies for rooftop water harvesting in India did nothing but accentuate the disparities between high-income and low-income classes, which can be considered as a Structural factor, favouring people having larger roof surfaces (high-income class) (Kumar 2009). In the United States, conflicts were due to the lack of an univocal legislative tool defining "who owns rain" and who is allowed to harvest and use it (Meehan and Moore 2014). Legal issues, again deriving from bad policies, constituted the triggering factor in Cochabamba (Wilk et al. 2017). Finally, the case of the shared water harvesting structures in the Lerma Chapala basin in Mexico is the example of how human interactions impact water management and are subtended as the final triggering factors of water conflicts (Scott and Silva-ochoa 2001).

The role of man intervention as key cause of the start of disputes should not be surprising. In their work "All about water and land? Resource-related conflicts in East and West Africa revisited", Seter et al. (2018)demonstrate that two state policies are the crucial triggering factors of conflicts. Their study analyzes the role of renewable-resource scarcity in some cases of conflicts between pastoralists and farmers or pastoralists in West Sahel and East Africa. Authors found that resource scarcity is never the most important cause, while "state policies favouring one group at the expenses of another group and state decisions to redraw administrative boundaries" are the main cause of the outbreak of conflicts in almost all the cases analyzed.

A similar outcome emerges from the study of Fatch and Swatuk (2018), that highlight as water scarcity is not the main triggering factor of violent conflicts in the context of the difficult transboundary water interactions in the Lake Malawi/Niassa/Nyasa, sub-basin of the Zambezi.

On the other hand, the cases of Cochabamba and Palestine provide examples of the fact that, where appropriate interventions are made, water harvesting can provide a useful tool for sustaining people and improving water access. In these cases, water harvesting is well rooted in customs, traditions and water management practices; furthermore, it constitutes almost the only source of water supply. Hence, the introduction of an anthropic external force, constituted by the multinational company to which the water supply service was sold in Cochabamba, and by the Israeli-Palestinian war, enables water harvesting to become a cohesive factor, able to sustain Palestinian people oppressed by the Israelis, and to act in the Cochabamba rising as "the last drop".

Moreover, the case of Cochabamba is particularly explanatory since water harvesting plays a double role. From one side, it is the demonstration that water harvesting, managed through a bottom-up approach and in a cooperative way, represents an effective mean for sustenance, as well as a cohesive factor. From the other side, it becomes the final triggering agent of a conflict, when anthropic external interventions are made with a top-down approach, without taking due consideration of rights, laws and water management practices traditionally in use.

It is possible to conclude that the main cause of conflicts related to water harvesting lies in an incorrect implementation, that exacerbates existing inequities or creates new ones. It can cause subtle physical balances to break, if interventions are made without the use of participatory processes during structures' design and management and where historical and social aspects are not considered. A merely technical answer to problems of water scarcity, dropped from above and disconnected from the social fabric, can be useless as well as harmful.

5 CONCLUSIONS OF THE REVIEW ON WATER HARVESTING AND WATER CONFLICTS

The presented analysis embraced and explored a variety of case studies in order to reach the ambitious goal of put in relation two fields, that of water harvesting and that of water conflicts, whose mutual influence has been poorly analysed until now.

It emerged that:

- Water harvesting can play a positive role as support tool in conflict situations. Anyway, it can also act as cause of conflicts
- Conflicts triggered by water harvesting practices are small-scale conflicts. Research on water harvesting' side effects, as well as that on small, "non sensational" conflicts is lacking. From this derives the importance of this first exploratory study
- The main causes of conflicts related to water harvesting practices are attributable to the lack of horizontality in structures' design and management, to anthropic interventions made without taking in consideration social dynamics and water management practices traditionally used.

The study allowed to clarify that water harvesting interventions, made "from below" and appropriately taking in consideration the existing social pattern, can act as support tool as well as a form of resistance in unequal conflicts.

Moreover, the role of water harvesting as causative mean of water conflicts was investigated. It emerged the existence of a variety of Potential Risk Factors, meaning correlational factors attributable to both structural and anthropic aspects that, if not altered, do not act as causative means of water conflicts. At the same time it clearly appeared that triggering factors related to water harvesting practices are attributable to Anthropic factors. Erroneous practices and myopic interventions, exacerbate delicate structural conditions, leading to conflicts.

Hence, water harvesting can effectively act as triggering factor if it is not supported by an adequate and in-depth analysis of the social fabric, of the water rules and rights traditionally in use. A mere analysis of the physical aspects can therefore be empty, if not harmful.

Further questions arose from the research. The study carried out by Meehan and Moore in the United States leads us to question ourselves on one of the most controversial themes, i.e.: "Who owns rain?". Disputes on who should be allowed to collect and use rainwater will always be current, until each country will address the topic and will include the collection and use of rainwater in appropriate legislative instruments.

In conclusion, the present research enlightened how much impacting man intervention can be on conflict dynamics. Water harvesting is clearly a valid mean to deal with water scarcity, but we can not afford to neglect the investigation of also negative implications, often due to short-sighted interventions that can lead to small, non-sensational water conflicts.

This study wants to represent a first effort to investigate the two almost completely separated worlds of water harvesting and water conflicts, providing a conceptual framework that constitutes a theoretical starting point for further studies.

If "water wars" will not be our future, it is for sure that an equitable, fair and sustainable water management must however be one of our greatest concerns.

Part II

THE CARRACILLO REGION (SEGOVIA): STUDY AREA

6 STUDY AREA

The Carracillo region (Figure 6.1) is located in the province of Segovia, in the Comunidad autonoma de Castilla y Leon, in the Duero basin. It is not defined by administrative boundaries, though its perimeter is marked by the villages of Pinarejos, Sanchonuño, Gomezserracín, San Martín y Mudrián, Chatún, Campo de Cuéllar, Arroyo de Cuéllar, Narros de Cuéllar, Chañe, Fresneda de Cuéllar, Navalmanzano, Samboal y Navas de Oro. This region extends between the rivers Cega, Malucas and Piròn, and it has an area of approximately 35000 ha, mostly covered by pine trees.

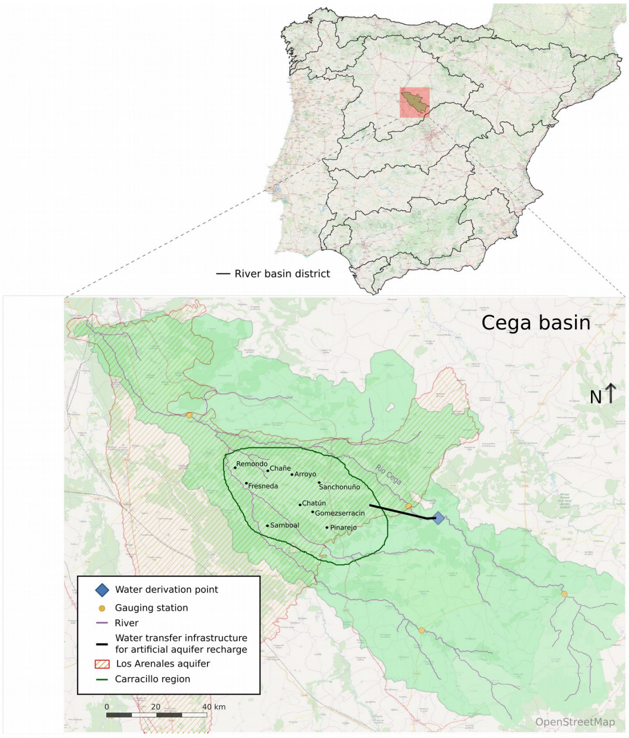


Figure 6.1: Study area.

The vast territory that includes these villages shares common characteristics. The predominant vegetation consists of *Pinus pinaster* and *Pinus pinea*, managed by *resineros* in order to sell resin and wood. The visual effect due to this vast flat land covered by pines trees led this area to be renamed *Mar de pinares*.

Figure 6.2: The village of Cuellar and the Mar de pinares in the background.

This area is characterized by the presence of numerous river channels consisting of natural streams, the so called *arroyos* (Arroyo del Ternillo, Marieles, Sierpe, Cabeza del Hombre, Malucas, etc.) as well as streams of smaller scale, capacity and size, named *caz*, *caceras* o *caces*. Surfacing of water, both temporary and permanent, usually corresponds to small wetlands called *navazos* or *bodones* (Figure 6.3). Many of these, like in the case of the Laguna del Señor, have disappeared, mostly due to anthropic causes (exploitation for livestock, drainage of farmland)((Instituto Tecnologico Agrario Junta de Castilla y Leon, 2018)

Lagoons still existing, anyway, constitute a unique ecosystem within pines woods, with which they establish a relationship of interdependence.

(a) Lagoon with water.

(b) Temporarily dry lagoon in drought period.

Figure 6.3: Lagoons in Carracillo region.

The Carracillo region is constituted by a flat land that rests on quaternary arena of sedimentary origin, located on Los Arenales aquifer, which surface spreads over 7754 km^2. According to Escalante (2014), the geological profile of this region is constituted by a superficial Quaternary aquifer, composed by fine sand dunes, alluvial river deposits and clays. Its average thickness is about 20 meters, with a maximum registered value of 57 m. Below those, alluvial deposits accumulated in a Tertiary aquifer up to 4 m of thickness, and a Tertiary aquitard constituted by clay.

The region is characterized by a clear predominance of agricultural activities. This area has always been characterized by subsistence agriculture and extensive sheep breeding. In parallel, pines management is actually one of the most ancient economic activities of the region. Pines workers, the so called resineros, use to exploit pines for resin. In Figure 6.4a a particular of resin collection is shown; a notch is engraved each month on the trunk and a container is placed under the cut to collect the resin. One side of the tree is processed at a time, and every five years resineros move to the next side. Usually, a pine is profitable for 25 years, though many grow much older (see e.g. Figure 6.4b).

One kilo of resin costs about 1 euro and on average a pine produces 5 kg of resin per year. Each resinero has approximately 8000 pines, so that in one year a resinero can earn about 40000 euros, while about 5000 euros go to the municipality as public taxation, leading to a double profit.

(a) Resin collection: particular of the notch engraved in the trunk once a month to collect the resin.

(b) Resinero with 100 years old pine. Usually pines remain profitable for resin extraction for about 25 years.

Figure 6.4: Resineros' activity.

Figure 6.5: Characteristic landscape of the Carracillo region: contrast between pines and agricultural exploitation.

Since the sixties, a new rural development model has been implemented, leading to an intensification of agricultural activities (Rivastabares et al., 2018)and to a change in the management of products and natural resources. Traditional crops like sugar beet and chicory were replaced by vegetables with high irrigation requirements like carrot, potato, cabbage, leek, lettuce, sweet corn, endive, sweet beetroot, onion, garlic, peas and courgettes. Moreover, numerous seedlings and nurseries produce both propagating material for agriculture and plants of strawberry aimed at exportation in particular in Andalucía, Europe and North Africa, for later growth and production.

In parallel, industries for the processing and marketing of agricultural products developed in the region.

Irrigation is performed with water proceeding both from quaternary aquifers constituted by sandy lithology and from deep aquifers made up of tertiary detritic materials. Water is extracted through wells with a depth between 10 and 25 meters from the quaternary aquifer and much deeper wells from the tertiary aquifer. Water is pumped through small power centrifugal pumps and vertical-axis submersible pumps depending on well depth (Instituto Tecnologico Agrario Junta de Castilla y Leon, 2018). These kind of wells concentrate on the northern area of the region, within the municipal terms of Chañe, Remondo, Arroyo de Cuéllar and Sanchonuño, where the thickness of the arena layer is minimal.

The hydrogeological formation where the aquifer from which groundwater extraction is performed is located is the so called *Sistema Acuífero number 8* (Terciario Detrítico de la Cuenca del Duero) and belongs to the groundwater body `ES020MSBT000400045`, Los Arenales.

Figure 6.6: Pines and cultivated fields.

The economic development was highly facilitated by the proximity of the phreatic level to the surface, which allowed intensive irrigation at low cost. This new economic model led the Carracillo region to become an example of agricultural productivity and development for the rest of Spain (Antequera et al., 2014). To date, the irrigable area is about 7600 ha, of which approximately 3500 ha are irrigated during each irrigation campaign.

Nevertheless, the economic development of Carracillo region led to a severe overexploitation of the quaternary aquifer (Fernandez Escalante et al., 2017). Furthermore, according to some local experts, the overexploitation of the aquifer could have even led to municipal water supply being unusable due to arsenic contamination in the tertiary aquifer. The relation between aquifer exploitation and arsenic contamination is supported by various authors (Garelick et al., 2008; Esteller and Cardona, 2011; Winkel et al., 2011).

7 MANAGED AQUIFER RECHARGE (MAR)

According to Dillon et al. (2009), Managed Aquifer Recharge (MAR) is defined as "the purposeful recharge of water to aquifers for subsequent recovery or environmental benefit".

The main objective of MAR is to store water from different sources, like storm water, desalinated water or groundwater from other aquifers. Among others, water harvesting techniques can be succesfully used in order to recharge the aquifer, as reported in many cases. Monji et al. (2016) describe the case of Sidi Bouzid plan in Tunisia, where the effectiveness of spate irrigation to enhance groundwater recharge was studied, reporting an effective contribute of this water harvesting technique. The validity of spate irrigation for groundwater replenishment is confirmed by the three-years study conducted by Hashemi et al. (2017). Moreover, Ochoa-Tocachi et al. (2019) investigate, at catchment scale, the contribution of pre-Inca water harvesting structures to the preservation of downstream natural springs, through the retention of upstream water during wet season and favouring its infiltration.

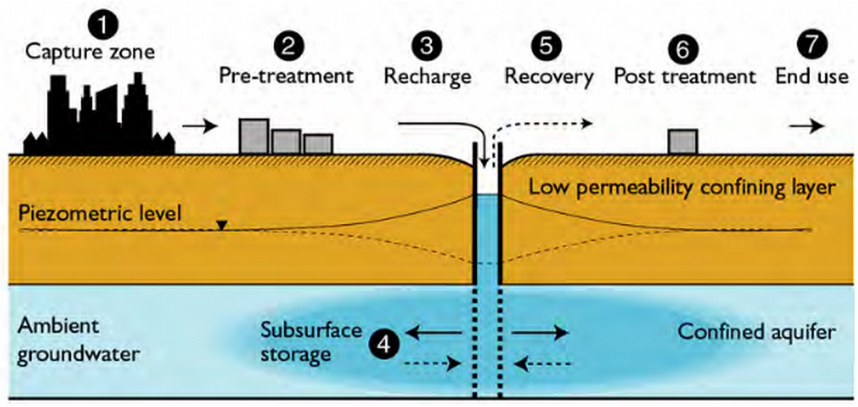
Other water harvesting techniques are commonly used for managed aquifer recharge, like percolation tanks (Massuel et al., 2014) and infiltration ponds. The MAR project implemented in Carracillo region actually takes advantage of infiltration ponds and lagoons, as will be described more in detail below.

MAR can be performed with multiple reasons (Grutzmacher and Kumar, 2012).Several examples of beneficial effects provided by MAR systems can be found. With appropriate treatments, it can be used to provide water for drinking, industries as well as for irrigation (Asano et al., 2006). Or it can be used to raise groundwater level in over-exploited aquifers (Dillon, 2009a,b), thus reducing land subsidence (Dillon, 2005). Moreover, it can improve water quality in degraded aquifers (Jakeman et al., 2016, cap. 16) and prevent saltwater intrusion (Casanova et al., 2007, 2008).

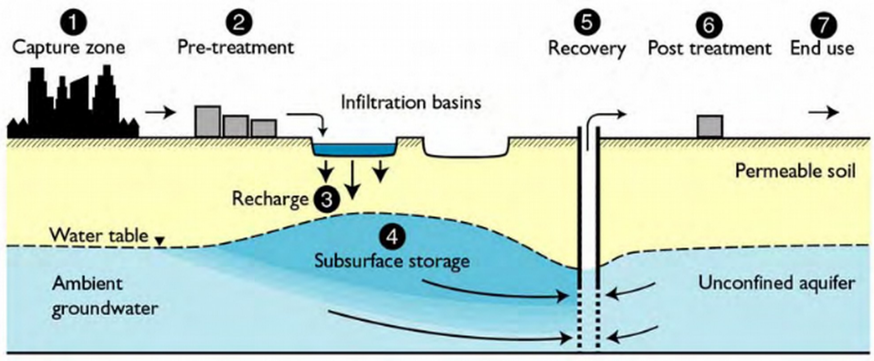
Depending on whether the aquifer is confined or not, a MAR project has some fixed components. Confine aquifer requires that water be injected through a well, due to the low permeable layer confining the aquifer. On the other hand, in unconfined aquifers water can infiltrate through infiltration basins and canals, due to the presence of a layer constituted by permeable soil.

Figure 7.1 shows the different phases involved in a MAR project with confined aquifer (7.1a) and with unconfined aquifer (7.1b).

A wide variety of MAR methods are spread all around the world. Some examples are reported (Dillon et al., 2009):



(a) Phases of MAR project in case of confined aquifer.



(b) Phases of MAR project in case of unconfined aquifer.

Figure 7.1: Different phases involved in a MAR project with confined and unconfined aquifer. *From Dillon (2009a).*

- *Aquifer Storage and Recovery (ASR)*: water is injected through a well in order to be stored, then it is extracted from the same well;
- *Aquifer Storage, Transfer and Recovery (ASR)*: water is injected through a well in order to be stored, then it is extracted from another well. This allows the water to be further treated, by spending more time in the aquifer;
- *infiltration ponds*: surface water is diverted into off-stream basins and canals, allowing water to infiltrate through the unsaturated layer reaching the unconfined aquifer;
- *dry wells*: commonly used where water table is deep, allowing high quality water to recharge the aquifer.

Moreover, some water harvesting techniques can be used in order to perform aquifer recharge:

- *rainwater harvesting for aquifer storage*: runoff is collected from rooftops and diverted into a well, where it percolates reaching the water table;

- *underground dams*: a trench is dug across an ephemeral stream, reaching the bedrock or other stable layer like clay. Flood flows are thus retained in the saturated alluvium for multiple uses;
- *sand dams*: these structures are constructed in ephemeral rivers and they trap sediment during flood events, creating an artificial aquifer.

8 THE RECHARGE PROJECT: HISTORICAL BACKGROUND

The Comunidad de Regantes "El Carracillo" (CIF: G-40142978) was constituted through *Resolución de 14 de septiembre de 1999* of the Confederación Hidrográfica del Duero. It was created as a community of users, according to *R.D. 849/1986 de 11 de abril*, where the *Reglamento de Dominio Público Hidráulico* was approved.

Through the *Real Decreto Ley 9/1998, de 28 de agosto*, the Comunidad de regantes was granted with concession C-21-844-SG, that allows the derivation of 1.37 m^3/s from Cega river. The objective of this concession is the recovery and maintenance of Carracillo's aquifer though artificial recharge (via the use of infiltration ponds), by providing the amount of water required to satisfy agricultural needs of the parcels collected under Comunidad de regantes. In particular, Concession C-21-844-SG involves the irrigation of 3000 hectares, has a duration of 50 years and establishes:

- derivation period: January to April;
- maximum instantaneous derivable flow: $1.37\,m^3/s$;
- maximum volume derivable/year: $14.2\,hm^3$;
- minimum river flow to always be maintained downstream the derivation: $6.9\,m^3/s$ (constant during the year).

Moreover, the publication of the *Real Decreto R.D.-Ley de 9/1998* sanctioned the fact that some hydraulic infrastructures were declared of general interest. Measures planned in the decree involved the construction of infrastructures for water supply and flood control, of structures for waste water treatment as well as hydraulic infrastructures for irrigation.

In order to accomplish measures planned in the decree, in 1999 TRAGSA (Empresa de Transformación Agraria) was charged by Subdirección General de Regadíos e Infraestructuras Agrarias, belonging to Dirección General de Desarrollo Rural of Ministerio de Agricultura, Pesca y Alimentación, with the redaction of *"Proyecto de Trasvase del Río Cega a la comarca del Carracillo (Segovia)"*.

Thus the artificial recharge of the aquifer in the Carracillo region too was accounted among the infrastructures considered of general interest.

In 2000, through reference file number 9233001, the implementation of the infrastructures involved in the recharge project was approved, charging TRAGSA with the execution. The implementation of the project took place within the European project MARSOL (http://www.marsol.eu/), carried out by TRAGSA and Ministry of Agriculture. Within this project, three pilot sites were created in the Arenales aquifer demo-site, meaning Santiuste basin, El Carracillo council and Alcazarén area. On these pilot sites, three different Managed Aquifer Recharge plants were implemented, adapting plants' features to both environmental and economic specific needs of each site.

The first phase of the Recharge project involved the construction and implementation of the following infrastructures:

- rehabilitation of an ancient dam on rio Cega (Salto de Abajo), shown in Figure 8.1a;
- construction of a 900 m open channel;
- construction of a 19 km pipeline.

Water transfer from the derivation point on Cega river (Salto de Abajo), takes place through gravity pipeline in polyethylene reinforced with glassfiber (Instituto Tecnologico Agrario Junta de Castilla y Leon, 2018). It has a diameter of 1.2 m in the first 6 km, a diameter of 1 m in the following 7.5 km and of 0.9 m in the final 6 km. It has a total length of 19.264 km. In addition, structures for housing operating parts (valves, drains, suction cups and cut-off valves) were realized.

(a) Salto de Abajo dam: rehabilitation phase.

(b) Salto de Abajo: working dam.

Figure 8.1: Salto de Abajo dam.

In addition to this, under the name of "second phase" the project prescribed:

- construction of a 14-km pipeline;
- construction of 96 retention structures (prefabricated concrete units) to improve channel depth;
- construction (or rehabilitation) of 17 infiltration ponds.

The implementation of infrastructures was concluded in 2003.

In the *Boletin Oficial del Estado numero 56 de 5 de marzo de 2004*, the *Resolución de la Secretaria General de Medio Ambiente* was published, stating that an environmental impact assessment was not mandatory for the project:

> En virtud del artículo 1.2 de la Ley 6/2001 la Secretaría General de Medio Ambiente a la vista del informe emitido por la Dirección Generalde Calidad y Evaluación Ambiental de este Ministerio de fecha 10 de diciembre de 2003, considera que no es necesario someter al Procedimiento de Evaluación de Impacto Ambiental el proyecto de Recarga del Sector Occidental del Acuífero de Los Arenales en la comarca de El Carracillo (Segovia).

The scheme in Figure 8.2, taken from (Fernandez Escalante et al., 2017) represents infrastructures and steps involved in the first two phases.

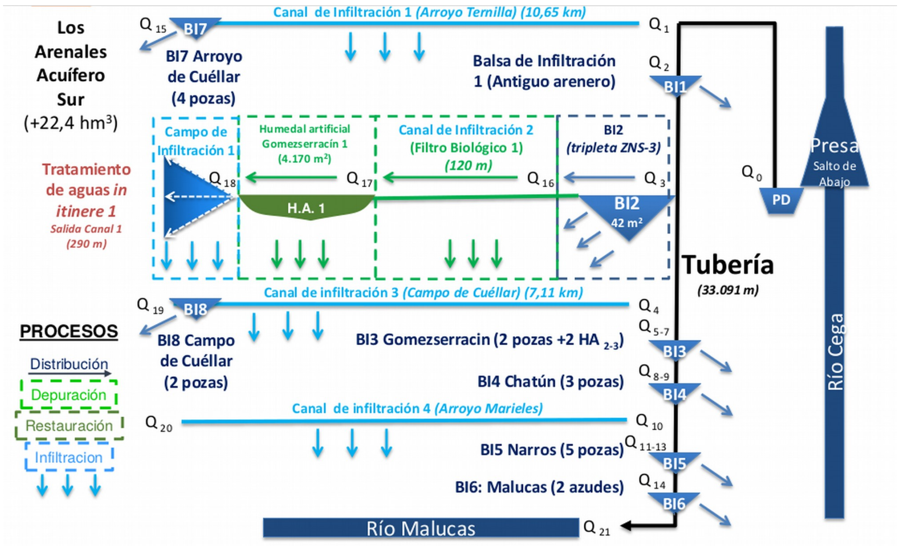


Figure 8.2: MAR's scheme of Carracillo recharge project: I and II phase, from (Fernandez Escalante et al., 2017).

The MAR system in Carracillo region is constituted by following components:

- 1 dam (*Salto de Abajo* dam);
- 46 km of transport pipeline;
- 17 km of infiltration canals;
- 17 infiltration ponds;
- 1 artificial wetland;

- 1 green bio-filter.

The *Salto de Abajo* dam creates an artificial reservoir from which derivation occurs. When upstream flow in Cega allows the diversion, water from the river goes through an iron hatch with manual opening (shown in Figure 8.5), then it is transported through 18 km of pipeline up to the first point of water leakage, immediately outside the village of Gomezserracin (acequia Carrabernardo). From there, the pipeline continues for about 14 km, with a total of 9 water spillage points. From these, water flows and infiltrates using four main existing channels: arroyo Ternillo (see Figure 8.6), 2 unnamed earthen channels and arroyo Marieles. The pipeline then ends in correspondence with arroyo Malucas.

Some of the water spillage points correspond with lagoons (see Figure 8.7), like in the case of the Cañada Real lagoon (8.8). Furthermore, Carracillo MAR scheme is characterized by a "triplet" scheme (ZNS-3), as can be seen in Figure 8.3 and 8.4. It consists of a sequence of naturalized structures that allow the minimization of Dissolved Oxygen content ($MARSOL_D5-3$) through the passage of water through an infiltration pond, a green bio-filter and an artificial wetland. Water diverted from Cega river comes out through the third valve (B12) in an area called "Dehesa Boyal", out of the village of Gomezerracin, where there is an old sand pit. Water coming out, directly flows into a 42 m2 infiltration pond.

This structure is followed by a green bio-filter. This is constituted by a 50 m long canal where natural vegetation reduces dissolved oxygen levels by direct consumption.

An artificial wetland follows the bio-filter canal. The wetland allows purification processes through lagooning and, at the same time, it enhances recharge activity. Finally, a spreading field allows water flowing from the artificial wetland to infiltrate.

Nevertheless, the first two phases only benefited a few villages, situated in the south-west area of the Carracillo region: Gomezserracín, Chatún, Campo de Cuellar y Narros del Cuellar. These villages are characterized by favorable geological features. The thickness of the arena layers, in fact, allows a direct recharge of the aquifer through infiltration of the waters flowing through channels and existing infrastructures.

Figure 8.3: El Carracillo "triplet" components

Figure 8.4: "Triplet" components: (a) infiltration pond; (b) bio-filter in a MAR channel; (c) artificial wetland.

Figure 8.5: Hatch with manual opening for water diversion on Cega river.

Figure 8.6: Arroyo Ternillo with recharge water.

Figure 8.7: Infiltration lagoon near Gomezserracin.

Figure 8.8: Cañada Real infiltration lagoon with water.

9 THIRD PHASE

A third phase is currently being implemented. The project is undergoing an environmental impact evaluation, and a report following environmental impact assessment has already been published (Instituto Tecnologico Agrario Junta de Castilla y Leon, 2018).

New villages will benefit from the third phase, meaning those situated in the north area, where no superficial (quaternary) aquifer exists: Sanchonuño, Arroyo de Cuellar, Chañe, Remondo y Fresneda de Cuellar. In Figure 9.1 villages benefited by first and second phase (blue circle) and by third phase (red circle) are shown. The third phase will involve three stages:

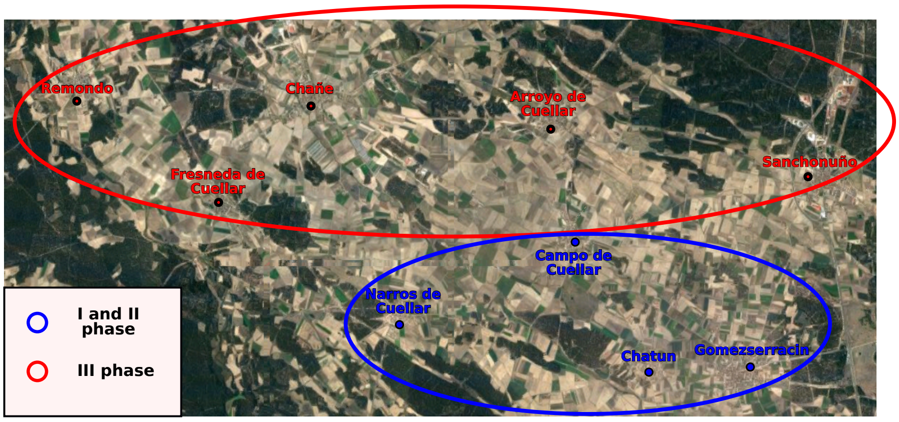


Figure 9.1: Villages benefited by first and second phase (blue circle) and by third phase (red circle).

1. *Artificial recharge*: Water diverted from Cega river will be stored in a 3600 ha sandstone lens, covered by pine trees, immediately outside the village of Gomezserracin.

2. *Extraction from wells*: During irrigation period water is extracted through wells and pumped to a weekly fill regulation pond.

3. *Transportation to Irrigation Network*: Water is transported, in a pressurized manner, to parcels to irrigate, through an irrigation network.

Thus, the following proceedings and infrastructures will be implemented:

- Construction of an aquifer charging network able to distribute water throughout the *Zona Almacén*. This will require the construction of 18 channels and two new infiltration ponds.

- Construction of 6 ha waterproofed regulation pond.
- Construction of 82 wells distributed throughout the *Zona Almacén*.
- Construction of an extraction system in order to extract water from wells. Moreover, as pipeline network to transport water from each well to the regulation pond will be created.
- Construction of an irrigation network through pipelines in order to transfer water from pumping station to irrigated plots.
- Creation of a new electrical network for electrical supply to both extraction system and pumping station.
- Reordering of rural property corresponding with parcels where infrastructures for recharge, extraction and regulation will be implemented.

A summary of infrastructures involved in the different phases of the recharge project is presented in the following Table 9.1.

Table 9.1: Infrastructures involved in the different phases of the recharge project.

First and second phase	
Salto de Abajo dam	rehabilitated
transport pipeline	46 km, constructed
infiltration canals	17 km, constructed
infiltration ponds	17
artificial wetlands	1
green bio-filter	1
Third phase	
channels (*aquifer recharge*)	18
infiltration ponds	2
waterproofed regulation pond	6 ha
wells (*Zona Almacén*)	82
extraction system for wells	
pipeline for wells	
irrigation network	
electrical network	

Moreover, the concession will undergo some modifications. The derivation period will be extended from December to May and the minimum river flow to maintain will go from 6.9 m^3/s to 0.6 m^3/s. To sum up:

- derivation period: January to April → December to May;
- Q derivable: 1.38 m^3/s;
- maximum volume derivable/year: 14.2 hm^3;
- minimum river flow to maintain: 6.9 m^3/s → 0.6 m^3/s.

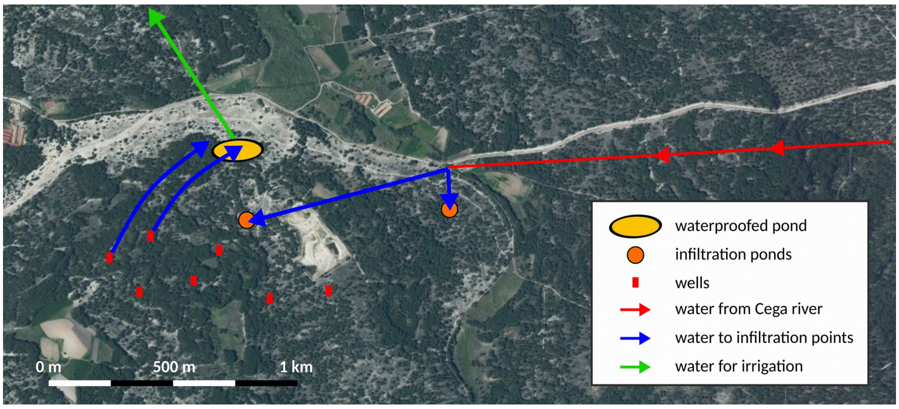


Figure 9.2: Third phase: steps.

According to the project, water diverted from Cega river flows through the pipeline constructed during the first phase and comes out of the first water spill, near Gomezserracin. Here water infiltrates into the soil, adapting existing structures and creating two new infiltration ponds. During the irrigation period, water is extracted from the 82 wells and pumped up to the waterproofed weekly storage basin. From there, water is pumped up to the villages benefited by third phase.

9.1 ARTIFICIAL RECHARGE

A pipeline network will connect to the existing main recharge pipeline through two independent networks (east and west) toward water drains. Moreover, existing ditches will be rehabilitated and two new infiltration ponds will be constructed.

A 14643 m^2 infiltration surface was established as necessary. This surface is divided between 18 infiltration canals with a total length of 9 km (corresponding to about 3000 m^2) and two infiltration ponds (east and west) of respectively 6192 and 5760 m^2.

9.2 EXTRACTION NETWORK

82 wells will be constructed (even if only 76 will be effectively active). Each well will have a maximum flow of 20 l/s. They all have a drilling

diameter of 500mm and they fully penetrate the quaternary aquifer reaching down the top layer of the tertiary aquifer.

Pipelines will carry water from the wells to the regulation pond. They will have a total length of approximately 13 km.

Furthermore, a waterproof regulation pond will be constructed, with following characteristics:

- Crest elevation: 831.6 m a.s.l.
- Bottom elevation: 824.7 m a.s.l.
- Total surface: 61.410 m^2
- Total volume: 163.366 m^3

9.3 IRRIGATION NETWORK

The irrigation network will be designed so that each year water will be supplied to only half of the parcels to be irrigated, bringing the irrigated surface to a total of 1521.4149 ha.

Irrigation network and hydrants will be designed in order to cover the whole surface of 3024.50 ha, while the hydraulic infrastructure (pipelines and pumping stations) will be designed for the yearly supply to the 1521.4149 ha that are irrigated during each irrigation campaign.

10 CEGA RIVER: SOME DATA

10.1 GENERAL CONSIDERATIONS

Difficulties arose in getting a hold of data, especially when it came to historical and current series of Cega river flow data, mostly because of defective or inactive structures.

Cega river has a total length of approximately 130 km.

In Figure 10.1, the positions of gauge stations on Cega river and their identification numbers are indicated.

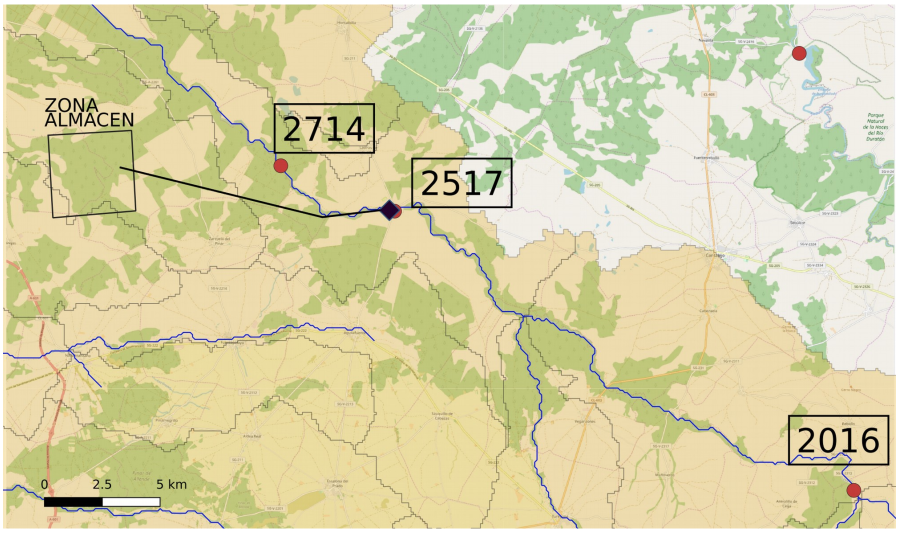


Figure 10.1: Position of gauge stations on the considered portion of Cega river. Gauge stations in red, derivation point in black. Data available from each station detailed in Table 10.1. From: `https://sig.mapama.gob.es/redes-seguimiento/visor.html?herramienta=Aforos`.

To date, none of them are active. The gauge station further upstream of the derivation (number 2016) has a good historical series (from October 1912 to September 2015), while the station immediately upstream of the derivation (number 2517) has data from October 2013 to September 2015. These two stations are located about 25 km from each other.

The station immediately downstream of the derivation (number 2714) has data only from October 2004 to September 2013, making impossible to compare its data with those of station number 2517.

Gauge stations in the considered portion of Cega river and available data are detailed in Table 10.1

Table 10.1: Gauge stations along the considered portion of Cega river, their position relative to the derivation point and years in which flow data is available for each of them.

Station	Position	Data period
2016	upstream	1912-2015
2517	upstream	2013-2015
2714	downstream	2004-2013

Based on available data, average values from the two stations upstream the derivation are shown in the following Table 10.2.

Table 10.2: Flow values provided from *CHD* for stations 2016 and 2517 upstream of the derivation, and station 2714 downstream the derivation, averaged over the available data period.

	Station 2016	Station 2517	Station 2714
Data period	1912-2015	2013-2015	2004-2013
Minimum annual flow [m^3/s]	0.66	1.56	0.70
Average annual flow [m^3/s]	3.31	2.07	1.75
Maximum annual flow [m^3/s]	9.31	2.42	3.01

It should be noted that flow data from station 2714 cannot be considered as a natural series due to the derivation (even if it occurs only for a few days a year).

10.2 RIVER FLOW DATA SERIES

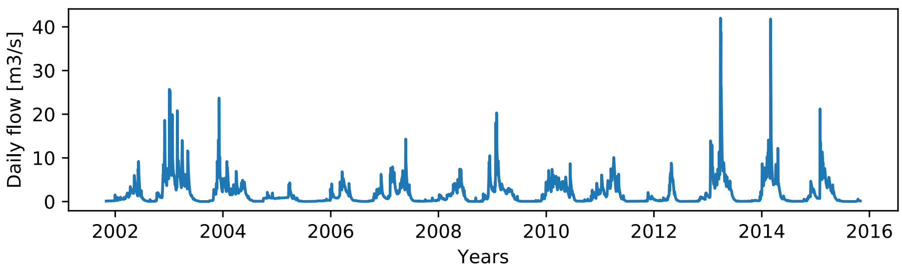


Figure 10.2: Average daily flows of Cega river for the period 2001-2015, as recorded by station 2016.

Cega river has a seasonal behaviour, as shown in Figure 10.2, where average daily flow values for the period 2001-2015 from station 2016 are presented. Flow peaks occur in correspondence with winter and spring months, while during summer flow values are often close to zero.

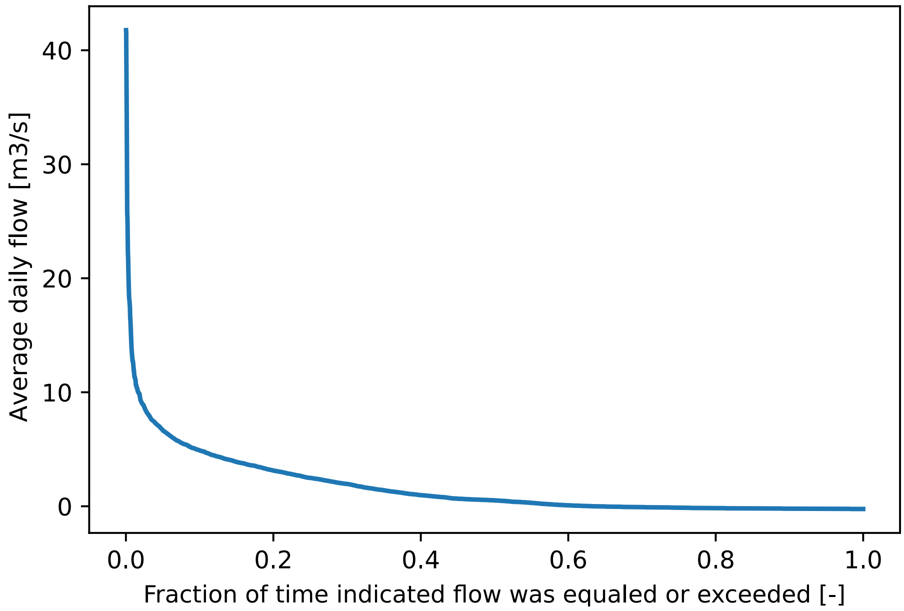


Figure 10.3: Duration curve of average daily flows in Cega river, as calculated over data for the period 2001-2015. A typical seasonal behaviour is shown.

This is confirmed by the flow duration curve shown in Figure 10.3. This has been calculated using data for the period 2001-2015, and presents a typical seasonal behaviour.

While during the period from July to October flows always assume limited, near-zero values, during the rest of the year they are generally larger, even though their variability also increases noticeably. This can be seen in Figure 10.4, where mean and standard deviation values for monthly flows during the period 2001-2015 are shown (data from station 2016).

We verified the strength of the correlation between data from station 2016 and those from station 2517, in order to legitimate the use of data from station 2016, from which we had a longer data set and some years in common with the station downstream of the derivation (years from 2004 to 2013). Thus we calculated the coefficient of determination (R^2) for average daily flow data from years 2013 to 2015 of the two stations, that further upstream of the derivation (number 2016) and that immediately upstream of the derivation (number 2517).

In the graph in Figure 10.5, each point is described by a set of coordinates. The x values are given by daily surface flow data from station 2016, while the y values are constituted by corresponding data from station 2517.

This plot shows that linear regression well explains the relation between the two sets of data (daily average surface flow from station 2016 – further upstream – and 2517 – immediately upstream the derivation point). In fact the R^2 value is 0.802 and the slope value of

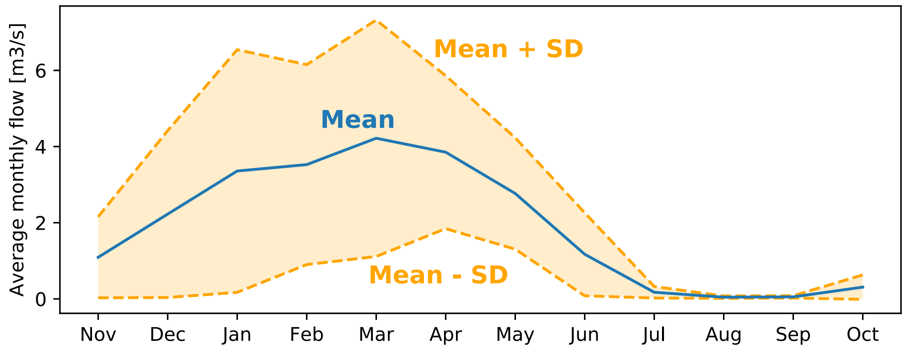


Figure 10.4: Average monthly flows of Cega river, as calculated over data for the period 2001-2015. Mean and standard deviation values are shown.

the trend line is 0.88, meaning clear proximity to the bisector of the first quadrant (slope value equal to 1), represented by the red line.

In this way we are now able to justify the use of surface flow data from station number 2016 in following analysis and evaluations.

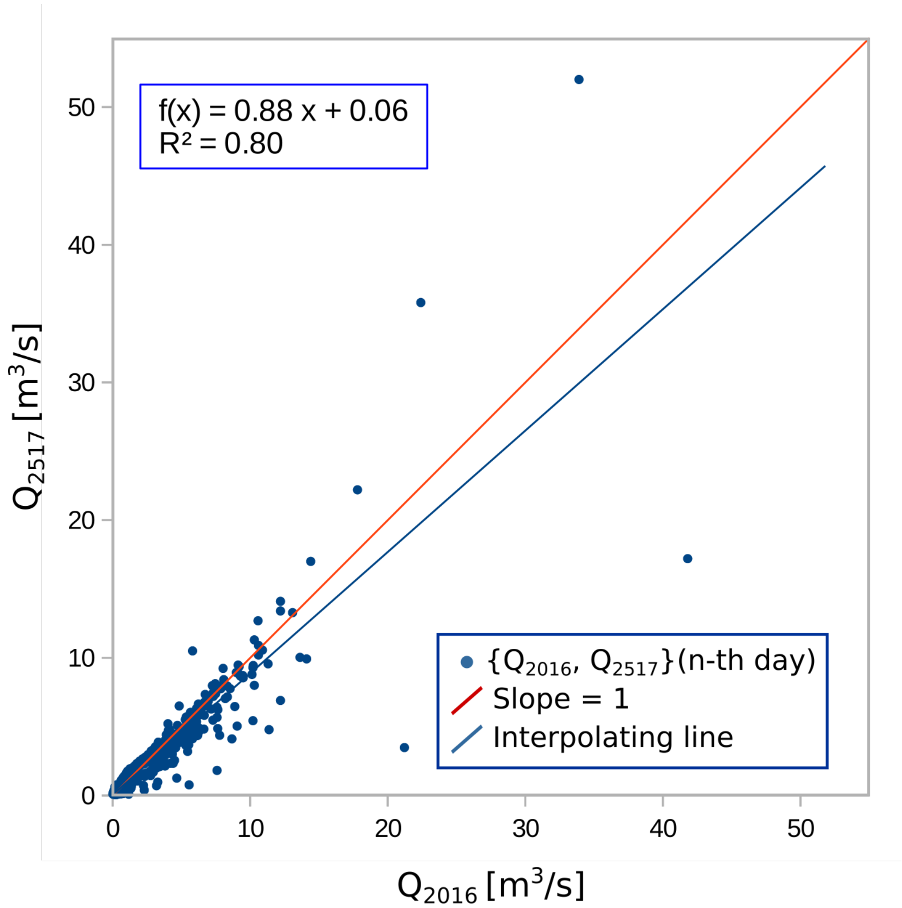


Figure 10.5: Correlation between daily surface flow data of Cega river from stations 2016 and 2517.

Part III

STAKEHOLDER ANALYSIS

11 INTRODUCTION TO STAKEHOLDER ANALYSIS

According to the definition provided by Freeman (1984) stakeholders are those actors that can be affected by a project plan, policy implementation and, in general, by decision-makers actions as well as who can influence them. Freeman's definition arises in the context of business management, thus decision-makers' actions should be thought as the achievement of corporations' purposes.

Moreover, in the context of natural resource management, Pomeroy and Rivera-Guieb (2006) provide a broader definition of the term, stating that stakeholders are *"Individuals, groups or organizations who are, in one way or another, interested, involved or affected (positively or negatively) by a particular project or action toward resource use"*.

To date, the importance of stakeholder analysis is universally recognized. In development projects as well as in natural resource management ones, stakeholder analysis can lead to the empowerment of marginal groups (Johnson et al., 2004). At the same time an analysis constructed superficially, based on a tailor-made selection of the stakeholders can result in marginalization, or in exacerbating marginalization, of significant groups. The same thing can happen where stakeholders are extremely powerful and organized, hence resulting in a greater influence on decision-makers (Chambers, 1994). Butler and Adamowski (2015) suggest to pay particular attention, in Participatory Model Building (PMB), in considering societal power dynamics. The fact of neglecting existing power dynamics could be caused by facilitators being outsiders of the system analyzed and can lead to *"wrong questions being posed or relevant stakeholders being excluded"*.

But what exactly is meant by Stakeholder analysis? There is no unique definition of the term. Grimble (1995) concretely defines stakeholder analysis as *"An approach and procedure for gaining understanding of a system by means of identifying the key actors and stakeholders in the system and assessing their respective interests in that system"*.

To make order on existing methods for stakeholder analysis, Reed et al. (Reed et al., 2009) propose a three-classes categorization. The first step in order to achieve stakeholder analysis is the identification and selection of key stakeholders. Thus, the first class involves those methods that allow their identification. They are:

- focus groups;
- semi-structured interviews;
- snow-ball sampling.

The second class involves those methods that allow to categorize stakeholders. They are:

- interest-influence matrices (Lindenberg and Crosby, 1981);
- stakeholder-led stakeholder categorization;
- Q methodology (Stephenson, 1953).

The third class involves those methods that allow to analyse relations between stakeholders. They are:

- actor-linkage matrices;
- Social Network analysis (Scott, 1988);
- knowledge mapping;
- radical transactiveness.

The case of the Carracillo region is as interesting as it is complicated. According to the definition provided by Mauelshagen (2006), the case of Cega river can actually be considered a water conflict. In fact, different actors compete over a limited source of water in order to achieve their objectives.

Thus, it represents a complex system that requires an in-depth analysis of the social fabric. This necessarily requires the identification of the main actors involved in the conflict and the relations that bind them.

Hence, *Stakeholder analysis* was performed with multiple objectives. First of all it was aimed at the identification of the main actors involved in the conflict. From this, analysis extended to the definition of the relative influence stakeholders have on each other and on the context in which they operate. The definition of conflictual relations led, then, to the identification of the main cores around which conflict develops.

Finally, an important role was played by interviews. In particular, the part on ecosystem services allowed to clarify the perception different stakeholders have of Cega river ecosystem services. This provided the basis for the considerations that will be the starting point of ecosystem services' modelling process.

12 TOOLS USED FOR STAKEHOLDER ANALYSIS

12.1 TOOLS

In December 2018 a workshop was organized in Chañe, in Carracillo region, by Universidad Complutense de Madrid in collaboration with Fundacion Botin-Nueva cultura del agua[1]. The workshop, named Taller sobre agua y desarrollo rural sostenible en la comarca del Carracillo (Hernandez-Mora et al., 2018) had multiple objectives. First of all it was aimed at collectively defining a vision for the future of Carracillo region. This was reached through the definition of values (principles, opportunities) and actors that can determine the realization of that vision. Moreover, the identification of means for the achievement of the vision was performed.

Since the workshop was thought as an awareness raising action and designed for the creation of a space for debate about the future of Carracillo region, efforts were made, with the help of local mayors, to involve representatives of distinct social groups, environmental organizations, agricultural unions, main economic sectors active in the region, private companies involved in water use and land use, as well as the main local, provincial and regional administrations with an impact on territorial, rural, agricultural and water policies. In order to facilitate the debate and the dynamic of the workshop, the number of participants was set to 35. Anyway, no one from the Consejería de Agricultura de la Junta de Castilla y León, Consejería de Medio Ambiente, nor from ITACYL (Instituto Tecnológico Agrario de Castilla y León) participated in the workshop, even if they had been invited. Thus, 32 people participated, as categorized in Table 12.1.

Beyond the fact that it was a training experience from a professional point of view, the workshop allowed a first direct contact with people of Carracillo, providing a substantial aid in stakeholders identification and selection.

Therefore, semi-structured interviews were performed with multiple objectives. Among other things, results were used in order to assess stakeholders categorization.

As stated by Hare and Pahl-Wostl (2002), a well done categorization has double benefits. On one hand it allows to narrow the area of investigation. On the other hand it structures it. In our case, this phase was achieved in a first moment through one of the methods belonging to the set of analytical categorizations proposed by Lopez

1 `https://www.fundacionbotin.org/`

Table 12.1: Participants in the workshop *Taller sobre agua y desarrollo rural sostenible en la comarca del Carracillo* organized by Universidad Complutense de Madrid in collaboration with Fundacion Botin-Nueva cultura del agua that took place in December 2018 in Chañe (Carracillo region).

Class	Number of participants
Farmers	3
Pines workers	1
Municipalities	5
Comunidad de regantes	4
Cultural associations	3
Environmental groups	2
TRAGSATEC	2
Confederación Hidrográfica del Duero	1
Experts	5
Hosts	1
Trade associations	5
Total	32

(2001). This tool allows a categorization of stakeholders into four classes, based on the concepts of interest and influence:

- *Key players*. They are those stakeholders that have high interest in the analysed phenomenon and high influence over it.
- *Context setters*. They are the stakeholders with high influence, but low interest, thus constituting a risk.
- *Subjects*. They are those stakeholders with high interest but low influence. They are usually constituted by marginal stakeholders.
- *Crowd*. They are those who have little influence and interest in the project outcomes. Usually there is little need to involve them in a more in-depth analysis.

At the same time, interviews allowed to perform one of the methods belonging to the *"reconstructive methods"* (Dryzek and Berejikian, 1993), the so called Stakeholder-led stakeholder categorization. This method involves semi-structured interviews in order to lead stakeholders to categorize themselves into categories they created.

Relationships between stakeholders were investigated by constructing an Actor-linkage matrix (Biggs and Matsaert, 1999). This commonly used method allows the construction of a matrix in which each stakeholder is compared with every other stakeholder and their relationship can be evaluated as conflicting, complementary or cooperative.

Finally, causal loops were used. When in the sixties the concept of feedback system was applied for the first time to industrial dynamics (Forrester, 1961), the idea of System Dynamics was born.

Feedback loops diagrams represent major feedback mechanisms. They are used in order to analyze the system from a qualitative point of view, improving system understanding. Causal loops allow to represent the structure of the system through the analysis of the relations between the variables involved in system itself. All the variables are connected through polarized arrows that will have positive or negative sign, depending on the relation between cause and effect. Positive sign means that cause and effect are directly proportional so that, if the cause increased, ceteris paribus, the effect would also increase. Dynamics that arise from this kind of relation define a positive feedback loop, also called "self-reinforcing" (R) loop. This kind of loop tends to reinforce or amplify whatever is happening in the system. On the other hand, negative sign means cause and effect are inversely proportional and, if one increased, the other would decrease. In this case, the feedback loop that emerges is a negative one, also called "balancing" (B). These kind of loops are self-correcting and oppose change. According to (Khan et al., 2007), the behavior as well as the high dynamism and complexity of water-related systems lead them to be considered complex systems. So that, feedback loops were used in order to visually represent, thus to clarify the dynamics among the stakeholders involved in the study.

12.2 interviews

50 semi-structured interviews were performed with multiple goals:

- to assess stakeholders categorization based in interest and influence;
- to categorize the identified stakeholders through Stakeholder-led-stakeholder categorization;
- to understand dynamics among stakeholders in order to construct the actor-linkage matrix;
- to understand stakeholders' perception of the ongoing recharge project and of the planned third phase;
- to define ecosystem services related to Rio Cega.

It is important to note that the interviews were aimed at a qualitative rather than a quantitative analysis of the social fabric underlying the recharge project. So that, to the interviews was often dedicated more than the expected one hour. In many cases people independently chose to spend the whole day showing the points along the Cega river that are important to them, or that they thought should be interesting for us to visit. This must be said so that the quality of work is not valued nor lost based on mere numerical considerations.

Hence interviews were performed as detailed in Table 12.2.

Table 12.2: Number of interviewees for each target group.

Target group	**Number of interviews**
Technicians and experts directly involved in the recharge project	5
Experts outside the project	5
Mayors	3
Small farmers	10
Large agricultural enterprises	10
Local workers	12
Environmentalists	5

We tried to uniformly cover up the main actors involved (both directly and indirectly) in the recharge project. We tried to give the same space and relevance to the actors in favor and to those against the implementation of the third phase of the recharge project, while maintaining an approach that is as technical and scientific as possible.

The class of technicians and experts directly involved in the project includes technicians from TRAGSATEC (Tecnologías y Servicios Agrarios) and Confederación Hidrográfica del Duero. It was fundamental, for us, to have a technical vision "from inside", provided by those scholars that conceived and designed the project. At the same time we wanted to have a scientific external view of the various issues concerning the project, so that we also interviewed experts outside the project, meaning hydrologists, hydrogeologists, agronomists, social scientists.

We were able to contact only three of the mayors whose villages are directly involved in the project, since others did not answer to our invitation to participate. They are the mayor of Pinarejos, Chañe, Sanchonuño.

Both small farmers and large agricultural enterprises belong to Comunidad de regantes, since they benefit from the concession that allows irrigation with water diverted from Cega river. Anyway, the two classes drastically differ at least for what concerns cultivated crops and markets where the products are sold.

Local workers include resineros, meaning people that manage pines selling wood and resin, as well as people actually working in different areas, like hoteliers, historians, barmen. The choice of interviewing also people not directly involved or affected by the recharge project may seem strange. Anyway, it was fundamental for us to have an holistic vision of the problem, collecting also the testimonies of whom sees the the recharge project and related implications in a more detached manner. Finally, environmentalists belonging to two different groups were interviewed. They are *Honorse-Mar de Pinares*, and *Si a las fuentes del Cega*.

12.2.1 *Structure of the interviews*

Interviews were divided into three parts: Recharge project, Actors, Cega river. Below you can find the original Spanish version used during the fieldwork, as well as an English translation.

"Me llamo Beatrice Laurita, soy estudiante de doctorado en ingegneria agro-forestal en la Università de Florencia, Italia. Como parte de mi trabajo de tesis estoy investigando el caso de la recarga del Carracillo, en particular las implicaciones que el proyecto de recarga actual y la tercera fase pueden tener para los ecosistemas del rio Cega. Ademas, estoy interesada en estudiar las perspectivas de las distintas partes interesadas y las relaciones que existen entre ellas.
El contenido de la entrevista será utilizado de forma anónima, y en ningún momento se citará o se atribuirá una opinión a una persona entrevistada en concreto.

"My name is Beatrice Laurita, I'm a PhD student in agro-forestry engineering at University of Florence, Italy. As a a part of my thesis work I'm investigating the case study of the recharge project in the Caracillo region, specifically the effects that the current recharge project and the third phase can have on river Cega's ecosystems. I'm also interested in studying the perspectives of the different parties involved, and the existing relationships among them.
The content of the interview will be used anonymously, and in no occasion an opinion will be quoted or attributed to a specific person.

Los resultados del estudio formarán parte de mi tesis doctoral y posiblemente también servirán para elaborar un artículo para una revista científica internacional. La entrevista durará cerca de una hora, ¿le parece bien?.
Sin embargo, si fuera posible, me gustaría poder grabar la entrevista. El único objeto de la grabación es ayudarme en el análisis del contenido de la entrevista y quedo responsable de guardarla y no compartirla. ¿Me da su permiso para grabar?"
Antes de empezar con la preguntas específicas, le agradecería me indicara su actual ocupación (y desde cuándo se dedica a ella) y su lugar de residencia (y desde cuándo vive ahí).

The results of the study will constitute a part of my PhD dissertation and may serve to elaborate a paper to be published on an international scientific paper. The interview will last more or less one hour. Would you be ok with that?
If it were possible, I would like to record the interview. The only function of the recording is to help me in the analysis of the interview's contents, and I will be responsible for its safekeeping and secrecy. Do you grant me the permission to record?
Before we start with specific questions, would you mind telling me your occupation (and how long you've been doing it) and your place of residence (and how long you've been living there)?

el proyecto

1. *¿Conoce el proyecto actual de recarga del acuífero? Y la tercera fase?*
2. *En su opinión, ¿Qué objetivos se quieren conseguir con la tercera fase del proyecto de recarga?*
3. *En su opinión, ¿El proyecto permite alcanzar esos objetivos?*
4. *En su opinión, ¿Cuáles son las principales debilidades y fortalezas de la tercera fase de la recarga?*

THE PROJECT

1. Are you aware of the current aquifer recharge project, and of its third phase?
2. Which goals do you think the third phase of the recharge project has?
3. In your opinion, is the project adequate to reach this goals?
4. In your opinion, which are the the main weaknesses and strengths of the third recharge phase?

los actores

5. *Quiénes son los actores que intervienen en el proyecto?*
6. *Qué papel tienen?*
7. *Qué intereses?*
8. *Quién son las personas mas afectadas (positivamente y negativamente) por el proyecto de recarga? Y por la tercera fase del proyecto?*

THE ACTORS

5. Who are the actors involved in the project?
6. Which is their role?
7. Which are their interests?
8. Who are the people most affected (in a positive and/or negative way) by the recharge project? And by the third phase?

el rio cega

9. *El rio Cega es importante? ¿Por qué? ¿Para quién?*
10. (Introduction to ecosystem services): *El mantenimiento de régimen de caudales ecologicos en el rio mantiene el rio vivo y le permite de asegurar servicios utiles y positivos para las personas, como por ejemplo las actividades recreativas, la recarga natural del acuífero, la conservación de la biodiversidad. Estos son los que en la literatura llaman "servicios ecosistémicos"*
11. *Le voy a dar una hoja con algunos de los servicios ecosistémicos que suele prestar un río según la literatura. Por favor, puntúe de 1 a 5. Una vez puntuados podrá matizar o comentar su puntuación, si lo considera necesario.*
12. *¿Quiere añadir a la lista algún servicio que presta el río Cega? (Y luego que lo puntúe)*

THE RIVER CEGA

9. Is the river Cega important? Why? For whom?
10. (Introduction to ecosystem services): Observing a regime of environmental flows in the river keeps it alive and allows to secure useful and positive services for the people, such as -for example-: recreational activities, natural aquifer recharge, biodiversity conservation. These are commonly known as "ecosystem services".
11. I'm going to give you a page with some ecosystem services that the scientific literature indicates as the more usually provided by rivers. Would you please rate them with a score from 1 to 5? Once you've rated them, you're invited to comment your choices, if you wish.
12. Do you wish to add to the list any service provided by the river Cega (and, in that case, its score as well)?

Ya terminando la entrevista:

13. *¿Hay algo que quiera añadir o puntualizar sobre lo que hemos hablado en la entrevista?*
14. *Hay alguien mas con quien sugiere hablar sobre los temas que hemos tratado en esta entrevista?"*

We reached the end of the interview:

13. Is there something you wish to add or specify over the topics we talked about in the interview?
14. Is there someone else you suggest to talk about the topics we covered in this interview?

Moreover we provided a list of the ecosystem services related to environmental flow proposed by Korsgaard et al. (2005) asking, for each item, to give a value from 1 to 5, based on the importance that the interviewed person attributed to the service.

Below you can find the original Spanish version provided during fieldwork, as well of their English version as it's indicated in Korsgaard et al. (2005).

producción

- *Provisión de agua por el abastecimiento urbano*
- *Provisión de agua por el regadio*
- *Pesca*
- *Producción de Plantas y frutos silvestres que se pueden recoger y comer*
- *Sustento de especies cinegéticas (caza)*
- *Provisión de materiales de construcción (madera, paja, . . .)*
- *Plantas medicinales*

PRODUCTION

- Water for urban water supply
- Water for agriculture
- Fish
- Vegetables and fruits
- Wildlife for hunting
- Inorganic material for construction
- Medicinal plants

regulación

- *Recarga natural del acuífero*
- *Mantenimiento de la vegetación de ribera*
- *Mantenimiento de una buena calidad química del agua*
- *Mantenimiento de una buena calidad física del agua (el agua no esta turbia, no hay acumulación de sedimentos que impiden al agua de drenar)*
- *Mitigación del clima*
- *Creación de zonas de refugio, alimentación y desplazamiento de especies*
- *Control de plagas*
- *Preservación de la diversidad de plantas y animales*

REGULATION

- Groundwater replenishment
- Vegetation support
- Chemical water quality control
- Physical water quality control
- Microclimate stabilization
- Provision of refuge areas for animals
- Pest control
- Biodiversity conservation

información

- *Turismo y usos recreativos locales (Paseos, bañarse en el rio, . . .)*

INFORMATION

- Tourism and recreational uses.

13 RESULTS AND DISCUSSION OF STAKEHOLDER ANALYSIS

13.1 STAKEHOLDER IDENTIFICATION

Starting from the participants selected for the workshop that took place in Chañe in December 2018, the stakeholders detailed in Table 13.1 were identified.

Table 13.1: Identified stakeholders.

Category	Description
Rainfed farmers	Production of crops that do not require irrigation (olive trees, winter cereals)
Export farmers	Production of crops for exportation (strawberries, raspberries, horticultural products)
Traditional farmers	Production of native and traditional crops
Comunidad de regantes del Carracillo	Brings together the farmers who benefit from the recharge project
Pines workers	They manage pine forests, extract resin, sell pines' wood
Environmental groups	Honorse-Mar de Pinares, Si a las fuentes del Cega. They work to raise awareness about the importance of maintaining landscape features and ecosystem services related to Cega river and pines (the so called Mar de Pinares)
Municipalities	They act as intermediaries between the needs of people and the Confederación Hidrográfica del Duero
Junta Castilla y Leon	It promoted Recharge project as an emergency means for facing Los Arenales aquifer overexploitation. It encourages agriculture for the production of export vegetables
TRAGSATEC	They realized the recharge project's preliminary studies and infrastructures

Category	Description
Confederación Hidrográfica Duero (CHD)	They apply national directives at the level of hydrographic confederation. Each Confederación calculates specific values of environmental flows for each water body that belongs to its basin

13.2 INTERVIEWS

13.2.1 *The project*

For what concerns the knowledge of the Recharge project, it emerged that, excluding the ten experts (both directly involved in the project and external to it), 14% of respondents were not sure about the objective of the third phase. In these cases, the most common answer was that third phase is aimed at improving quality of the quaternary aquifer, contamined with arsenic.

Actually, the objective of the third phase is "Satisfacer demandas, incrementar disponibilidad y economizar empleo de agua" (To satisfy water demand, increase availability and economize water use) (Confederación Hidrográfica del Duero, 2015). No official document refers to water quality.

Speaking of the implications third phase would have, it emerged that there is a great schism in the opinions. From one hand, export farmers, Comunidad de regantes, Confederación Hidrográfica del Duero and municipalities are united by conviction that there will only be positive impacts. Moreover, they claim that Cega river would be more positively impacted, since it would be finally regulated, avoiding harmful floods and preventing excess winter water from reaching the sea. On the other hand, pines workers, local workers and environmental groups assert that there will inevitably be negative repercussions. People living near Cega river are afraid that it would dry up and that there would be no more water for villages that rely on Cega for urban water supply. Moreover, people living on pines' management claim that the impact on pines will be very serious. All of them fear that biodiversity will suffer enormously from the implementation of the third phase, both biodiversity of Cega river and that related to the maintenance of different landscapes.

In particular, pines workers fear that excessive rise of the water table can damage roots, causing rot. Moreover, they are afraid that the cyclic filling and emptying of the sand lens could cause pines water stress. Pines workers argue that effects of the recharge are already visible along the channels in which water diverted from Cega flows during recharge days. Their opinion, supported and strengthened by centuries of tradition and years of experience, is that pines dried up due to the fact that trees were used to have water during years in which it was possible to perform recharge, so that their roots did not develop in depth. During following years, however, recharge was not performed, due to natural Cega conditions. This caused the pines to suddenly found themselves having to look for water at higher depths, without having developed an adequate root system.

Thus the existence of a net division emerged. Stakeholders that will directly benefit from the implementation of the third phase and that are linked to a development model based on intensive agriculture for exportation, are actually convinced that the third phase will only lead to positive repercussions for people, for local economy and the environment.

On the other hand, people living in close contact with Cega river, or depending from it for water supply, as well as stakeholder linked to an economic model traditionally based on agriculture with local crops and pines management, are able to have a longer term vision, and they look with fear at the direction taken with the recharge project.

13.2.2 *Cega river and ecosystem services*

The table presented in Figure 13.1 summarizes the results of the part of the interviews on ecosystem services.

Each ecosystem service has five possible scores (1-5). To each score corresponds, for each target group, the number of people that awarded that score to that ecosystem service. All respondents agreed in giving the highest score to all ecosystem services related to regulating function, meaning Groundwater replenishment, Maintenance of riparian vegetation, Chemical water quality control, Physical water quality control, Microclimate stabilization, Provision of refuge areas for animals, Pest control and Biodiversity conservation.

For what concerns services related to production, to Water for urban water supply, Vegetables and fruit as well as to Medicinal plants the highest score was attributed by all respondents. Almost all interviewees gave a score of 5 to water for agriculture, apart from three of the environmentalists and from two of the experts outside the project, that gave it a score of 4. Wildlife for hunting and fishing resulted in higher variability. It was maybe easier for people to associate these services with practical activities of their daily lives. Fishing obtained the highest score from 80% of all respondents. Two out of ten of small farmers, one out of ten of large enterprises and from three out of twelve of local workers gave it a score of 4. Wildlife for hunting obtained the highest score only from 40% of the interviewees. 54% of the respondents gave this service a score of 4. Finally, two of the mayors and one of small farmers gave it a score of 3.

		Experts inside project					Experts outside project					Mayors					Small farmers					Large agricultural enterprises					Local workers					Environmentalists				
Number of interviews per group		***5***					***5***					***3***					***10***					***10***					***12***					***5***				
Score		**5**	**4**	**3**	**2**	**1**	**5**	**4**	**3**	**2**	**1**	**5**	**4**	**3**	**2**	**1**	**5**	**4**	**3**	**2**	**1**	**5**	**4**	**3**	**2**	**1**	**5**	**4**	**3**	**2**	**1**	**5**	**4**	**3**	**2**	**1**
Production	Water for agriculture	5					3	2				3					10					10					12					2	3			
	Fish	5					5					3					8	2				9	1				9	3				5				
	Water for urban water supply	5					5					3					10					10					12					5				
	Vegetables and fruit	5					5					3					10					10					12					5				
	Wildlife for hunting	5					4	1				1		2			1	8	1			4	6				2	10				3	2			
	Medicinal plants	5					5					3					10					10					12					5				
	Inorganic material for construction	5					5					1	2				3	7				8	2				8	4				5				
Regulation	Growndwater replenishment	5					5					3					10					10					12					5				
	Maintenance of riparian vegetation	5					5					3					10					10					12					5				
	Chemical water quality control	5					5					3					10					10					12					5				
	Physical water quality control	5					5					3					10					10					12					5				
	Microclimate stabilization	5					5					3					10					10					12					5				
	Provision of refuge areas for animals	5					5					3					10					10					12					5				
	Pest control	5					5					3					10					10					12					5				
	Biodiversity conservation	5					5					3					10					10					12					5				
Informa tion	Tourism and recreational uses	5					5					3					10						10				12					3	2			

Figure 13.1: Detailed results of the stakeholder interviews.

To Inorganic material for construction the highest score was given by 70% of respondents, while 30% gave it a score of 4. Finally, Tourism and recreational uses received a score of 5 from all respondents but from two of the environmentalists, that gave it a score of 4.

As expected, this part of the interviews did not lead to a clear distinction between stakeholders. Moreover, a clear preference for what concerns water destination did not emerge.

On the other hand, interesting information emerged from the non-structured part of the interviews. Conversations showed that one of the most deeply rooted beliefs is that water reaching the sea is lost water. This belief is a prerogative of two classes of stakeholders, that of technicians from TRAGSATEC, and that of Comunidad de regantes. This suggests the fact that they do not have a clear understanding of the mechanisms that underpin the concept of ecosystem services.

Thus we preferred not to trust the results of the interviews provided by these stakeholders, that put on the same level almost all the ecosystem services provided by Cega river while claiming that water diversion from Cega is something that benefits the river, since it ensures that precious water is not lost.

Water for agricultural needs may just as well be considered an ecosystem service. In the particular case of Cega river, however, it makes sense to keep it separated from other services (such as biodiversity conservation or tourism). Its satisfaction requires a physical extraction of water from the river, thus subtracting resources from other services, placing itself in a position of direct competition with them.

We felt that the perception stakeholders have of Cega river ecosystem services is clearly divided between those who are convinced that Cega river's greater utility lies in supplying water for agriculture, and those who consider the river as a system of ecosystems. The competition mechanism may then explain the argument adduced by the stakeholder groups according to which water left unextracted is lost water, suggesting that an honest answer to the interviews would have placed water for agricultural needs in first place.

13.2.3 *Actors*

This part of the interview was basically aimed at making stakeholders categorize themselves into classes, through the so called stakeholder-led-stakeholder categorization. As stated by Hare and Pahl-Wostl (2002), stakeholder-derived stakeholder categorization is the necessary tool to complete analytical stakeholder categorization. Only through the combination of these two approach it is possible to have a wide as well as complete view of actors involved and of their roles in the context analyzed. In fact, while analytical categorization allows a formal classification thus organization, the latter enables to take into account mental models (Doyle and Ford, 1998) of stakeholders involved.

People were asked to identify actors that, in their opinion, will be most impacted by third phase of the recharge project, both positively and negatively, directly and indirectly. Four main stakeholders emerged from their considerations. Cega river was mentioned by 96% of interviewed, Large agricultural enterprises by 90% of the respondents and resineros (pines workers) by 70%. Confederación Hidrográfica del Duero was only mentioned four times and, interestingly, by environmentalists. This can be explained by the fact that environmentalists are usually well informed and have a more complete view of facts, people involved and relations between them.

Without considering the ten experts, TRAGSATEC was mentioned only once. Moreover, Junta de Castilla y Leon, as well as municipalities, were never mentioned, meaning that they are not considered stakeholders by those whom we consider as such. It could be comprehensible that the interests that Junta de Castilla y Leon has for the project as well as the influence it has on it are not perceived. The role played by Junta, in fact, is made explicit by legal means, so that it can be seen as something too high to have interests in the recharge project or in the effects the project could have on everyday life of people living in the Carracillo region.

Furthermore, municipalities were never mentioned. It makes sense to suppose that the role they play could be seen as a role of facade. They could not be perceived as actors closely connected with interests and issues of the people they represent. This would explain the fact that they were never mentioned during interviews.

It is interesting to underline that Cega river is considered a stakeholder to all effects. The fact that 48 out of the 50 respondents considered Cega river as one of the actors most impacted by third phase of the recharge project, made explicit a sensitivity of people to nature and highlighted the close bond that unites people of Carracillo region to Cega river.

Due to the low percentage of people that considered Confederación Hidrográfica del Duero as a stakeholder (only 2%), we considered more appropriate not to take it in consideration, leading the categorization to only three stakeholders: Large agricultural enterprises, resineros and Cega river.

13.3 STAKEHOLDER CATEGORIZATION: ANALYTICAL CATEGORIZATION

Following consultation with experts, the identified stakeholders were classified according to Lopez (2001). Stakeholders were classified according to the interest they have that the recharge project is implemented through the third phase. Moreover, they are classified according to the influence they have on the project, meaning the power they have to make the project fail or succeed. The result of this classification is shown in Figure 13.2.

Interviews already anticipated the existence of a net division both in the perception of the impacts the third phase could have, as well as of the conception of Cega river ecosystem services. This breach emerges again in the categorization based on interest and influence.

As mentioned above, Key players are those actors having high influence on the project and high interest in it. We identified as Key players first of all the Comunidad de regantes del Carracillo. They directly benefit from the recharge project since they need more and more water due to the production of horticultural crops. Moreover, they pressured the Confederaciòn Hidrográfica del Duero to lower the value of the environmental flow set for Cega river in order to derive

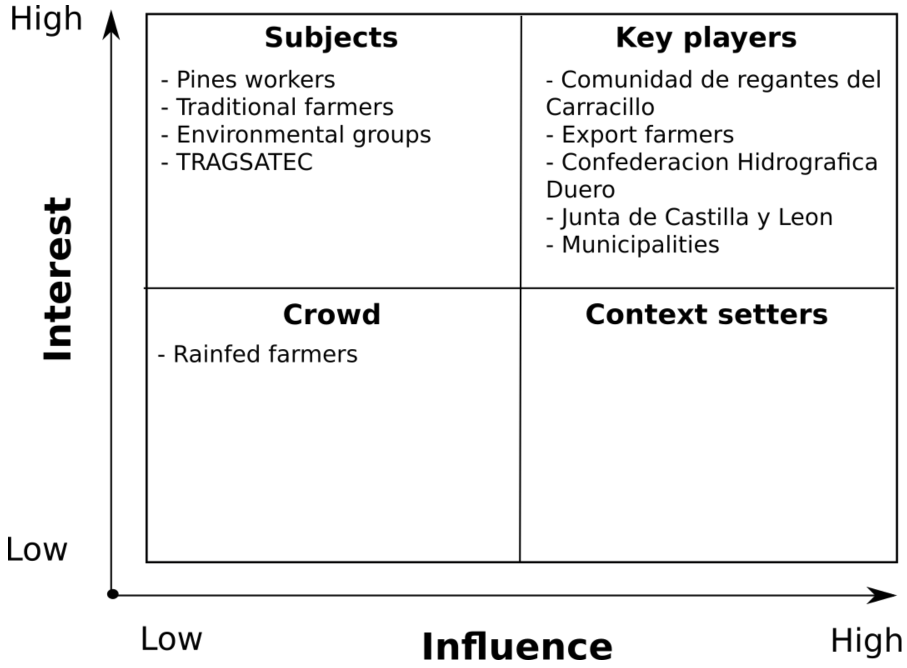


Figure 13.2: Classification of stakeholders based on interest and influence in/over the third phase of the recharge project, according to (Lopez, 2001).

more water[1], meaning that they have an high interest as well as high influence.

The Comunidad de regantes includes all the farmers of the Carracillo region, who will therefore benefit from the recharge project. It includes farmers that produces crops for exportation, small local farmers and rainfed farmers. Export farmers were identified as key players since they have more power, thus more influence. In fact the Comunidad Autonoma de Castilla Y Leon, through the Junta de Castilla y Leon, its highest decision-making body, is pushing towards a regional economy based on horticulture aimed at exportation. This caused export farmers, and therefore Comunidad de regantes, to be invested with great power, resulting in great influence as well as interest.

The Confederación Hidrográfica del Duero was considered as key player since it has a great interest that the third phase is implemented. This would reduce the pressures from Comunidad de regantes. At the same time, it has great influence on it, since it is responsible for managing water resources in the region and it could lower or raise the thresholds set, adapting them to the needs of farmers.

Finally, Municipalities were considered key players due to their intermediary role between people and institutions. They theoretically

1 n 2007 the Comunidad de regantes petitioned for lowering environmental flow values from 6.9 m^3/s to 1.9 m^3/s and in 2009 the Ministry of Environment authorized the new concession. It has been in force as long as the Audiencia Nacional, through the Resolucion de 21 March 2013, brought the concession to the original conditions.

want to serve the interests of people, while playing an institutional role that gives them legal powers to do it.

For what concerns Subjects, we identified four: Pines workers, Traditional farmers, Environmental groups, TRAGSATEC.

TRAGSATEC is the first having high interest since the preliminary studies and the construction of the infrastructures have been entrusted to this company. However, it has not office to influence the success of the project, since they work on commission. Pines workers are directly involved in the project and they have a huge interest in the project not being done, since they would be directly and personally affected by the implementation of the third phase. Anyway, they have no legal power or resource that allows them to exert pressure or influence the success of the project.

Traditional farmers have a role with uncertain boundaries. They benefit from the recharge project, since they also need water for agriculture (even if in smaller quantities). At the same time, they see in the current development model, that led to the need for the project, the end of a more sustainable economic model, in which agriculture with native products was one of the fundamental prerogatives. So that, they have interest in the project being done, anyway they have no influence on it, since they represent a small part of the local economy, which will tend to be eliminated.

Environmental groups have great interest in the third phase not being implemented, since they think it would negatively impact Cega river's welfare and pinares landscape. Anyway, apart from press releases, demonstrations and activities aimed at raising awareness, they do not actually have the power of influencing the success of the project. They could probably have in the future, by organizing and joining together, but current conditions do not allow it yet.

Rainfed farmers were considered as Crowd, since they have low interest and low influence on the recharge project. In fact, due to the type of farming they do, they would not benefit from the implementation of the third phase. At the same time, their social and economic conditions can be compared with those of traditional farmers, so that they would not be able to influence the success of the project.

Finally, no context setters were identified, meaning that we did not identify actors having high influence and low interest.

13.4 RELATION ANALYSIS

13.4.1 *Actor linkage matrix*

An actor-linkage matrix (Biggs and Matsaert, 1999) was constructed in order to analyse relations existing among the identified stakeholders, and is presented in Figure 13.3. The results to the interviews related to three questions about actors were used to construct the matrix. The questions are:

- Which is their role (of the actors involved in the third phase)?
- Which are their interests?
- Who are the people most affected (in a positive and/or negative way) by the recharge project?

As emerged from the definition of conflict provided by Mauelshagen (2006), water conflicts arise when actors with different objectives compete over a limited water source. Since we did not want to explicitly ask to every interviewee what his goal was, these questions were thought in order to "force" each actor to think about the goal and role of every other actor involved in the third phase of the recharge project. The answers provided cross results that allowed to bring out, among other things, existing conflicting relations. Resulting conflicting relations are highlighted in yellow in Figure 13.3.

	Rainfed farmers	**Export farmers**	**Traditional farmers**	**Comunidad de regantes**	**Pines workers**	**Environmental groups**	**Junta Castilla yLeon**	**C.Hidrografica Duero**	**TRAGSATEC**
Rainfed farmers									
Export farmers	CC								
Traditional farmers	CO	CC							
Comunidad de regantes	C	CO	CO						
Pines workers	CO	CC	CO	CC					
Environmental groups	CO	CC	CO	CC	CO				
Junta Castilla y Leon	C	CO	C	CO	CC	CC			
C. Hidrografica Duero	C	CO	CO	CO	C	CC	CO		
TRAGSATEC	C	CO	CO	CO	C	CC	CO	CO	

CO= Cooperation
CC= Conflicting
C = Complementary

Figure 13.3: Actor linkage matrix as resulting from stakeholder interviews, according to (Biggs and Matsaert, 1999).

In first instance, there is something that must be underlined. Municipalities were not considered in the matrix since it emerged from interviews that the role they play is purely a facade. Their interests end when the mandate ends and they change political position depending on how comfortable it is. So that, it would be difficult as well as useless to frame them in terms of conflictual, cooperating or complementary relationships.

Rainfed farmers only have conflicting relations with export farmers, since they are afraid that the economic trend of recent years leads export agriculture to earn more land at the expense of rainfed agriculture. The same fear characterizes also the conflicting relationship between traditional farmers and export farmers. Moreover, traditional farms see in the new economic model characterized by intensive horticulture and export, the root of the problems related to water scarcity and overexploitation of the aquifer.

The Comunidad de regantes, which unites from a legal point of view both traditional and export farmers, maintains a conflicting relationship with pines workers and environmental groups. The last accuse the Comunidad to require increasing amounts of water, making the recharge project (deriving water from Cega river) necessary and fundamental. Moreover, environmentalists claim that the project is negatively affecting Cega river's biodiversity. At the same time, the third phase of the recharge project requires that the diverted water is stored in the sandstone lens in the pines area. This is raising fears in pines workers, who worry for the impact the project could have on the welfare of the pines. For the same dreads, pines workers also have conflicting relations with Junta de Castilla y Leon, that promoted the recharge project.

Environmental groups, as already mentioned, accuse Comunidad de regantes, and in particular export farmers, of carrying on an unsustainable economy, that made it necessary the recharge project, now seriously threatening Cega river's well being. For this, they mainly charge with the policy of Junta de Castilla y Leon. Moreover, environmentalists incriminate Confederación Hidrográfica del Duero for submitting to Comunidad de regantes' requests to excessively lower Cega river's minimum flow to maintain. Finally, they denounce TRAGSATEC, which was entrusted with the planning and construction of the infrastructures, to have underestimated recharge project impacts on the river and pines as well as, more in general, to have submitted environmental interests to economic ones.

13.4.2 *Causal loops*

Butler and Adamowsky (2015) suggest to focus on the construction of causal loops for the analysis of complex systems, rather than on the quantification of the variables involved in the system through the definitions of the descriptive equations. Starting from this suggestion, we thought causal loops could successfully be used in order to represent and understand complex dynamics between stakeholders involved in Carracillo case study. The resulting scheme is presented in Figure 13.4.

This causal loop refers to the dynamics and effects underpinning the implementation of the third phase.

The economic policies of the Junta de Castilla y Leon sustain a kind of agriculture increasingly aimed at exportation and production of horticultural crops. This requires ever increasing amounts of water (Antequera et al., 2014). The implementation of the third phase, would on one hand increase water available for agriculture. This would however result in the expansion of hectares to irrigate (Rivas-tabares et al., 2018), leading to an increase in water demand (self-reinforcing loop), thus bringing export farmers back to dissatisfaction, due to the impossibility of meeting their needs.

On the other hand, runoff downstream the derivation would seriously decrease, gravely impacting Cega river ecosystem services. At the same time, implementation of third phase would require new infrastructures and the storage of diverted water into the sandstone lens, that would have serious impacts on pines area.

The combination of the two issues would lead environmentalists to put pressure on Junta in order to change concession's parameters. The risk of conflict triggered by environmentalists would lead the Junta to mitigate the conditions and terms of the recharge project. This would decrease water available for agriculture, leading export farmers to put pressure on Confederación Hidrográfica in order to change concession's parameters. Again this would cause an increase in the risk of a conflict.

Thus, it is possible to affirm that the recharge project in Carracillo region has the characteristics of the "Fixes that Backfire" (Gohari et al., 2013), in which a short term solution results in a weak balancing loop that triggers a stronger reinforcing loop. In fact, to address the problem of water scarcity, a recharge project was made. Anyway the project did nothing but provide a quick solution to a much more serious and deeply rooted problem, leading it to reemerge in a more severe manifestation. The economic model based on horticulture for exportation led to overexploitation of the aquifer. The recharge project will only provide short term solution to the water scarcity problem, while improving agricultural expansion and economic growth that will require more and more water. Moreover, the third phase of the project is likely to destine Cega river to death, seriously threatening region's water reserves and increasing water scarcity problem.

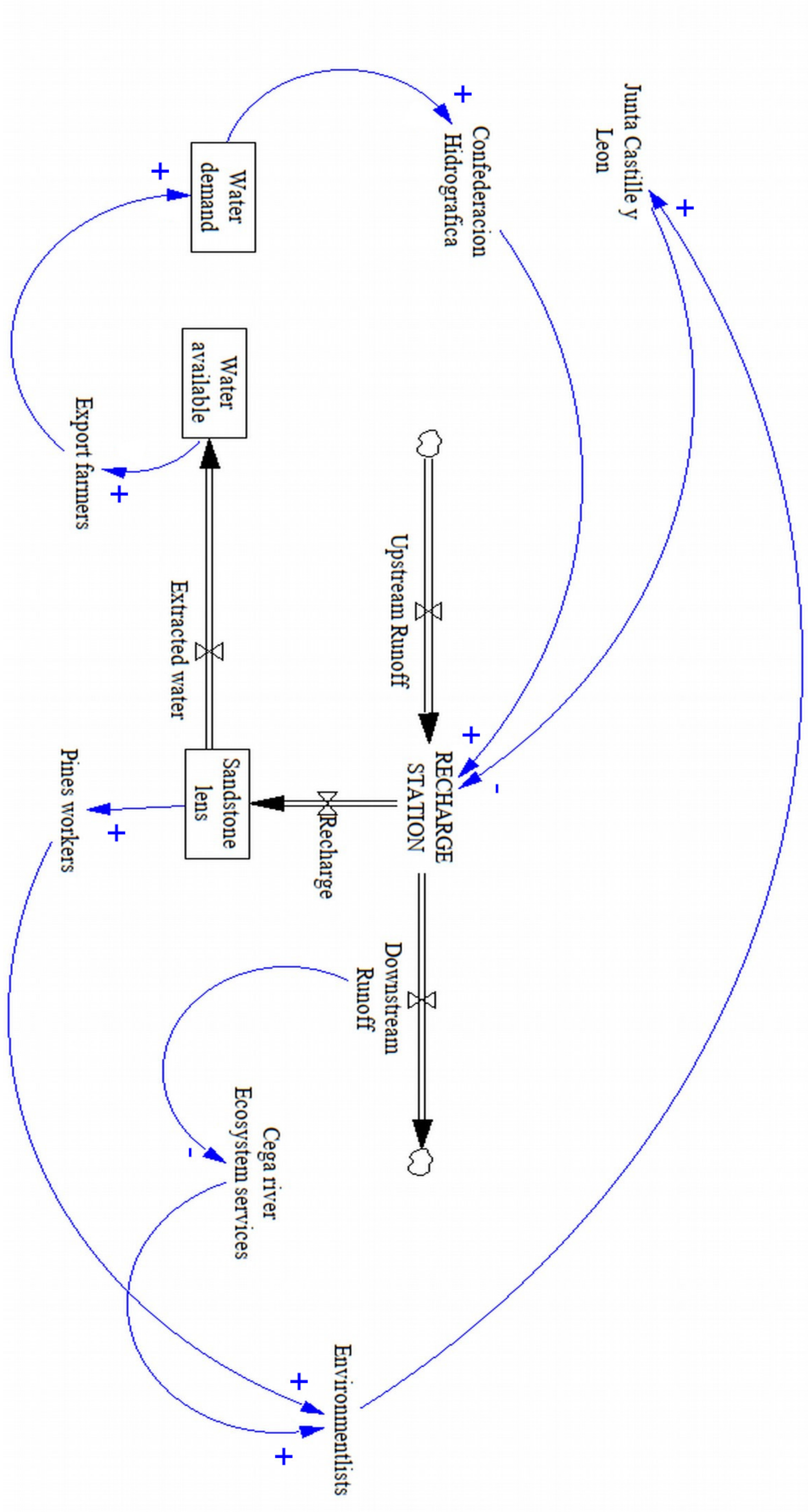


Figure 13.4: Causal loop diagram (Butler and Adamowsky, 2015) detailing the dynamics between stakeholders in the Carracillo case study. Positive sign means that cause and effect are directly proportional (self-reinforcing loops); negative sign means that cause and effect are inversely proportional (balancing loops).

14 STAKEHOLDER ANALYSIS CONCLUSIONS

Stakeholder analysis played a fundamental role in the definition of the social context in which which we would have operated. Moreover, it allowed to identify actors involved in the conflict and the relations between them.

From interviews, in the first place, it emerged that there is great disinformation about the project. The objectives are not clear, as well as the way of pursuing objectives. Furthermore, people don't know where to find information. In addition to this, people complain that there was any kind of involvement nor consultation of the groups that would be more affected by third phase, neither in planning phase nor in the implementation one.

It emerged that a clear division exists in the perception of the impacts that the implementation of the third phase could have. The same division appears also from the categorization based on interest and influence. On one hand there are those stakeholders that have always relied on activities closely connected with the well-being of the river (resineros, traditional farmers). Therefore they have a more holistic vision of the impacts the implementation of the third phase could have on the environment as well as on society. On the other hand, stakeholders that rely on an economic model based on intensive horticulture for exportation, so that will directly benefit from implementation of the third phase, first of all export farmers, are convinced that the implementation of the third phase will only lead to beneficial effects, from an economic point of view as well as for the environment. In fact, they add that the recharge project allows to take advantage of water that would otherwise reaching the sea, being lost.

This belief, that characterizes at least some exponents of the two stakeholders groups of Comunidad de regantes and TRAGSATEC, convinced us that a division exists also in the perception of ecosystem services provided by Cega river. On one hand, some stakeholders truly believe that water released downstream of the derivation plays a significant role in maintaining fundamental services provided by the river, like biodiversity conservation and tourism. On the other hand, some stakeholders are convinced that water that is not diverted in order to be used for irrigation is water that will be wasted. In this way a short circuit is created, since the more water is derived to satisfy farmers' demand, the more the well-being of the river as well as the quality of ecosystem services downstream the derivation deteriorates. For this reason, in the next phases of the study water diverted for agriculture will be considered separately from other services.

It should be underlined that the the part of the interviews on ecosystem services had some weaknesses. It makes sense to suppose that, put before the possibility of being judged by those who would read the interviews, most of the interviewees provided precautionary answers. Another consideration should be done, meaning that this method of awarding scores may not be the most appropriate method. Could have made more sense to ask respondents to assess ecosystem services in increasing order of importance.

Going forward, stakeholder analysis brought out the existing gap between the perception experts outside the case study have of actors involved in the conflict and the perception the actors themselves have. In fact, stakeholder-led-stakeholder categorization highlighted that those considered as stakeholders by stakeholders are Export farmers, Resineros and Cega river.

This tripartition emerged also by analysis of conflicting dynamics performed through actor-linkage matrix. This tool allowed to define three main stakeholders with higher number of conflictual relations. Environmental groups have five conflicting relationships: with export farmers, Comunidad de regantes, Junta de Castilla y Leon, Confederación Hidrográfica del Duero and TRAGSATEC. Then, export farmers have four conflicting relationships: with rainfed and traditional farmers, pines workers and environmentalists. Finally, pines workers have three conflicting relations: with export farmers, Comunidad de regantes and Junta de Castilla y Leon.

Hence, it emerged that three main cores characterize Carracillo conflictual dynamics. From one hand, Cega river's ecosystem services were not considered in the hydrological planning process. If the third phase of the MAR project came into effect there could be drastic repercussions on river ecosystems, due to further lowering of environmental flow.

Secondly, agricultural water requirements are expected to grow, due to policies that encourage the cultivation of crops with high water requirements, in particular vegetables for export.

Finally, if the third phase of the MAR project came into effect there would be repercussions on the economy related to pine management, due to storage of great amounts of water in the soil and to the construction of new infrastructures in the pinares area.

We believe that every part is equally important and should be adequately deepened. Anyway, in order to perform a sufficiently thorough study, we decided to focus only on the system constituted by the bargaining game between agriculture and Cega river's ecosystem services, leaving out the aspects related to the effects on pine trees.

Part IV

COMPARISON AND EVALUATION

15 THEORETICAL BACKGROUND

15.1 ECOSYSTEM SERVICES

15.1.1 *Ecosystem Services: definition and quantification methods*

The concept of ecosystem services provides an holistic tool able to make concrete ecological and economical benefits deriving from nature (Millennium Assessment, 2005). With regards to riverine environment, they are those benefits provided by rivers and landscape belonging to associated watersheds (Thorp et al., 2006). According to Postel et al. (1997), riverine ecosystems support peoples' livelihood by providing multiple services, that involve water for agriculture, fishing, drinkable water as well as for supporting recreational activities. Thus, this definition involves both services directly provided by water flowing within the river itself (hydroelectric energy) and benefits provided in areas hydrologically connected to rivers (water for agriculture) (Hanna and Bennett, 2018). The Millennium Ecosystem Assessment (Millennium Assessment, 2005) provided a categorization of ecosystem services into four classes, meaning Cultural, Provisioning, Regulating and Supporting. This classification is the most used, though other frameworks emerged (Hein et al., 2006; Carpenter et al., 2009)so that, to date, the discussion about ecosystem services classification is still open.

Despite the importance of ecosystem services is universally recognized, these "silent actors" (Korsgaard et al., 2008), are usually not considered having same dignity and weight as other actors in bargaining and conflicting processes. This takes on considerable importance in water-related conflicts. For this reason, efforts are being made in order to provide methods for ecosystem services' quantification.

According to Hanna and Bennett (2018), the most used method to quantify ecosystem services is statistical analysis, that involves descriptive statistic and also monetary valuation. An example is provided by Gonzales-Caban and Loomis (1997), that applied the contingent valuation method (CVM) in order to determine the willingness-to-pay (WTP) of households in Porto Rico. This method allowed to define the amount of money people would be willing to pay to maintain ecosystems' integrity in the Rio Mameyes and to avoid the construction of a dam on the Rio Fajardo. The study included a first phase to acquire information on ecological aspects of the two involved rivers. Moreover, authors performed focus groups in order to define the level of understanding of some terms related to water use and water natural processes, as well as of the consequences that the construction of the dam and the derivation of water from Mameyes river would have on the environment and on the well-being of riverine ecosystems.

However, monetary valuation of ecosystem services can lead to controversial results, due to erroneous assumptions and, more often, to the difficulty of monetarily valuing some ecosystem services (Kenter et al., 2011).

The second most used method to quantify ecosystem services is constituted by Geographic Information System (GIS). Though, some issues can occur, for example related to the use of low resolution of secondary data that can distort the results, as emerged from the study of Tomscha et al. (2017) and Di Sabatino et al. (2013).

15.1.2 *Service Provision Index*

Korsgaard et al. (2008)propose a practical tool, the Service Provision Index (SPI), able to assess environmental flows as well as pragmatically link environmental flow to ecosystem services and economic value. This tool allows to evaluate ecosystem services provided by Environmental Flow from an economic point of view, thus allowing Environmental flow to be considered at the same level of other water users in water allocation processes.

This approach involves three phases: (I) Linking flows to services; (II) Linking services to value; (III) Evaluating Environmental Flows scenarios.

I The first phase involves some necessary steps.

- Identification of ecosystem services sustained by environmental flow in a given river. This can be achieved consulting the list of environmental services sustained by environmental flow compiled by Korsgaard (2007). Ideally this step should be achieved through a participatory process with stakeholders.
- Identification of flow classes. A Flow class is identified as "any characteristic of the natural flow regime that is considered vital for provision of a particular service".
- Development of Service Suitability (SS) curves. These curves describe how suitable is a given flow to sustain a given service. Service Suitability ranges from 0 to 1.
- Calculation of the Service Provision Index (SPI). It calculated as the weighted average of the service suitability of each flow class:

$$SPI = \sum_{i=1}^{n} w_i \cdot ss_i(q_i), \tag{15.1}$$

where i is the flow class number; n is the number of flow classes; w_i is the weight of flow class i; ss_i is the Service Suitability of flow class i and q_i is the flow $[m^3/s]$ for flow class i.

II The second phase involves the following steps.
  - Definition of spatial and temporal scale of evaluation, in order to establish the benefits of who should be included
  - Establishment of the relationship between the economic value of each identified ecosystem service and SPI. This step can be achieved through the use of evaluation methods like Adjusted market price or Cost avoided. The economic value must be calculated when the ecosystem service is fully provided, in order to have for the value a corresponding SPI of 1. Thus the production function can be calculated, linking the economical value to the SPI.

III The third phase involves the calculation of the total value and the total Service Provision Index of each scenario.

This framework was applied to the Zambesi river, in Mozambique (Fanaian et al., 2015). Five ecosystem services provided by the Zambesi river downstream of the Cahora Bassa dam were identified. They are hydropower, irrigated agriculture, fisheries, wildlife tourism, flood regulation. For each ecosystem service, suitability curves were constructed for all the months of the hydrological year. Then economic values were calculated for each ecosystem good. For the first four goods, adjusted market price valuation method were used. The value of flood regulation were calculated by using cost avoided method.

Finally, the total economic values of ecosystem services was evaluated under different flow regimes scenario. Results show that flow regimes aimed at preserving environment can be of greater economic benefit compared to current water management, totally focused on hydropower production.

15.2 COLLABORATIVE MODELLING FOR DECISION SUPPORT

Water management has being facing problems that are becoming even more complex. New aspects need to be considered: climate changes, strong industrialization, intensive agriculture and hardly increasing water demand due to population growth (Adamowski et al., 2009; Daniell and Mazri, 2010). Modelling approaches can effectively provide powerful tool to deal with the new challenging items. Moreover, the increasing complexity requires even more holistic models to try to understand water-related systems and actors involved, and to predict their behaviour.

Collaborative Modelling for Decision Support is a multi-purpose concept that comprehends *"collaborative modelling with participatory processes to inform natural resource management decisions"* (Lorie, 2010). This concept includes a variety of approaches developed for different applications by many experts. Examples are constituted by Shared Vision Planning, Mediated modelling, Group Model Building, Computer-aided negotiation, Participatory Modelling (Langsdale et al., 2013). Some of these tools were implemented through the use of *System Dynamics (SD)*.

Lund and Palmer (1990)were among the first to question the actual usefulness and effectiveness of water resource system models in contributing to resolve water related conflicts.

Authors argue that modelling tools can help planners and, in general, people involved in water-related conflicts management, through providing:

1. a better understanding of the problem;
2. a help for the involved parties in formalizing their objectives and in quantifying measures of system performance;
3. the development of alternatives;
4. rapid evaluation of different alternatives;
5. confidence in solutions proposed;
6. a forum for negotiations and conflict resolution.

Moreover, authors discuss three settings for model development and use. They are:

- *Monolithic model development and use*. Models are managed and run by a single modelling authority.
- *Pluralistic Model development and use*. Several interest groups develop and use different models of the same system. In this way, models describe different perspectives of the parties involved.
- *Shared vision modelling*. A single model or modelling framework is developed by those decision-makers that will be affected by water-related decision resulting from the model.

Some steps are needed in order to create a shared vision model:

1. definition of who will use the model and how will use it;
2. translation of modelling functions into a common model;
3. development and evaluation of alternatives.

The development of a shared vision model has the double objective of reaching an agreement on technical data contained in the model allowing to focus on interpretation of the results, rather than on model contents. Moreover, this approach allows to create a *"technically-based forum where parties can negotiate"*. Authors conclude that, in order to create a complete and effective tool for conflicts resolution, it is necessary to include institutional context of water conflicts in the analysis.

Palmer et al. (1999), define those characteristics a Shared Vision Model should have: model relevance, validity, transparency, flexibility and accessibility. Authors report the results of the application of the shared vision model in the context of the National Drought Study (Werick and Whipple, 1994). Among the case studies, five Drought Preparedness Studies were conducted in many basins of the United States in order to improve existing water management practices. The shared vision model was successfully applied in three of the five study areas. In these cases, some advantages emerged, meaning *"reduced programming time, ease of modification and the transparency of the model content"*. Moreover, participants highlighted that the model allowed the analysis to be more precise, easier to implement, more quantitative and collaborative.

In more recent times, some studies confirmed that SD, if developed using a participatory approach, is proven to be effective in processes of Participatory Model Building and group learning events, due to its flexibility and easy interface.

Butler and Adamowsky (2015)propose a use of *Participatory Model Building (PMB)*, implemented through SD, for empowering marginalized communities in water management practices. Authors do not provide a case of practical application of the tool. Anyway they suggest that the involvement of stakeholders in the whole model building process, from development to implementation, can constitute a form of Anti-oppressive practice applied to water resources management. Indeed, authors recognize that *"all decisions made about the access or allocation of water resources either perpetuate or challenge current oppressions"*.

Authors propose some measures that can prove useful. First of all they suggest that the first three phases of the PMB, meaning definition of the problem, identification of stakeholders and selection of the stakeholders to be involved in the decision-making process, are done in an iterated manner, in order to consider the input of the different stakeholders involved.

For what concerns problem definition, authors suggest to pay particular attention in considering societal power dynamics. Authors suggest that the selection of the stakeholders to be involved in the PMB be achieved through the set based on power and interest proposed by Bryson (2004).

Moreover, they suggest to focus on the construction of causal loop, rather than on the quantification of the variables involved in the system through the definitions of the descriptive equations. This allows also people with less mathematical basis to successfully participate in the whole process.

15.3 ENVIRONMENTAL FLOW

According to the IUCN report "FLOWS: The essentials of environmental flows" (Dyson et al., 2003), "the goal of environmental flows is to provide a flow regime that is adequate in terms of quantity,quality and timing for sustaining the health of the rivers and other aquatic ecosystems".

Hao et al. (2016) propose a classification of the methodologies for environmental flow assessment into three groups, meaning Hydrological Index Methodologies, Hydraulic Rating Methodologies and Habitat Simulation Methodologies. Hydrological Index Methods involve approaches based exclusively on historical runoff series, leading to wide application possibilities. Among the most commonly used processes there are Montana Method (Tennant, 1976) and Range of Variability Approach (RVA) (Richter et al., 1997). RVA is based on Indicators of Hydrologic Alteration (Richter et al., 1997), that consist of five classes, each one constituted by one runoff characteristic (scale, timing, frequency, duration and rates of change), that are used to represent hydrological processes related to ecological ones.

Furthermore, Hydrological Index Methods involve those approaches that are based on hydraulic characteristics, such as river width, average depth, flow velocity, wetted perimeter and hydraulic radius. Thus environmental flow values are derived from turning points in correlative curves between runoff and selected hydraulic indexes. The most representative method is the Wetted Perimeter Method (Gippel and Stewardson, 1998). This method allow to set environmental flow values based on the direct relation between wetted perimeter of river section and stream flow.

Finally, Habitat Simulation Methodologies try to set existing relationships between stream flow and habitat requirements of target aquatic species. So that, hydraulic as well as biological information are considered together in order to determine the suitability of habitats for target species, related with hydrological and hydraulic characteristics.

Instream Flow Incremental Methodology (IFIM) (Bovee, 1986) is one of the most commonly used Habitat Simulation Methods and it was the first framework used for negotiation in water allocation disputes (Paredes-Arquiola et al., 2011). This method integrates hydraulics and habitat suitability, through the use of hydrological as well as ecological models. Both macrohabitat (river morphology, water quality, temperature, turbidity and transparency) and microhabitat (water depth, velocity, riverbed and surface coverage) are involved in the model. Physical Habitat Simulation System (PHABSIM) (Gore et al., 1998)was developed by US Fish and Wildlife Service for micro habitat simulation. Based on the combination of hydraulic characteristics of the analyzed water body and habitat suitability for specific fish species, this tool allows the generation of Weighted Usable Area (WUA), put in relation with instream runoff. Thus, the inflection point of the WUA is usually considered as the minimum environmental flow.

The European Water Framework Directive (WFD) (European Parliament, 2000)establishes water management being implemented at regional level, through community action that must lead member states to achieve "Good Status" in all types of water bodies (inland surface waters, transitional waters, coastal waters and groundwater). The Good Status is a wide concept that involves the combination of Good Chemical Status and Good Ecological Status. The latter is defined from a qualitative point of view and includes evaluations on populations of fish, macro-invertebrates, macrophytes, phytobenthos and phytoplankton.

Four target classes are set. Class A refers to an ecological status that presents negligible modification from natural conditions. Class B refers to a status that presents slight modification from natural conditions. Class C refers to a status that presents moderate modification from natural conditions. Finally, class D refers to a status that presents high degree of modification from natural conditions.

According to the WFD, the Spanish Government approved the Water Planning Decree (MARM, 2008), setting the obligation to determine environmental flow values for all water bodies. Furthermore, the Spanish normative established that ecological flows must be included as a management tool in every River Basin Management Plan (RD 907/2007).

Paredes-Arquiola et al. (2011) propose a study aimed at developing an holistic framework in order to propose environmental flow values able to ensure good environmental conditions while maintaining hydropower production and water supply availability. This tools combines habitat analysis with conflicting water resource management needs and objectives. It was applied in the Duero river basin through three phases. A first phase allowed the assessment of the effects of environmental flow values for different scenarios. Then, a participatory process allowed the selection of the best set of environmental flow values. Finally, an optimization process allowed to maximize environmental flows in the basin.

This work constituted an important theoretical basis for our study and there is a similarity in the objectives. Though, the case study with which we had to deal, presented different assumptions. First of all, environmental flow values for the water body under analysis have already been set.

The aim of our study is not to propose new environmental flow values, but rather to propose new rules for the concession regulating the recharge project, based on the analysis of ecosystem services provided by the river thus on environmental flow values able to ensure these services; and on agricultural needs. Moreover, the tool we designed has the objective of supporting participatory water management processes as well as to facilitate mediation processes, with the main future goal of its application to other case studies.

16 TOOLS FOR COMPARISON AND EVALUATION

16.1 RECHARGE CONCESSION OPTIMIZATION SOFTWARE

16.1.1 *Why use an open source software*

The decision of using an open source software like Python is mainly due to the belief that academic research needs to be shared, accessible to all and free of proprietary technologies.

Using proprietary software almost always means using proprietary file formats. This forces anybody interested in analysing the results or prosecute the study to buy the same software to reliably manage those formats and the data they hold. The algorithms used in proprietary software are almost always closed-source and patent protected, with the obvious consequence that nobody can really syndicate their effective accuracy.

Open Source, at the contrary, is totally transparent. Every single line of code can be, and almost always is, analysed by other scientists, all with the same target of growing a collective, comprehensive concept of science. Every bug found and every new feature added is discussed and agreed by the scientific community involved in the project. Every single step of data analysis from a research is available to everyone who could need it, to verify it or simply to study it.

Finally, when it comes to software developed in the hopes to be used outside the scientific community (as is the case at hand), openness of the source allows any potential user to approach it without any restriction due to economic capabilities.

16.1.2 *Objectives of the software*

From what discussed in the previous chapters comes the need to assess the effects of the recharge project. No decisions involving the territory should ever be taken without a truly inclusive participatory process taking place. This is especially true when it comes to water bodies, since they constitute a vital part of any ecosystem, and since their management allows to obtain fundamental resources for services such as potable water or irrigation.

Water demand for services is always rising (Adamowsky et al., 2009), while natural sources of water remain roughly the same, at best. This kind of scenario leads to a point where water extracted from water bodies may just be enough to alter natural biodiversity conservation, and conflicts may arise between groups of people advocating the river conservation and water users.

Biodiversity conservation is usually accounted for through Environmental Flows (EF). These are calculated, as seen before, considering both ecosystem preservation and water resource demands (Paredes-Arquiola et al, 2011). Much software exists to assess the problem of determining EF through optimization processes. They all start from physical habitat simulation data (habitat indicators vs. flow curves), hydrogeological data (such as groundwater inputs), information about infrastructures and, most importantly, management rules such as existing laws. In some cases, though, conflict arises because of the current river administration, and the existing laws and management rules. Such is the case for the recharge project taking place in Cega river. Here both the EF values proposed by the Hydrological Confederation and the recharge rules are contested. In such a situation, management rules have to be subjectible to revision for any participatory process to be viable. More generally, from a scientific point of view, including existing management laws in an optimization process together with ecological and human water needs seems dubious, since laws can be modified while ecological need quantification is the result of scientific analysis of objective data. At best, it is a way to look for system optimum points that could be reached without the need for rules to change.

With the final intent of providing a tool to support participatory processes in the Caracillo region, a model has been developed that allows to perform a quick analysis of the consequences of different recharge concession rules on biodiversity conservation, on the satisfaction of agricultural water needs, and potentially on any other ecosystem services (which, for the present research, have been found to be water for urban areas in Las Lomas and river-related tourism). The algorithm doesn't necessarily assume any parameter to be fixed, and the software's modularity make it adaptable to different scenarios where different kinds of data are available. Approximate data or relationships produce results that can then be refined as soon as more precise inputs become available.

16.1.3 *General structure of the software*

16.1.3.1 *Technicalities*

The software has been written in Python 3.6. It requires the following libraries to work:

- `numpy` for basic mathematical operations and data handling;
- `scipy` for optimization algorithms;
- `datetime` and pandas for time-history data handling;

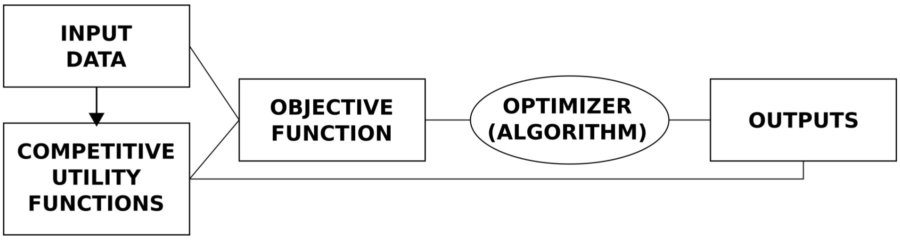


Figure 16.1: General structure of the optimization software.

- `matplotlib` for plotting;
- `csv` for tabular input-output operations;
- `h5py` for creation and loading of `HDF5` files.

Its structure loosely follows the principles of *"software modularity"* (Lutz, M. 2013): any single function can be substituted with another characterized by the same inputs and outputs. This allows to account for subsequent refinement of the functions or new data availability, and more generally to extend the software's application to other case studies.

The software is conceived to be released as *free software* (Stallman, R.M., 2002) with GPLv3 licensing. This requires, among other things, its source code to be readable and modifiable by the user. In the particular context of its application to participatory processes, it is our belief that the software's openness can aid shed the veil of "mystery" (and therefore untrustworthiness) around the technical inputs, allowing for a deeper comprehension of their reasons. Along with this, openness of the software's source code allows it to be adapted to other case studies in the future.

16.1.3.2 *General outputs*

The software produces two kinds of outputs, both considered useful for the participatory process. Starting from the definition of the competitive utility functions (that, in our case, consist in Ecosystem Services' and Farmers') it allows to produce personalized plots to check both their time- and parameter-dependent behaviour. All utility functions depend on parameters that govern them, or scenarios, which for the case at hand consist in a dictionary of recharge concession rules:

```
concession_rules_dictionary = {
```

`'name':`	name of the scenario
`'months':`	list of months during which recharge is allowed
`'min_flow':`	minimum flow to be guaranteed downstream of the derivation
`'max_recharge':`	maximum instantaneous intake
`'Vmax':`	maximum volume extracted yearly

}

Using the defined plotting functions it is possible to show the variability of one or more of the utility functions over time, or over values of one of the concession parameters. Graphs like these will be presented in the following chapters. There is hope that they prove useful when proposing a technical solution to the general public or to stakeholders without a technical background. Similarly, it is possible to show graphically the impact of a change in concession rules, simply creating two dictionaries for the different scenarios and plotting their comparison.

The second kind of output is the result of an optimization process, and represents an answer to the ever-pending question *"What would be the best compromise?"* (in this case, between the competing utility functions).

16.1.3.3 *Optimization*

The choice of the best set of concession parameters cannot obviously be left to an algorithm alone. Stakeholders and decision-makers should be the ones to do it, through a participatory design process. Nevertheless, when concerning themselves with potentially large amounts of data that require some processing to become understandable (such as in the case at hand), a software solution may provide useful insight into the inner workings of the problem.

The optimization algorithm implemented in the software strives to find values for the concession parameters that, under the hypothesis that the model rightfully describes the physical problem, allow to get as close as possible to what has been defined as the system optimum. This optimization can either be single- or multi-parameter, in the sense that one or more of the parameter values can be fixed. As an example, for the recharge concession it makes sense to investigate the optimum value for the minimum flow to be guaranteed downstream, as this value impacts both the farmers' and the ecosystem services' utility functions. It would also make sense to assess the value of the maximum recharge flow, since for a river, such as Cega is, characterized by a very irregular flow, a higher instantaneous intake may allow more recharge during high-flow days without compromising the environment. The optimization algorithm can produce an estimate of the best value for the coupled parameters. Still, changing the maximum recharge flow may not be feasible, as it may require a different infrastructure (for infrastructure details, cfr. Part ii). For this reason, it also makes sense to optimize the problem, single-parameter, with respect to minimum flow alone.

The optimization process consists in choosing tentative values for the unknown parameter(s) and iteratively evaluate an objective function, changing parameter values until the function is maximised or minimized. The choice of an objective function becomes then crucial, as it constitutes a mathematical definition of what the parties involved in the design process consider as "optimum". The software allows for the definition of a custom objective function. To analyse the case study one was chosen that we believed was appropriate for the behaviour of the utility functions that were considered. In particular, the optimization process was tasked with the maximization of the sum of the *Service Provision Index* function and of the farmer utility function. The algorithm governing the iterative process is the *Nelder-Mead* (or *Downhill simplex*) *method* (Nelder, J.A. and Mead, R., 1965). It was chosen for its broad applicability and general reliability, that make it appropriate as a general-purpose algorithm in a software that allows the substitution of the objective function. The Nelder-Mead method is already implemented in Python as part of the `scipy.optimize` library.

16.1.4 *Structure of the software for its application to the third phase of the recharge project*

The structure of the model, applied to the case study of the Carracillo region, s shown in Figure 16.2. Inputs and utility functions can be defined as presented in Table 16.1.

Since water for Caracillo agriculture is extracted from the sandstone lens, its hydrological balance was calculated considering precipitation, evapotranspiration and deep percolation together with water extracted from Cega river. The extraction follows the rules of the considered concession scenario, and is ultimately the function where concession parameters apply directly.

16.2 ECOSYSTEM SERVICES' UTILITY FUNCTION

As emerged by Stakeholder Analysis, interviews performed in the Carracillo region did not provide objective results regarding the perception stakeholders have of ecosystem services provided by Cega river.

Thus, one representative ecosystem service was selected for each one of the classes defined by Korsgaard et al. (2005). Water for urban water supply was chosen among Production services, Biodiversity

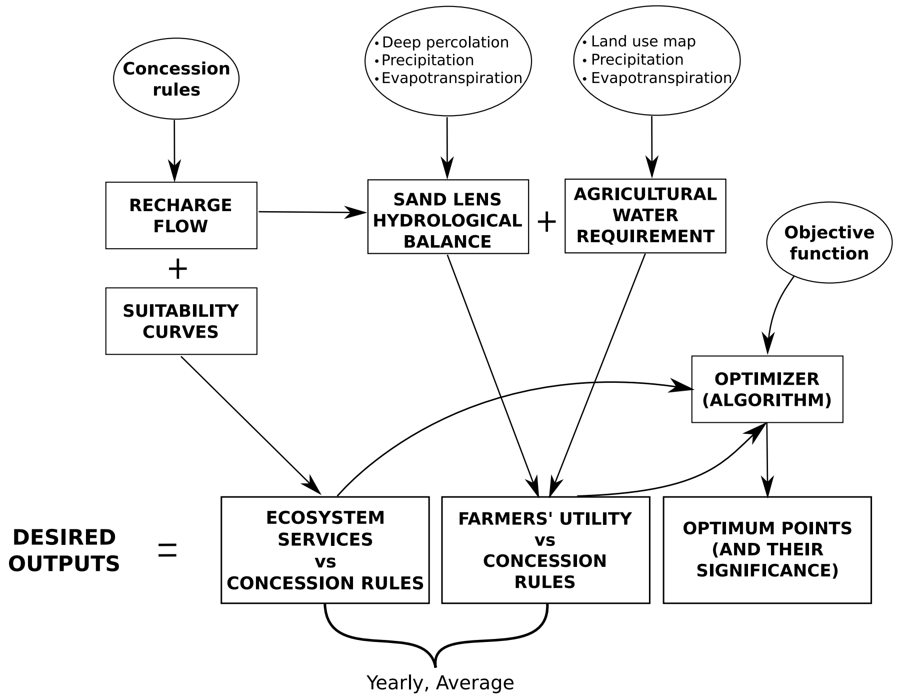


Figure 16.2: Specific modules of the software for its application to the third phase of the recharge project.

conservation was chosen among Regulation services and Tourism and recreational activities was selected among Information services.

Though, before performing Service Provision Index, we provide some data about current values proposed in order to maintain the "welfare" of Cega river.

16.2.1 *Some preliminary considerations about environmental flow values proposed for Cega river*

In the Boletin oficial del estado (BOE) of January 19th 2016, monthly environmental flows values were set for the hydrological planning cycle of the period 2015-2021. Environmental flow values are defined by Confederaciones Hidrograficas (each Confederacion Hidrografica establishes the values for the catchment area of its relevance) for each water body.

In order to have a clear overview on environmental flow thresholds proposed by Confederacion Hidrografica del Duero (CHD), a comparison was made between values set by CHD and values calculated through different expeditious methods.

Thus water body number 382 was selected. It involves the stretch of Cega river from its source up to 3 km downstream of the derivation point, as shown in Figure 16.3.

In Table 16.2 a summary can be found presenting the comparison of the values of average monthly flow calculated on the basis of real

Table 16.1: Utility functions and necessary inputs for the optimization software.

Inputs	Utility functions
- meteorological and hydrogeological data (precipitation, evapotranspiration, deep percolation); - agricultural data (land use, crop water needs); - recharge concession data (proposed values for a given scenario (e.g. the third phase) of the recharge project	Carracillo farmers' utility function
- meteorological and hydrogeological data (precipitation, evapotranspiration, deep percolation); - recharge concession data (proposed values for a given scenario (e.g. the third phase) of the recharge project; - historical mean flow values for Cega river.	SPI utility function, composed by: - biodiversity conservation; - tourism; - Las Lomas water provision.

data from station 2016, the values of monthly environmental flow set by CHD for the period 2015-2021 and the values of average monthly flows simulated through the use of SIMPA (Integrated System for Rainfall-Runoff Modelling) model (Ruiz García, 1999) for the period 1980-2010.

This model, implemented in GRASS, was created by combining different hydrological tools in order to deal with problems related to water resources management as well as flood risk assessment or water quality evaluation.

Tennant method, commonly known as *Montana* method (Tennant, 1976), was selected. Tennant expeditious methodis recognized worldwide as one of the most effective methods for environmental flow estimation, due to its easy applicability and low cost. Tennant proposed this method based on the studies performed on hundreds of rivers in the USA in order to determine the optima life-conditions for fishes. It sets at 10% of average monthly flow values that are just enough for the habitat to be considered alive. It sets at 30% of average monthly flow values that allow the habitat to be considered satisfactory. Finally, it sets at 60% of average monthly flow values that allow the habitat to be considered excellent.

Thus we compared values obtained through this method with environmental flow values proposed by Confederacion Hidrografica del

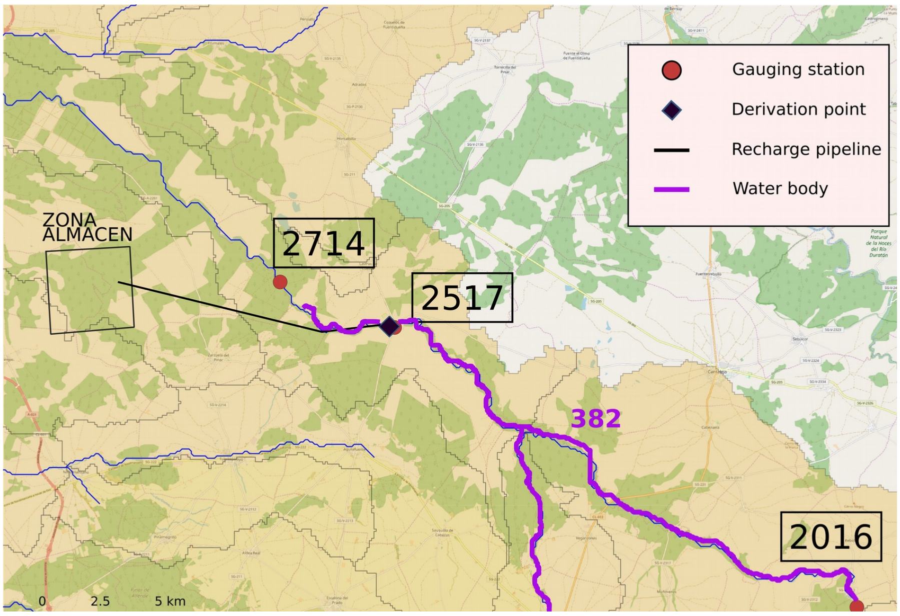


Figure 16.3: Water body number 382, selected for the study.

Duero (CHD). The results can be seen, in tabular form, in Table 16.3, and represented in graphs in Figure 16.4, where both natural and simulated flow values are used.

It is possible to note that with both simulated and real data, environmental flow values proposed by CHD are lower than 10% of average monthly flow. In particular, using real data, it emerges that CHD values are on average 16% lower than the threshold proposed by Tennant as "Survival", while using simulated data, they are on average 12% lower.

To date, this expeditious method was selected in order to have a first overview on the controversial topic of where to sets the limits for an healthy riverine ecosystem. Certainly, further studies will be of fundamental relevance for a better and more precise characterization of the study area.

16.2.2 *SPI: Suitability curves construction*

16.2.2.1 *Biodiversity conservation*

As set in Korsgaard's framework for Service Provision Index calculation (Korsgaard et al., 2008), the first step is to define, for each identified ecosystem service, a suitability curve. This means that the ecosystem service X must be put into operation of a flow class, identified as "any characteristic of the natural flow regime that is considered vital for provision of a particular service". The curve will be in a range from 0 to 1, where 0 is attributed to that value of the flow class

Table 16.2: Comparison of environmental flows from *CHD* against average monthly flow values as recorded during the years 1989-2010 and as simulated for the same years using *SIMPA* model.

	Average monthly flow 1980-2010 (real data) $[m^3/s]$	**Average monthly flow 1980-2010 (simulated data)** $[m^3/s]$	**Environmental flow values (CHD)** $[m^3/s]$
October	0.44	3.35	0.12
November	1.85	5.13	0.14
December	3.58	5.12	0.19
January	4.1	4.43	0.13
February	4.15	3.79	0.17
March	3.92	4.1	0.23
April	4.33	4.53	0.27
May	4.13	5.57	0.28
June	2.55	2.55	0.15
July	1	0.92	0.12
August	0.53	0.68	0.12
September	0.65	1.04	0.12

that does not allow the provision of the considered service, while 1 is attributed to the value that allows a full provision.

Korsgaard suggests that, in the absence of precise data, average monthly flow can be used as flow class with good approximation. Thus, we decided to construct our suitability curves based on average monthly flow, starting from average daily flow data from station number 2016, therefore from year 1912 to 2015.

Biodiversity conservation was constructed according to the concept of environmental flow. So that, we considered monthly environmental flow values as the thresholds below which biodiversity conservation is not provided. Anyway, since values proposed by Confederacion Hidrografica del Duero seemed inappropriate, as previously demonstrated, we decided to use environmental flow values that would result applying Tennant's parameters to Cega average daily flow data.

Our program returns a list of 12 values, meaning suitability values (from 0 to 1) of each month, valuing the suitability of average monthly flow to provide biodiversity conservation.

First of all, the program performs a skimming. Considering one month at a time, analyzing daily flow data from station number 2016 (upstream the derivation), we have not considered in the analysis those data lower than 10% of monthly average flow (Q10, hereafter).

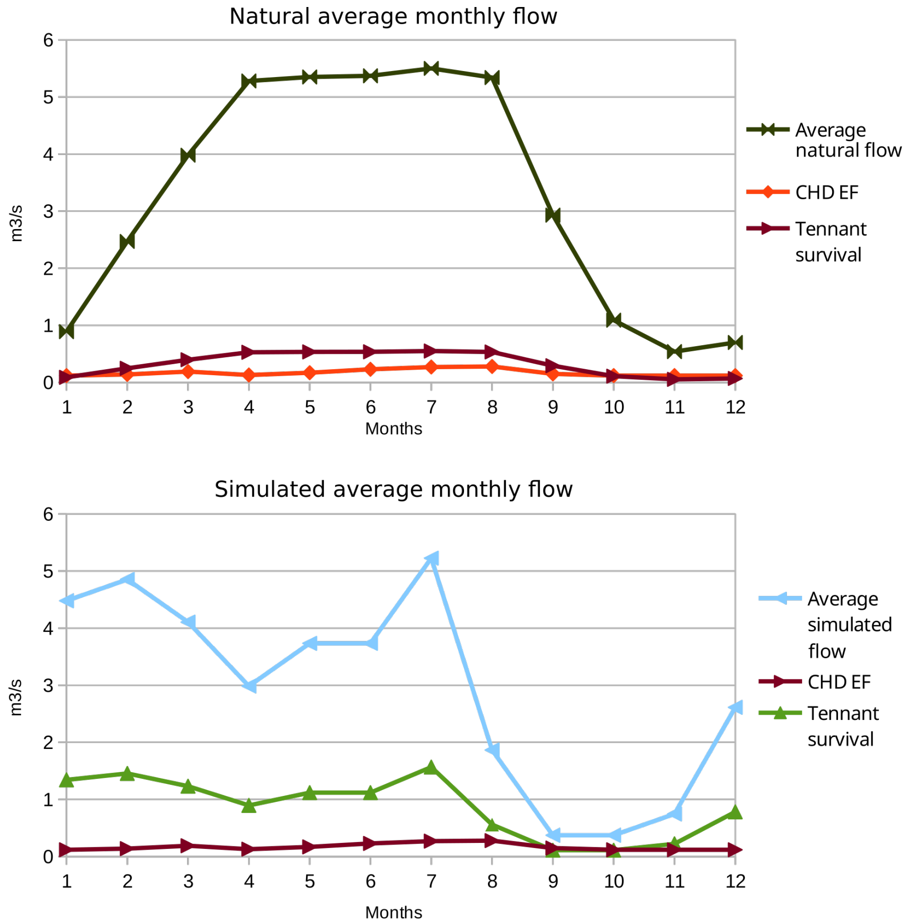


Figure 16.4: Comparison of EF values prescribed by the CHD with Tennant's Survival treshold values (Tennant, 1976), using both natural and simulated average flows for the years 1980-2010.

In fact, we considered it appropriate to attributed the cause of their low flow values to the natural course of the river, rather than to anthropic activity. Thus, for each month daily flow data lower than Q10 were not considered. If all the days of a month have a value lower than Q10, to that month is attributed a value of 0.

Then, among the days left from the skimming, flow values downstream ($Q_{dstream}$) the derivation are considered and, in particular, the day with the lowest flow is examined. For it, the rules detailed in Table 16.4 apply.

Where Q10 is the value that Tennant identified as just enough for the river to be considered alive, Q30 is the value that leads to the maintenance of a satisfactory environment, while Q60 is the value that allows the river to be in excellent conditions. The values of 0.8 and 1.0 given respectively to 30% and 60% of the average monthly flow stem from a graph presented in Tennant (1976), reported here in Figure 16.5.

Table 16.3: Comparison of environmental flows for water body 382 as dictated by *CHD*, and as resulting from estimation with *Tennant (Montana)* method.

	EF Values (CHD) $[m^3/s]$	Tennant survival $[m^3/s]$	Tennant satisfactory $[m^3/s]$	Tennant excellent $[m^3/s]$
October	0.12	0.09	0.27	0.53
November	0.14	0.25	0.74	1.48
December	0.19	0.40	1.19	2.39
January	0.13	0.53	1.58	3.17
February	0.17	0.54	1.61	3.21
March	0.23	0.54	1.61	3.22
April	0.27	0.55	1.65	3.30
May	0.28	0.53	1.60	3.20
June	0.15	0.29	0.88	1.76
July	0.12	0.11	0.33	0.65
August	0.12	0.05	0.16	0.32
September	0.12	0.07	0.21	0.42

Tennant reports a direct relation between depth, width, and velocity parameters (all increasing with river flow), and the well being of aquatic organisms and their habitat (Tennant, 1976):

> Width, depth, and velocity are physical instream flow parameters vital to the well-being of aquatic organisms and their habitat. Sixteen hundred measurements of these parameters for 48 different flows on 10 of the streams [...] show that they all increase with flow, and that changes are much greater at the lower levels of flow [...] Width, depth, and velocity all changed more rapidly from no flow to a flow of 10% of the average than in any range thereafter. Ten percent of the average flow covered 60% of the substrates. Depths averaged 1 foot, and velocities averaged 0.75 foot per second. Studies show that these are critical points or the lower limits for the well-being of many aquatic organisms, particularly fishes. This substantiates the conclusion that this is the area of most severe degradation or that 10% is a minimum short-term survival flow at best. Flows from 30% to 100% of average result in a gain of 40% for wetted substrate, average depth increases from 1.5 to 2 feet, and average velocities rise from 1.5 to 2 feet per second. These are within good to optimum ranges for aquatic organisms.

Table 16.4: Rules for the determination of biodiversity conservation suitability monthly value. The reference $Q_{dstream}$ is the lowest one of the series, after the initial skimming has taken place.

$Q_{dstream}$	Suitability value
< Q10 (10% average monthly flow)	0.0 to the whole year
< Q30 (30% average monthly flow)	$0.8(Q_{dstream} - Q10)/(Q30 - Q10)$
< Q60 (60% average monthly flow)	$0.8 + 0.2(Q_{dstream} - Q30)/(Q60 - Q30)$
> Q60	1.0

And, after this (Tennant, 1976):

> Ten percent of the average flow: This is a minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic life forms. [...]
>
> Thirty percent of the average flow: This is a base flow recommended to sustain good survival habitat for most aquatic life forms. [...]
>
> Sixty percent of the average flow: This is a base flow recommended to provide excellent to outstanding habitat for most aquatic life forms during their primary periods of growth [...].

Following the indications from Tennant, it was decided to consider Q10 as a lower limit for the attribution of a Suitability value, so that to any flow less or equal to Q10 corresponds a value of zero. Values of 0.8 and 1.0 were arbitrarily attributed to 'good' and 'optimum' conditions, and hence to Q30 and Q60 values, respectively.

Two things must be emphasized. First of all, the resulting curve is a triphasic one, with a greater slope in the the first phase. In fact, as stated by Tennant, the greatest impacts on wildlife and vegetation occur in the shift from 10% to 30% of average monthly flow, as shown in Figure 16.5. Moreover, 30% of average monthly flow is yet considered satisfactory, so that to values between 10% and 30% it is attributed a suitability value of 0.8. In Figure 16.5 the assumed suitability curve is also shown in red.

Then, it is fundamental to note that in case of days that have a flow value downstream the derivation lower than Q10, a suitability value of 0 is attributed to the whole year. This is both an ethical and a technical choice, since we want to implement a constraint to the optimizer as well as to concession rules, penalizing laws that allow to derive water even if flow is lower than 10%, leading to "catastrophic degradation to fish and wildlife resources and harm both the aquatic and riparian environments" (Tennant, 1976).

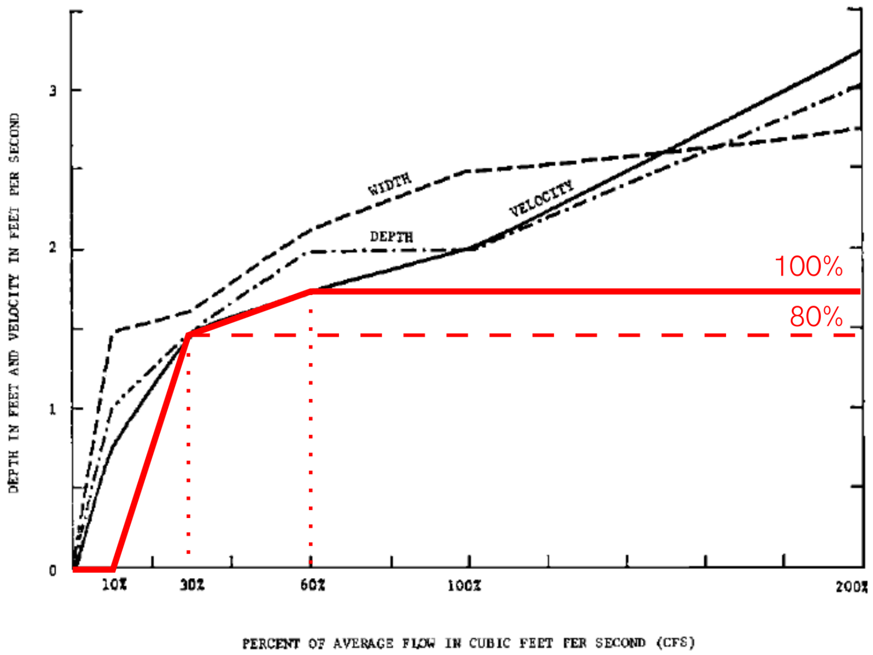


Figure 16.5: Flow values and associated service suitability, elaborated from Tennant (1976).

16.2.2.2 *Urban water supply*

Urban water provision from Cega river is regulated by Concession C-7267-SG, that benefits Mancomunidad Las Lomas, which brings together the municipalities of: Cuellar (with its municipalities: Arroyo de Cuellar, Dehesa Mayor, Escarabajosa, Fuentes de Cuellar, Lovingos, Torregutierrez), Navalmanzano, Pinarejos, San Martin y Mudrian, Sanchonuño, San Cristobal de Cuellar.

The concession is calibrated on a target population of about 20000 people. The parameters of the concession are:

- annual maximum volume (m^3): 1403303.60
- maximum flow (m^3/s): 0.11944
- maximum monthly volume (m^3):
  - October: 101695.52
  - November: 98415.01
  - December: 101695.52
  - January: 101695.52
  - February: 92674.14
  - March: 101695.52
  - April: 98415.01
  - May: 101695.52

- June: 131855.37
- July: 170805.58
- August: 170805.58
- September: 131855.37

Therefore, we considered Urban water supply ecosystem service fully provided (=1) when all the parameters were satisfied simultaneously.

16.2.2.3 *Tourism and recreational opportunities*

We considered Tourism ecosystem service as function of the environmental flow, since we estimated that the threshold that causes tourism to occur is the well-being of the river. Also in this case we utilized environmental flow values calculated through Tennant method. In particular we considered 30% of average monthly flow (Q30) as reference environmental flow value (ef). Thus we calculated the suitability curve as:

```
  if avg_monthly_flow >= ef:
Suitability value = 1.0
else:
Suitability value = avg_monthly_flow/ef.
```

The resulting curves for the different months of the year are presented in Figure 16.6.

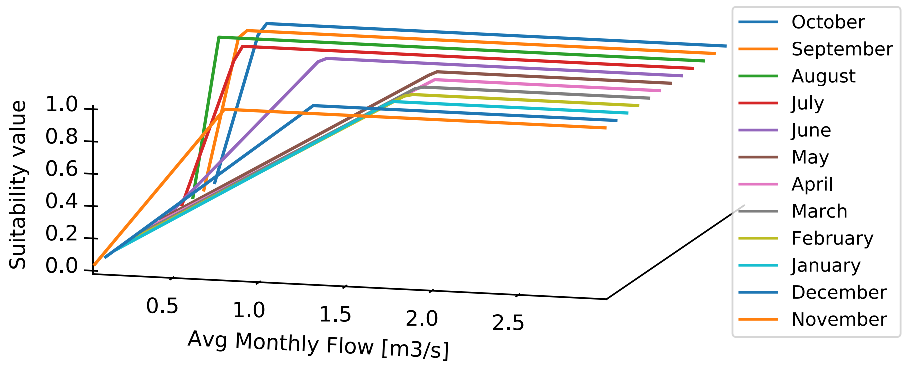


Figure 16.6: Service suitability curves for tourism and recreational opportunities.

16.2.3 *SPI: Ecosystem services' utility function*

As stated by Korsgaard et al. (2008), Service Provision Index was calculated through equation 15.1 as the sum of the suitability value of each ecosystem service multiplied by a weight and then normalized between 0 and 1 by dividing for the weights. Actually, if nothing is made explicit, the same weight is given to all ecosystem services.

The numerical value obtained is expression of the satisfaction of ecosystem services as function of average monthly flow. This quantification gives ecosystem services the possibility to be considered in the optimization process, making them become a real actor.

16.3 carracillo farmers' utility function

Farmers' utility function was calculated as function of agricultural water requirement and of water available for irrigation. With the implementation of the Third phase of the Recharge project, water diverted from Cega river would be stored in an area of around 1236 ha (the so called Zona Almacén), near Gomezserracin. As previously said, this is an area of pines, characterized by the presence of a sandstone lens, that makes it ideal for water storage. Water diverted from Cega river during the period granted by the concession (December-May), would be stored in this natural reservoir and then extracted during the irrigation period (approximately from March to October).

Thus, there is a shift between water storage in the lens and its extraction for irrigation. This made it necessary to insert an intermediate passage in the calculation of farmers' utility function. Thus, we calculated the hydrological balance of the lens. In this way the utility function became function of agricultural water requirement and of water actually available in the lens, having considered hydrological inputs and losses that may have occurred in the temporary shift.

Hence, first the procedure for calculating irrigation requirements will be described. Then we will proceed reporting the process for performing hydrological balance. Finally, farmers' utility function will be derived. The schemer shown in Figure 16.7 represents the steps necessary in order to achieve farmers' utility function calculation.

16.3.1 *Agricultural water requirement*

The cultivated area in the Carracillo region is about 7600 ha, of which almost 3000 ha constitute the irrigable area. This area is fixed and set by the Concession C-21-844-SG, granted through Real Decreto Ley 9/1998.

In order to calculate Agricultural water needs, ITACYL Land use maps were used. These maps were produced by the Instituto Tecnologico Agrario de la Junta de Castilla y Leon for years from 2011 to 2018, based on orthophotos, on existent land use maps (from Corine Land Cover European project) and on satellite images (Landsat). They have a resolution of 20mx20m (2011 to 2016) and of 10mx10m (2017-2018).

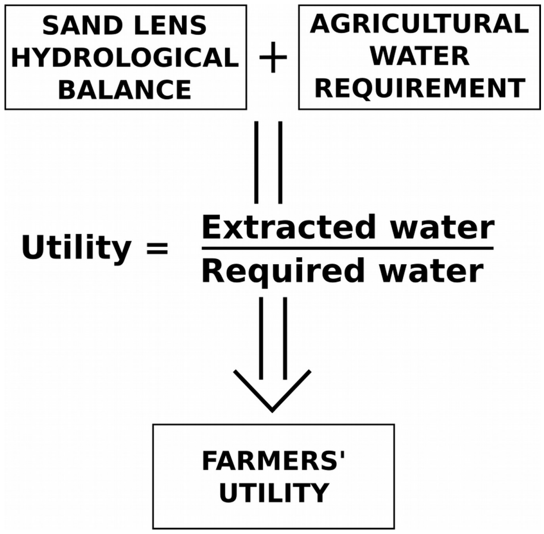


Figure 16.7: Carracillo farmers' utility function: steps for the calculation.

33 classes are involved in ITACYL Land use map, divided into Irrigated crops, Rainfed crops, Woods and pastures, Other. The analysis was performed on Qgis, considering years from 2011 to 2017. We chose not to use year 2018 since land use classes significantly changed from 2017 to 2018, making difficult qualitative and quantitative comparisons.

First, we differentiated between irrigated and non-irrigated crops, considering for the analysis only irrigated crops, namely: *corn, rape, barley, sorghum, peas, wheat, alfalfa, sunflower, oats, beet, potato, vegetables, orchards, nuts orchards*. We carried out the study focusing on single crops. With regard to the class vegetables, it was decided to consider the agricultural water needs of tomatoes, since it is the most demanding crop, from the water needs' point of view.

For each type of cultivation the vegetative period was defined, based on information obtained during interviews and comparing them with FAO Guidelines for computing crop water requirements (Allen et al., 1998). Each crop's vegetative period is divided into three phases, initial, medium, late, each of which is associated with crop coefficients (K_c).

With *agricultural water requirement* we reference to plants' evapotranspirative demand. Thus, we used daily Reference evapotranspiration (ET_0) values from Gomezseracin weather station, calculated using Penman-Monteith equation. From the same station we also obtained daily rainfall data. We calculated average values of ET_0 and rainfall on monthly cumulative values from 2011 to 2017. Furthermore, for greater accuracy, months from April to September were divided into three decades each one, so that for these months cumulative values were not calculated on the whole month, but on decades. The resulting average agricultural water needs for the period 2011-2017 are summarized in Table 16.5.

Table 16.5: Average agricultural water needs per crop, per time of the year, for the period 2011-2017.

	Average agricultural water needs for the period 2011-2017 [mm/period]														
	CORN	WHEAT	RAPE	BEANS	PEAS	SORGHUM	BARLEY	ALFALFA	SUNFLOWER	OATS	BEET	POTATO	VEGETABLES	ORCHARDS	NUTS
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	8.74	0.00	0.00	0.00	0.00	8.74	0.00	0.00	8.74	0.00	8.74	0.00	0.00	0.00
Mar	0.00	33.84	10.30	0.00	14.72	8.83	33.84	11.77	0.00	33.84	14.72	33.84	0.00	17.66	0.00
Apr 1 dec	0.00	20.60	20.60	0.00	20.60	21.49	4.48	17.01	6.27	4.48	18.80	20.60	0.00	17.01	7.16
Apr 2 dec	8.19	31.41	31.41	0.00	31.41	32.78	6.83	25.95	9.56	6.83	28.68	20.48	0.00	25.95	10.93
Apr 3 dec	5.56	21.32	21.32	0.00	21.32	22.24	4.63	17.61	20.39	4.63	17.61	13.90	12.98	17.61	16.68
May 1 dec	11.49	44.03	44.03	0.00	44.03	45.94	9.57	36.37	42.11	9.57	0.00	28.71	26.80	36.37	34.46
May 2 dec	11.91	45.67	45.67	0.00	45.67	47.66	0.00	35.74	43.69	0.00	0.00	0.00	27.80	37.73	35.74
May 3 dec	12.17	46.64	46.64	0.00	46.64	48.67	0.00	0.00	44.61	0.00	0.00	0.00	42.59	38.53	36.50
Jun 1 dec	16.46	16.46	63.11	0.00	63.11	65.85	0.00	0.00	60.36	0.00	0.00	0.00	57.62	52.13	49.39
Jun 2 dec	72.77	18.98	72.77	0.00	69.61	75.93	0.00	0.00	69.61	0.00	0.00	0.00	66.44	60.11	56.95
Jun 3 dec	79.36	20.70	79.36	0.00	75.91	72.46	0.00	0.00	75.91	0.00	0.00	0.00	72.46	65.56	62.11
Jul 1 dec	69.94	18.25	69.94	0.00	0.00	63.86	0.00	0.00	66.90	0.00	0.00	0.00	63.86	57.78	54.74
Jul 2 dec	79.03	0.00	24.05	0.00	0.00	72.16	0.00	0.00	24.05	0.00	0.00	0.00	72.16	65.28	61.85
Jul 3 dec	86.71	0.00	26.39	0.00	0.00	0.00	0.00	0.00	26.39	0.00	0.00	0.00	79.17	71.63	67.86
Aug 1 dec	77.81	0.00	23.68	0.00	0.00	0.00	0.00	0.00	23.68	0.00	0.00	0.00	71.04	64.27	60.89
Aug 2 dec	74.80	0.00	22.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61.79	61.79	58.54
Aug 3 dec	58.96	0.00	19.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	53.35	53.35	50.54
Sept 1 dec	51.80	0.00	0.00	24.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	46.86	46.86	32.06
Sept 2 dec	40.63	0.00	0.00	40.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.76	25.15
Sept 3 dec	0.00	0.00	0.00	26.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.91	16.36
Oct	0.00	0.00	0.00	35.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.45	0.00
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOT	757.59	326.64	621.69	127.34	433.00	577.87	68.10	144.46	513.54	68.10	79.81	126.28	754.91	875.75	737.91

Carrying out the analysis per crop type, for each month (or decade of month) we proceeded to subtract from the average value of ET_0 that of rain, multiplying the outcome by the Kc relative to the vegetative phase associated with each month. The result was divided by 0.8, considering an irrigation efficiency of 80% (in the study area, irrigation is performed almost exclusively through sprinklers). In this way we obtained the amount of water (mm) required by each crop type on average in the period from 2011 to 2017. Adding the result obtained for each plant we achieved the total average agricultural water need.

In order to determine the requirement per hectare per year, first the number of pixels belonging to each class was extrapolated from the Land use map, then converting it in the number of hectares dedicated to each land use class each year. The average irrigation requirement of each crop was multiplied by the number of hectares dedicated to that crop and multiplied by 10 in order to obtain the amount of water required in $m^3 \cdot ha \cdot year$. Finally, the operation was performed for each year.

No significant patterns in land use over the years (no crop rotation) can be identified though. Moreover, Concession C-21-844-SG establishes a maximum number of hectares that can be irrigated per year (3000 ha). For these reasons, the historical series of land use was extended backwards (from 2001 to 2011) in order to be able to consider earlier years where other necessary data (such as Cega flow values) were available. This was made by calculating the average agricultural water requirement for the period from 2011 to 2015 and then using it for the previous period, for which no land use data were available. This choice was made in the awareness of making an overestimation, however cautionary.

16.3.2 *Hydrological water balance*

16.3.2.1 *Calculation of water diverted from Cega*

Water is diverted from Cega river according to some rules established by the Concession. The old Concession (C-21-844-SG) has been active since 2000. It defined some parameters for the derivation:

- Derivation period: January to April
- Q max derivable: 1.37 m^3/s
- V max derivable/year: 14.2 hm^3
- Q min (Minimum river flow to maintain): 6.9 m^3/s

To date, the new Concession was approved and it will come into force shortly. It establishes that the derivation period will be extended from December to May and the minimum river flow to maintain will pass from 6.9 m^3/s to 0.6 m^3/s.

Anyway, the calculation of the derived flow rate from Cega river is merely hypothetical, since we do not have real data about how much water was diverted and when. The function created for the simulation of water diverted from Cega is function of the rules, thus of the parameters defined by the concession, and of a "fix part", that allows to import sets of data from different sources. In the first instance we decided to perform the simulation using the rules established by new Concession, but they can be modified in order to investigate different scenarios. The scheme in Figure 16.8 summarizes the steps performed in order to set water diverted from Cega river.

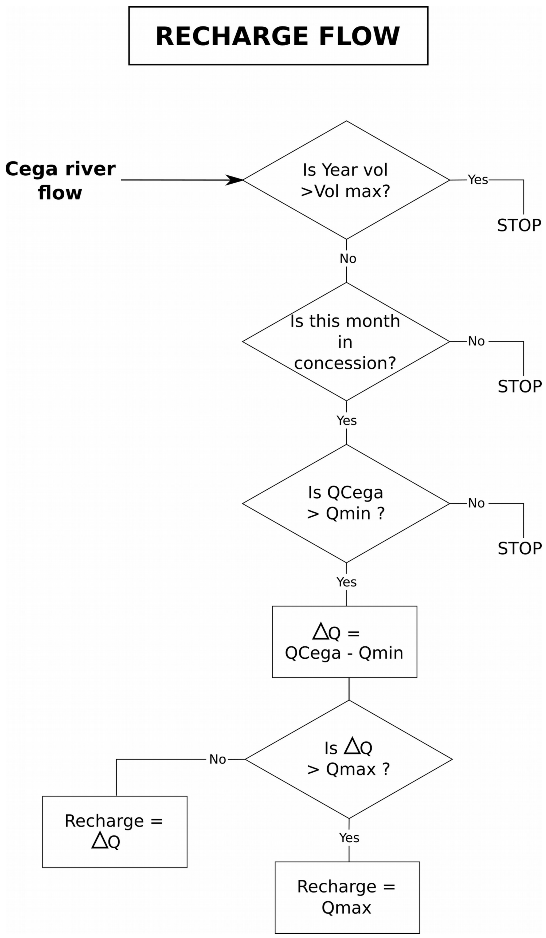


Figure 16.8: Flowchart of the algorithm that calculates water diversion.

The simulation was performed importing historical data (from station 2016) of average daily flow rate for years from 2011 to 2015. Starting from 1/11/2011 of the first available year, first the program checks if the month in question is included among those established by the Concession to derive water. In fact, the program only works with months set by rules for derivation.

Then, in the derivation period, for each day, daily flow is considered. If the daily flow rate is greater than the Minimum river flow, we hypothesize to derive the daily flow minus the minimum river flow.

Moreover, if the difference between daily flow and minimum river flow is greater than the Maximum derivable flow ($Q_m ax$), we hypothesize to derive $Q_m ax$.

At the and of each day, the calculation of the derived volume in that day is performed. The value will be then added to the volume derived in the previous days. At the beginning of the new cycle, first of all it is checked if the maximum volume has been reached. If not, the cycle starts again by considering a new day. Otherwise, the program stops.

16.3.2.2 *Soil Water Balance (SWB) for estimating deep percolation*

In order to calculate deep percolation, the *Soil Water Balance* (SWB) (U.S. Department of the Interior and Survey, 2010) model was used. It was developed in the framework of Groundwater Resources Program by U.S. Department of the Interior and U.S. Geological Survey. This model allows to estimate potential recharge through a modified version of the *Thornthwaite-Mather* soil-moisture-balance.

Recharge is calculated as:

recharge = (precip + snowmelt + inflow) – (interception + outflow + ET) – Δ soil moisture

This model was chosen because it is well suited to being a fast tool, since it needs few inputs, constituted by quite easily available data, both tabular and gridded:

- precipitation, and minimum and maximum air temperature (tabular or gridded);
- land-use classification (gridded);
- hydrologic soil group (gridded);
- flow direction (gridded);
- soil-water capacity (gridded).

Among the outputs, SWB also provides Soil moisture surplus values, defined as "the amount by which infiltrated water exceeds the maximum water capacity of the soil. Under most conditions, the soil-moisture surplus value is equivalent to the daily groundwater recharge value". Thus, it actually constitutes deep percolation.

16.3.2.3 *Inputs: Weather data*

First of all, the model requires to establish one evapotranspiration calculation method from five available. The Thornthwaite-Mather method was selected.

Climate data were provided by the weather station of Gomezserracin. We considered the period from 2011 to 2017. For each year, a text file containing daily climate data was created. Mandatory data are daily Precipitation (Precipit) in inches and Average (TAVG), Maximum (Tmax) and minimum (Tmin) daily temperature in Fahrenheit. Due to the availability of data, we chose to use also Average relative humidity (Avg Rel Hum) provided as percentage, Minimum relative humidity (Min Rel Hum) provided as percentage and wind speed (WINDVEL) provided as meters per second. In Table 16.6, an extract of one of the files containing climate data is provided, as an example.

Table 16.6: Example of weather data to be used as input for the SWB model.

Month	**Day**	**Year**	**TAVG [F]**	**Precipit [in]**	**Avg Rel Hum [%]**
1	1	2011	38.73	0	93.7
1	2	2011	42.03	0	92.9
1	3	2011	37.18	0	87.9
1	4	2011	43.39	0.08	92.3
1	5	2011	47.14	0.24	87.5
1	6	2011	50.29	0.04	85.2
1	7	2011	48.99	0.31	82
1	8	2011	47.73	0.08	76.3
1	9	2011	43.3	0.2	87.6

Day	T_{max} **[F]**	T_{min} **[F]**	**WINDVEL** [m/s]	**Min Rel Hum [%]**
1	46.44	28.35	0.42	86.4
2	46.45	35.22	0.56	79.4
3	45.5	31.24	0.72	67.08
4	46.83	36.21	1.37	87.9
5	53.22	43.93	2.04	73.9
6	54.43	45.73	2.5	76.7
7	53.69	45.37	2.9	65.84
8	52.61	42.84	3.64	60.33
9	48.99	39.22	1.18	67.52

16.3.2.4 *Inputs: Land-use classification*

Gridded input files must be provided as ASCII files. We created them through the use of QGIS. Once the area under examination was selected (the "Zona Almacen", 1236 ha), the four ASCII files were created for this area, with a resolution of 50 m. In order to create the integer grid Land-use classification file we used the land-use map provided by Corine Land Cover (CLC) European project (European Environment Agency, 1985). We decided to use this map instead of the

ITACYL one, since the last one has more specific classes describing the type of crops cultivated. Contrariwise, in this case we were interested in having an overview of all possible land uses.

Moreover, the model uses Land-use classification together with a lookup table containing Curve-number for each land-use type, Maximum infiltration rates for each soil type, Interception storage values, Root-zone depth for each soil group. The code already provides a lookup table containing Anderson Level II land-use classification described by Dripps (2003). The manual suggests that the lookup table provided can be modified or directly re-created. Due to the difficulty in retrieving data for the study area, in the first instance we decided to use the values provided by the model. Thus, classes contained in the CLC map have been made to fall into the more generic classes provided by Anderson Level II land-use classification.

This makes the model more precautionary, since American land-use classes are wider and they do not enter into specifics about which crops are cultivated.

16.3.2.5 *Hydrologic soil group*

Based on soil-type map, the Hydrologic soil group grid file was created by matching one or more texture class with one of the four hydrologic soil groups, from "A" to "D". They are defined on the basis of infiltration capacity. "A"group corresponds to high infiltration capacity, thus to low potential for surface runoff production. On the other hand, "D" corresponds to to low infiltration capacity, constituting the most suitable for producing surface runoff.

Moreover, the model requires the input grid file to be constituted by integers. Thus we attributed to each hydrologic soil group a number ranging from 1 (group A) to 4 (group D).

16.3.2.6 *Flow direction*

The flow-direction grid must be created consistent with the D8 flow-routing algorithm. Since each GIS has its own flow directions codification, we met some difficulties. In fact, Grass numbers directions from 1 to 8, starting eastward and going counter clock-wise. Instead, Arc GIS (suggested by SWB's developers for creating input files), codes directions with multiples of two increasing in clockwise direction. Moreover, SWB considers closed depressions those cell characterized by flow-direction values that are not power of 2. Thus, we translated QGIS codification into Arc GIS one. It was performed with the following sed commands:

```
sed -i -e '8,$s/-//g' FLOW_DIRECTION.asc
sed -i -e "8,$s/ 1/␣128/g" FLOW_DIRECTION.asc
sed -i -e "8,$s/ 2/␣64/g" FLOW_DIRECTION.asc
```

```
sed -i -e "8,$s/ 3/ 32/g" FLOW_DIRECTION.asc
sed -i -e "8,$s/ 4/ 16/g" FLOW_DIRECTION.asc
sed -i -e "8,$s/ 5/ 8a/g" FLOW_DIRECTION.asc
sed -i -e "8,$s/ 6/ 4/g" FLOW_DIRECTION.asc
sed -i -e "8,$s/ 7/ 2/g" FLOW_DIRECTION.asc
sed -i -e "8,$s/ 8/ 1/g" FLOW_DIRECTION.asc
sed -i -e "8,$s/ 8a/ 8/g" FLOW_DIRECTION.asc
```

16.3.2.7 *Soil water capacity*

In order to estimate available water capacity for soil-texture groups, we based on information provided by USDA. For each one of the five soil texture classes identified, Available water capacity (in inches per foot of thickness) values were attributed as detailed in Table 16.7.

Table 16.7: Available water capacity for different soil textures, from *USDA*.

Soil texture	Available water capacity [in/foot]
Sand	1.20
Sandy loam	1.60
Loam	2.20
Clay loam	3.00
Clay	3.60

Hence, through QGis a grid file was created, with an available water capacity value associated to each soil type class.

16.3.2.8 *Limitations of the model*

The Soil Water Balance model undoubtedly has some positive aspects. It takes relatively few inputs compared to other soil-water balance models. This means that it was thought and created to be an expeditious tool.

Anyway, the model has its limitations. If on one hand the model is clearly designed to be an expeditious tool, on the other hand it is not so versatile. It is very rigid with regards to the input data format. Moreover, it is long and cumbersome to change input data. When the model stops, for any reason, a generic error message appears in the log file, without any explanation about the reason or details about the error.

Furthermore, grid input data are expected to be created through Arc GIS. This is at least ethically unacceptable, since the research environment should be completely independent of proprietary technologies. This is even more unacceptable if an open source alternative exists. In this case the open source alternative is constituted by QGIS.

Finally, it may not be that easy retrieving data as Maximum infiltration rates, Interception storage values, Root-zone depth. This would occur especially in rural countries with difficulties in accessing information and technologies.

16.3.3 *Calculation of Carracillo farmers' utility function*

As mentioned above, farmers' utility function is function of agricultural water requirement and of water available for irrigation, thus of water actually available in the sandstone lens.

Hence, first of all the hydrological water balance of the sandstone lens was calculated considering Rainfall, Evapotranspiration, Deep percolation, Agricultural water requirement, Water diverted from Cega. At first, the hydrological water balance was calculated for a reference year. We consider the year from 1/11/2011 to 31/10/2012. Moreover, data required for the hydrological balance calculation are available only for years from 2011 to 2015. In particular, the Land use map was provided for years from 2011 to 2017 (but the series was expanded, as already specified), while daily flow data are available only up to 2015.

Many evaluations assume meaning when computed over several years (to reduce the influence of the peculiarities of each single year). The lens, together with the third phase of the recharge project, is still in design phase, and it is expected for it to be operational starting from 2023 (Arranz, 2019). To be able to advance considerations over recharge effects in the future, the hydrological data from past years was used, under the hypothesis that the overall behaviour of the lens and the zone's climate won't change significantly.

The hydrological balance of the lens was calculated on a daily basis starting from day 1/11/2011. No data regarding its water contents at that date was available, so a starting hypothesis was made, considering it empty at Day 0. This abides to a general precautionary principle, since the only effect of this decision may be to temporarily reduce the value of Carracillo farmers' utility function, nudging the following optimization processes in their favour. Apart from this, during November the irrigation season has already ended, while water has not yet begun to be derived from Cega, so an empty (or almost empty) lens wouldn't be impossible.

We then proceeded to calculate the volume of water in the sandstone lens at the end of a day x as inputs - outputs, in particular:

Volume of water in the sandstone lens on day x-1 + Rainfall + Water diverted from Cega – Evapotranspiration – Deep percolation – Water extracted on day x for irrigation.

Water extracted on day x for irrigation depends on water available in the sandstone lens on day x-1. If agricultural water requirement of day x is less than or equal to the volume of water available in the lens on day x-1, then the agricultural water requirement is extracted. Otherwise, the entire volume of water present in the lens is extracted.

At this point we were able to calculate farmers' daily utility as the fraction of irrigation requirements met by the water extracted. The average value for the year was then calculated considering only the days with a non-zero water need.

17 RESULTS OF COMPARISON AND EVALUATION

17.1 SPI AND FARMER UTILITY FUNCTION

17.1.1 *Weighted optimization*

The main purpose of the model, and of the underlying software, is to assess the conflicting needs of the ecosystem (through the evaluation of services provided by the river) and of Carracillo farmers.

The core of the problem, once the variables at stake have been quantified and a routine for optimization has been established through the definition of an objective function, lies in the attribution of weights.

The Service Provision Index function (eq. 15.1) (Korsgaard et al., 2008) requires the attribution of weights to the considered ecosystem services, in our case *biodiversity conservation*, *tourism and recreational activities* and *water provision for Las Lomas community*.

The choice of different weights might as well have a drastic effect on the results of the optimization, and is as such of the utmost importance. In case of a real-world application of the model proposed here, choosing weights would normally be competence of the decision maker, either a spokesperson for the *CHD* or better yet an assembly of stakeholders, should a participatory design process start.

For research purposes, the effect of two different sets of weights has been investigated. The purpose is here to look for any regularities (such as repeating or similar optimization results) that present themselves regardless of chosen weights. In that case, and in that case alone, some considerations regarding those results could be advanced, since the data would suggest that they are inherent to the problem whichever the considered weights are.

The first set of weights that was considered (hereafter *"Weight Scenario A"* or *WSA*) is an extreme-case choice of uniform weights and corresponds to an uninformed decision about the problem. The second set (*"Weight Scenario B"* or *WSB*) simulates an expert decision through the application of *Analytic Hierarchy Process (AHP)* (Saaty, 2008), and is better detailed in the following. The resulting weight sets are summarized in Table 17.1.

The application of *AHP* is a way of rendering the matter less subjective, even though, according to Saaty (2008):

> Using judgements has been considered to be a questionable practice when objectivity is the norm. But a little reflection shows that even when numbers are obtained

Table 17.1: Weight scenarios chosen in order to look for similarities in optimization results. Weight scenario A corrisponds to an uninformed decision, Weight Scenario B simulates an expert decision through the application of AHP.

Service	Weight Scenario A: uninformed	Weight Scenario B: expert (AHP)
Biodiversity conservation	0.33	0.77
Tourism	0.33	0.05
Water provision	0.33	0.18

> from a standard scale and they are considered objective, their interpretation is always, I repeat, always, subjective. We need to validate the idea that we can use judgements to derive tangible values to provide greater credence for using judgements when intangibles are involved.

17.1.1.1 *Analytic Hierarchy Process (AHP) and weight attribution for Weight Scenario B*

Weight Scenario B tries to simulate the decision process of an expert evaluating the case study. Weights were assigned to the different ecosystem services using the *Analytic Hierarchy Process (AHP)* (Saaty, 2008), performing pairwise comparisons between the services. Two different aspects, and thus two different sets of comparisons were employed:

- *how important* the service is, and
- *how crucial river conservation is* for its satisfaction.

The final weight adopted for each service was the product of the two weights resulting from the comparisons.

Two pairwise comparison matrices were built, as shown in the following Table 17.2, and the relative weights were obtained calculating their principal eigenvectors. In the comparison, *biodiversity conservation* was considered more important than *water provision* (since it only concerns a single community) which in turn is more important than *tourism and recreational activities*. To compare the relative importance of river conservation for the services, Figure 17.1 was observed.

The resulting weights of [0.19, 0.05 and 0.01] were then normalized to 1 for a better comparison with the uninformed choice (*Weight Scenario A*).

17.1.1.2 *Function behaviour under different Weight Scenarios*

Table 17.3 shows the average values assumed by Carracillo farmers' utility function and ecosystem services in the years 2001-2015, to-

Table 17.2: Pairwise comparison matrices for ecosystem services weight attribution, as required by the application of *AHP* (Saaty, 2008).

Dependence on river conservation			
	Water provision	Biodiversity	Tourism
Water provision	1.00	0.11	0.25
Biodiversity	9.00	1.00	4.00
Tourism	4.00	0.25	1.00
Weights	0.07	0.72	0.22
Cons. ratio	0.039		
Importance of the service			
	Water provision	Biodiversity	Tourism
Water provision	1.00	0.33	6.00
Biodiversity	3.00	1.00	9.00
Tourism	0.17	0.11	1.00
Weights	0.28	0.66	0.06
Cons. ratio	0.039		
Weight product	0.05	0.19	0.01

gether with SPI values calculated according to *Weighted Scenario A* and *Weighted Scenario B*. In each case, third-phase concession rules were considered. The same data, shown in a graphic form, is presented in Figure 17.1.

SPI values in WSA are consistently higher than in WSB, and in both cases their average value over the considered period is higher than the value of Carracillo utility. A higher value though doesn't mean anything in itself, since there is no way to directly compare the two different functions.

The average value of biodiversity conservation is 0.23 ($sd = 0.14$), the lowest of all considered functions. In particular, its comparison with the average values assumed by Tourism (0.64, sd=0.14) and Water provision (0.93, sd=0.07) constitutes the reasoning behind the choices made during pairwise comparison in *AHP* for construction of *WSB*.

The consistently high value assumed by the water provision service allows to highlight an apparent paradox in construction of SPI that can only be solved through an accurate attribution of weights. The introduction of another ecosystem service in the SPI would in principle would bring even more importance to the conservation of the river. But if the weights are homogeneous, such as in *WBA*, its effect on the SPI changes depending on the average value that the service has during the years. A service characterized by a consistently high

Table 17.3: Function values for Carracillo utility, ecosystem services and SPI calculated according to third-phase concession rules. SPI calculated using weights from WSA and WSB.

Year	Carracillo utility	Biodiversity conservation	Tourism	Water provision	SPI WSA	SPI WSB
2001	0.25	0.15	0.57	1.00	0.57	0.33
2002	0.45	0.52	0.77	0.85	0.71	0.59
2003	0.39	0.42	0.87	1.00	0.76	0.55
2004	0.22	0.12	0.37	0.83	0.44	0.27
2005	0.37	0.04	0.49	0.97	0.5	0.23
2006	0.46	0.25	0.80	0.99	0.68	0.41
2007	0.35	0.14	0.55	0.93	0.54	0.31
2008	0.38	0.22	0.68	0.92	0.61	0.38
2009	0.39	0.34	0.82	1.00	0.72	0.49
2010	0.34	0.19	0.65	0.85	0.56	0.33
2011	0.14	0.06	0.40	0.89	0.45	0.23
2012	0.45	0.33	0.75	0.99	0.69	0.47
2013	0.45	0.28	0.61	0.98	0.62	0.43
2014	0.38	0.22	0.65	0.85	0.57	0.36
MEAN	0.36	0.23	0.64	0.93	0.60	0.38
SD	0.10	0.14	0.15	0.07	0.10	0.11

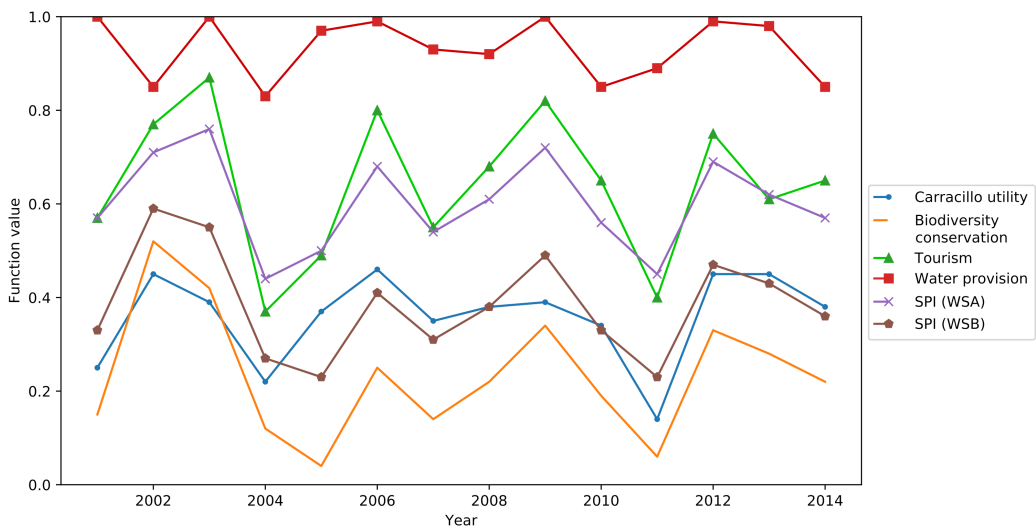


Figure 17.1: Function values for Carracillo utility, ecosystem services and SPI calculated according to third-phase concession rules. SPI calculated using weights from WSA and WSB.

value will inevitably bring the SPI up, so that if this parameter is used to assess river vulnerability, the decision maker may be nudged in the wrong direction. This further explains why, in the *AHP* phase, the difficulty in satisfying a given ecosystem service was considered.

To further compare the results of the different *Weight Scenarios*, let us consider the graphical outputs obtainable from the model.

The function `plotFuncVsParam` produces plots that the values of a function (utility values for Caracillo farmers, or SPI, or a single ecosystem service) to a concession parameter (that can be the minimum flow to maintain, the maximum flow to derive, the period in which to derive), over one or more years. Other parameters remain constant, and are derived from a selected set of concession rules. In our case, the rules corresponding to the third-phase concession.

The trend of SPI against the minimum flow value to be maintained downstream of the derivation is shown in Figure 17.2 for years from 2001 to 2014. The same plot is generated using weights from *WSA* and *WSB*.

A general trend may be identified in the form of a plateau that is reached at variable minimum flow values in each year. This behaviour seems not to be affected by the change in weights, with the only macroscopic difference being the obviously higher values in WSA.

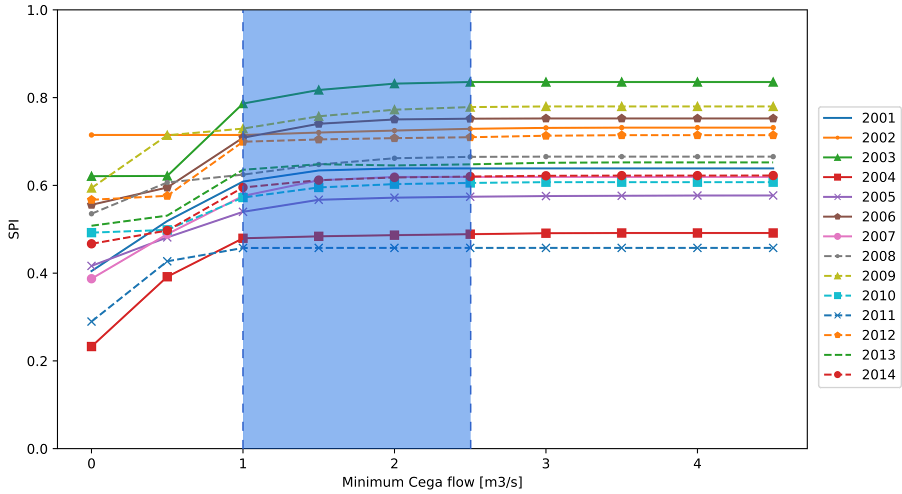
All curves reach a derivative of less than 0.01 for values of the minimum flow contained in the blue-shaded area, that stretches from 1.0 to 2.5 m^3/s.

This behaviour may lead to the consideration that, since the SPI derivative sinks to such low levels after 2.5 m^3/s, one should be very wary of eventual optimization results proposing minimum flows over that value, since practically no benefit would come to the ecosystem in imposing them.

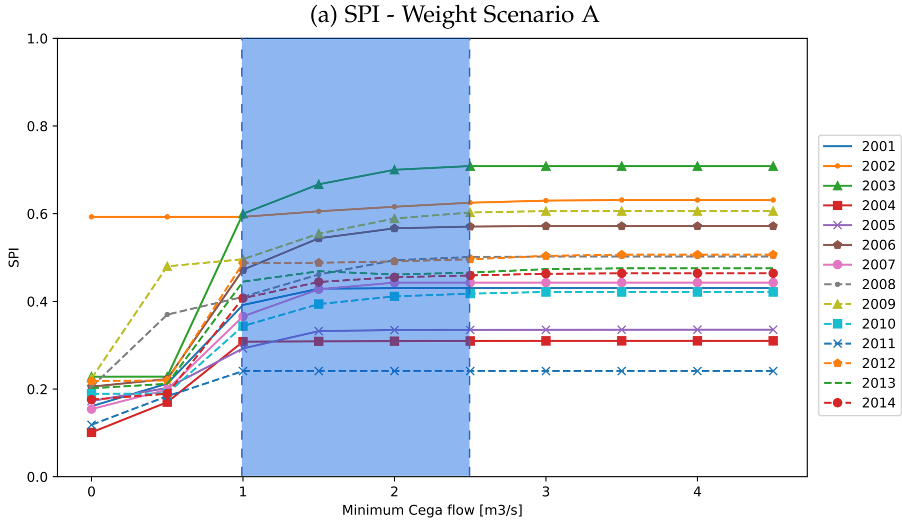
We shall now open a parenthesis to show that an apparent correlation exists between lower function values and years characterized by a lower integral flow in the considered tract of Cega river. In the following Figure 17.3, function values corresponding to third-phase concession rules are compared to the ones for the second phase, in order to better understand the impact that the new regulation will have on both Carracillo agriculture and Cega's ecosystem. The yearly integral flow calculated from gauging station 2016 data is also shown, in order to corroborate the correlation hypothesis that would explain the years in which the new concession has a lesser effect.

Once again, the same graph is proposed for both *Weight Scenario A* and *Weight Scenario B*.

This plot also shows that a different set of weights corresponds to a different evaluation of the impact that the change in concession rules has over the SPI: the shaded area corresponding to it is clearly



(a) SPI - Weight Scenario A

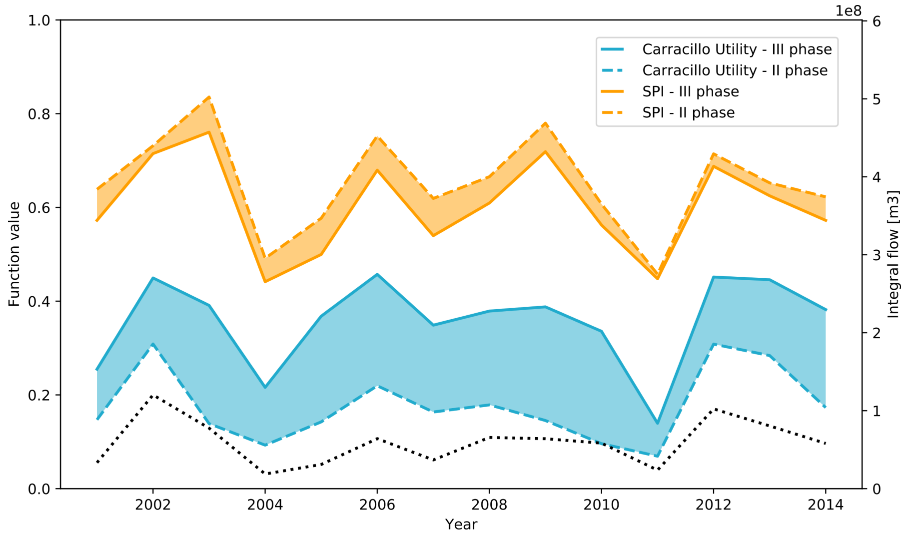


(b) SPI - Weight Scenario B

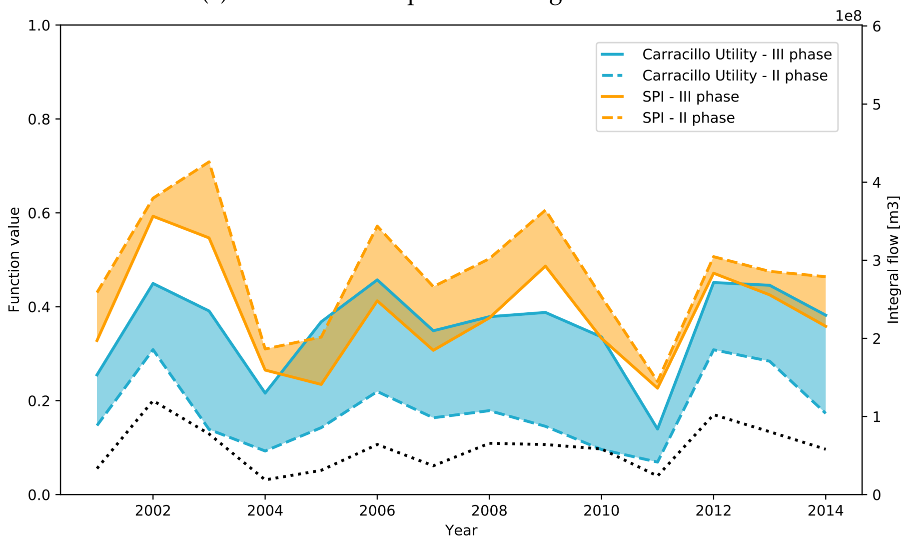
Figure 17.2: SPI functions (years from 2001 to 2014) with increasing values of minimum flow to maintain downstream the derivation. The blue area enfolds all minimum flow values in correspondence to which the curves reach a derivative of less than 0.01.

greater for Weight Scenario B than it is for Weight Scenario A. In this particular case, then, an uninformed selection of ecosystem service weights would have led to an underestimation of the recharge effects on the ecosystem.

Finally, the model allows to produce a graphical visualization of the effect that a variable in the concession rules has over the average value that a certain function assumes over the years. This is done using the built-in `plotAveragesVsParam` function. An example of its use is shown in Figure 17.4 and in Figure 17.5, where the effect of, respectively, minimum flow to mantain downstream the derivation and maximum derived flow is shown over SPI and Carracillo utility



(a) Concession comparison - Weight Scenario A

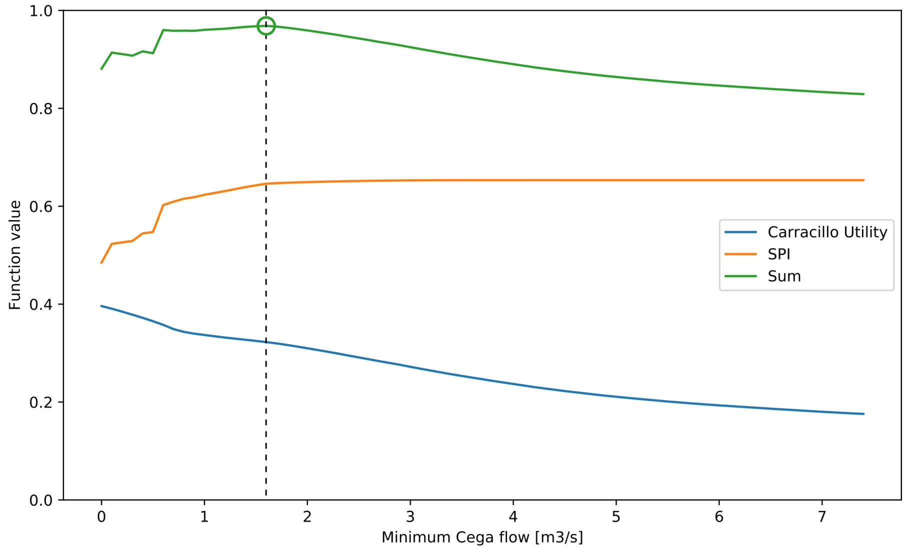


(b) Concession comparison - Weight Scenario B

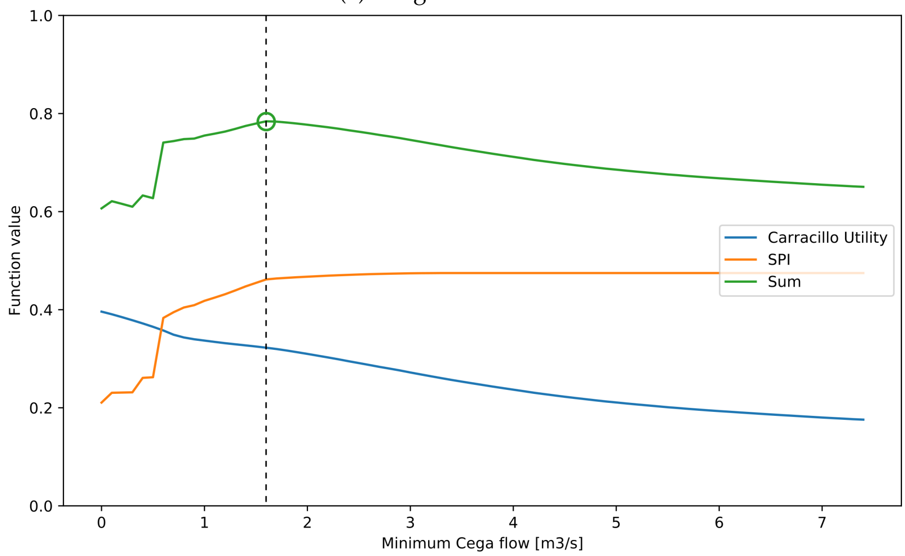
Figure 17.3: Comparison between Carracillo utility function and SPI values for second- and third-phase concession rules over the years. The difference between corresponding curves has been hatched to better show the effect that the new concession will have. The yearly integral flow calculated from gauging station 2016 data is also shown as a black dotted line.

functions. Their sum (the sum of their y-values) is also shown. Its maximum corresponds to the result of single-parameter optimization, as will be better explained in the following section.

Looking at Figure 17.4, a potentially very interesting result shows: the maximum value of the functions' sum seems to correspond to very similar values of the minimum flow. This, if confirmed by the optimization process, would suggest an inherent "optimality" of such a value, allowing us to deem it suitable for a revised set of concession



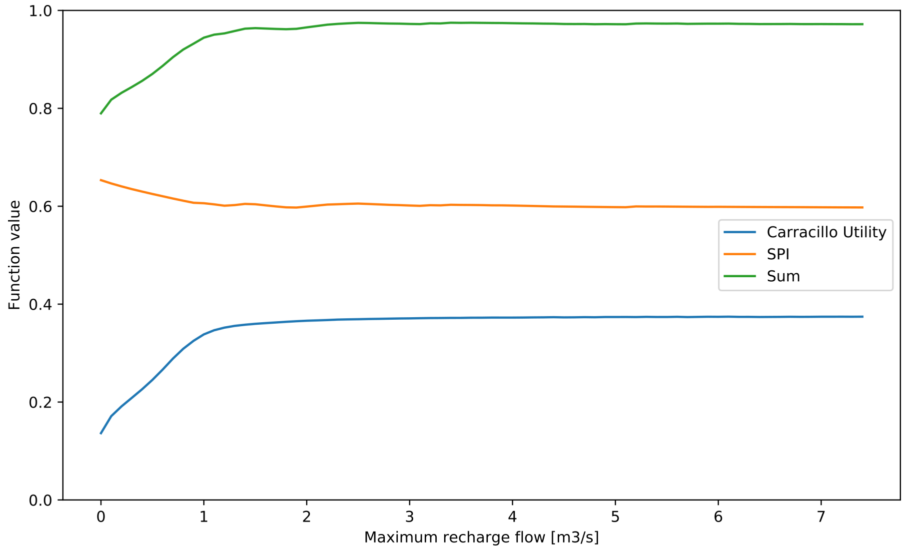
(a) Weight Scenario A



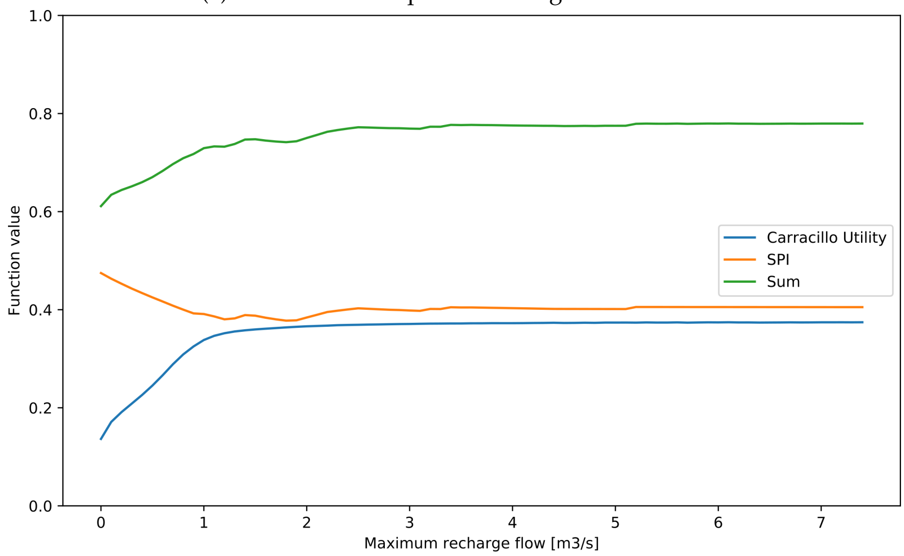
(b) Weight Scenario B

Figure 17.4: Carracillo utility function and SPI values averaged over the years (2001-2017) for different values of the minimum flow to be maintained downstream the derivation. Other concession rules correspond to those prescribed by the third phase of the recharge project. The sum of the two function (the sum of their ordinates) is also shown, its maximum (under the vertical dashed line) corresponding to the result of a single-parameter optimization.

rules regardless of the chosen *Weight Scenario*. Figure 17.5, on the contrary, doesn't allow much speculations. The low value of the slope for the sum of the two functions, however, warns us that any value resulting from the optimization should be verified to ensure that the algorithm didn't choose an unrealistically high flow that only accounts for a marginally higher value of the objective function.



(a) Concession comparison - Weight Scenario A



(b) Concession comparison - Weight Scenario B

Figure 17.5: Carracillo utility function and SPI values averaged over the years (2001-2017) for different values of the maximum flow to be derived from Cega river. Other concession rules correspond to those prescribed by the third phase of the recharge project. The sum of the two function (the sum of their ordinates) is also shown, its maximum corresponding to the result of a single-parameter optimization.

17.1.2 *Ecosystem service provided by pine trees*

It is important to underline, before proceeding with the optimization results, that the ecosystem services that will be negatively impacted by the implementation of the third phase will not only be those related to Cega river. In fact, pines trees provide ecosystem services, both production services and information ones. On the one hand they constitute an important part of the local economy, providing resin and wood. On the other hand, pine management is a secular activity, in which people living in Carracillo region identify and around which people gather.

A study was performed in 2005 (Garcia Vinas and Gomez Sanz, 2005) to assess impacts that implementation of the third phase could have on pines located over the so called *Zona Almacen* (1236 ha). Results show that the use of the aquifer as a receptor in winter and as a source in summer can lead to different negative impacts.

During the artificial recharge phase following effects are likely to be expected:

- increase in the water table and flooding of some areas;
- saturation of the entire soil profile. Prolonged stagnation will lead to physiologic consequences for roots.

During the extraction phase:

- severe depression of groundwater levels and decrease in water availability in soil;
- water stress, especially for those individuals that are closer to the extraction points.

This study confirms what emerged during interviews with *resineros*, since they fear the water stress that could be caused to pines by the cyclic filling and emptying of the sand lens, and at the same time that the excessive rise of the water table could damage roots, causing rot.

The analysis of issues related to pines' ecosystem services is beyond the scope of this thesis, but we felt it useful to provide some data and considerations, to give an idea of which would be the implications for the pines' ecosystem services in the worst case scenario.

About three quarters of the *Zona Almacen* (approximately 927 ha) are covered by *Pinus pinaster*. In the absence of precise data, we hypothesized planting distance of pines to be equal to $5\,\text{m} \times 5\,\text{m}$ circa. This means that on average there are 370,000 pines. In the extreme case in which all pines died, this would cause an economic loss of 1,850,000€ in one year (considering 5€ per tree for the sale of the resin).

A more accurate estimate could be made considering which pines will probably be more affected. According to a study performed by Garcia Viña and Gomez Sanz (2005), these are:

- those individuals located in areas where groundwater level is found at depths less than 2 m (approximately 15% of the occupied area);
- individuals located around the 82 extraction points;

- individuals located into the two infiltration ponds and other natural lagoons;
- individuals grown along canals for aquifer recharge.

Moreover, the uprooted pines for the construction of new forest roads and for the accumulation pond (6 ha) must be considered. After a first approximated count based on technical data provided by the official documents of the project, it emerged that pines located in following areas will be damaged:

- 139 ha where groundwater level is found at depths less than 2 m;
- 183,075 m^2 occupied by new forest roads;
- 61,410 m^2 where the regulation pond will be constructed;
- 11,952 m^2 where infiltration lagoons will be created;
- 40,230 m^2, considering 2m buffer along infiltration canals.

Thus pines trees located on a total area of 168.7 ha are likely to be damaged by third phase implementation. About 67400 pines trees (18% of total pines coverage) would be lost, causing an economic loss of about 337,000€ in one year.

Moreover, only the economic aspect was considered, while the real challenge would be the quantification of other ecosystem services provided by Mar de pinares.

To include ecosystem services provided by pines trees in the model, weights must be attributed to different ecosystem services in order to insert them in the SPI calculation. Though, this part, perhaps even more than the analysis on ecosystem services provided by Cega river, will require a direct involvement of resineros and of people whose everyday life involves this complex ecosystem, which is something that wasn't possible in the limited framework of the present research.

17.2 OPTIMIZATION RESULTS

The optimization algorithm implemented in the software strives to find values for the concession parameters that allow to get as close as possible to what has been defined as the system optimum. This optimization can either be single- or multi-parameter, meaning that one or more of the parameter values can be fixed. The objective function to be maximised is the sum of Carracillo utility and SPI, meaning that the optimum is set in correspondence to the greatest total "*satisfaction*" of the system.

The optimization was performed using, as a basis, values from the third-phase concession. Both a single-parameter optimization focusing only on the value of minimum flow (Q_{min}) and a multi-parameter optimization regarding both the former and the maximum derived flow (Q_{max}).

The results of the single-parameter optimization are presented in Table 17.4. As was expected after looking at the Sum function in Figure 17.4, the resulting optimum for both *Weight Scenarios* is very similar, staying somewhat close to a value of $1.60\,m^3/s$. This suggests, once again, that an inherent advantage comes from setting the minimum flow to be guaranteed downstream the derivation to a higher value than the one prescribed by third-phase concession.

Table 17.4: Minimum flow to be guaranteed downstream the derivation as a result of single-parameter optimization with other parameters equal to third-phase-concession ones. The results, shown for both *Weight Scenario A* and *Weight Scenario B*, correspond to the maximum value of the *Sum* function in Figure 17.4.

	WSA	WSB
Minimum flow downstream the derivation	$1.61\ m^3/s$	$1.59\ m^3/s$

Going now to multi-parameter optimization, it is possible to observe the results in Table 17.5. In this case, the value of the maximum flow that can be derived from river Cega is not fixed, so that the optimum point corresponds to the peak of a three-dimensional surface constructed over the minimum flow and maximum intake plane, with the sum of Carracillo utility function and SPI as z-values.

Table 17.5: Minimum flow to be guaranteed downstream the derivation and maximum derived flow as a result of multi-parameter optimization with other parameters equal to third-phase-concession ones. The results are shown for both *Weight Scenario A* and *Weight Scenario B*.

	WSA	WSB
Minimum flow downstream the derivation	$1.62\ m^3/s$	$1.55\ m^3/s$
Maximum derived flow	$6.83\ m^3/s$	$9.65\ m^3/s$

Once again the optimum for the minimum flow to be guaranteed downstream the derivation, while showing a residual variation between *Weight Scenario A* and *Weight Scenario B*, remains in the closest proximity to the value of $1.60\,m^3/s$.

The results of the optimization for what concerns the maximum flow to be derived require some considerations to be placed in context. First of all, a high value for the parameter is to be expected, and shouldn't surprise when considered from a purely theoretical point of view: once the ecosystem services have all been safeguarded by the imposition of a high enough *minimum flow* value, allowing the derivation of a large amount of water isn't capable of doing much damage, and can only benefit Carracillo farmers, thus rising the value of the Sum function. In a way, allowing the derivation of any flow value while maintaining a minimum flow downstream the derivation wouldn't differ significantly from reducing the overflow with a spillway.

Secondly, it should be noted that the gradient of the two-dimensional Sum function in the direction of the maximum derived flow is always positive but very close to zero after a certain value. This is easily understandable looking at Figure 17.5, where the Sum function in green is nothing more than the product of slicing of the three-dimensional curve. Such a gradient means that, from a purely practical point of view, no tangible benefit comes from choosing a value of maximum derived flow over the one where gradient change happens. The very high values that come from a purely mathematical optimization should be treated as such, as merely mathematical and impractical results.

Finally, since after the derivation water is transported to the lens through an open-channel pipe, it would make sense to restrict the changes to concession rules to only changing the minimum flow value to be guaranteed downstream. This way, no change in infrastructure is necessary.

As a final remark it should be noted how, even though slightly influenced by the chosen *Wheight Scenario*, the optimum minimum flow sets itself in close proximity of a value of $1.60\,m^3/s$. Such a value is much higher than the one prescribed by third-phase concession rules of $0.60\,m^3/s$ (almost three times higher!), suggesting that a renegotiation of the concession should take place, as it would allow to better account for ecosystem needs without too big an impact on Carracillo agriculture.

17.2.0.1 *Optimization with CHD-prescribed environmental flow values*

In a last trial, the biodiversity conservation utility function was calculated using environmental flow values provided by Confederacion Hidrografica del Duero for the hydrological planning cycle 2015-2021, instead of values calculated through Tennant method.

A single-parameter optimization was then performed using the utility function thus obtained. It emerged that the optimum minimum flow calculated for the period from 2001 to 2015 corresponds to a value of $0.67\,m^3/s$ for *Weight Scenario A*, and of $0.84\,m^3/s$ for *Weight Scneario B*. As expected, they are both lower than the value obtained using the biodiversity utility function calculated through Tennant method, but it must be noted that they are both still higher than the value of $0.6\,m^3/s$ imposed by the third phase concession.

Part V

CONCLUSIONS

18 CONCLUSIONS AND FURTHER DEVELOPMENTS

The present work represents an interdisciplinary analysis of a water related conflict. The relevance of this study is attributable to three main aspects:

- it represents a first attempt of analysing two realities whose relationship has never been investigated so far: that of water harvesting and that of water conflicts;
- it confirms the importance of an integrated approach in the design and management of water infrastructures;
- it provides scientific-based technical data that could support the mediation process in the water conflict in Carracillo region (Spain).

In the first instance, this study led to the definition of a framework that identifies anthropic factors as triggering factors of water harvesting-related conflicts. The framework highlights the need for a thorough analysis of the social contest, since restricting the analysis to physical aspects alone can be harmful.

In accordance with what emerged from the literature review that constituted the base for the creation of the proposed framework, anthropic factors also constituted the triggering factor of the ongoing conflict around an artificial aquifer recharge project in the *Carracillo* region (*Duero* basin), in Spain. The recharge project has been implemented since 2000, and involves the derivation of water from a small river (*Cega* river) in order to recharge the Quaternary aquifer in the Carracillo region, overexploited due to intensive horticulture activities.

Difficulties in actually performing recharge, due to Cega river natural conditions, led the *Comunidad de Regantes* to put pressure on the *Confederacion Hidrografica del Duero* in order to modify the current concession and extend the derivation period while lowering the minimum flow value to be guaranteed downstream the derivation.

The lack of a thorough analysis of the impact that the third phase could have on ecosystem services of Cega river triggered a conflict. On one hand, stakeholders who live in close contact with the river, led by environmentalists, are worried about the future of Cega river. On the other hand, Carracillo farmers demand the water that was promised to them when the recharge project was promoted.

For all these reasons the project represented an interesting opportunity to study the consequences of management choices on different social and economic scenarios.

Objectives of the study were an analysis of the social dynamics underpinning the water-related conflict and the creation of a tool to support technical roles in participatory processes in water planning and management. Such a tool would ideally allow the involvement of ecosystem services in the design and planning of a recharge concession, and could be applied both in Carracillo region and in other cases.

The first objective was achieved through stakeholder analysis. 50 semi-structured interviews were conducted, allowing to collect data about knowledge and perception of the recharge project, about other actors involved and about ecosystem services provided by Cega river.

Three main actors with conflicting objectives were identified: export farmers, environmentalists and pine workers. Around these stakeholders the conflict developed. The results of the stakeholder analysis constitute the basis over which the proposed mediation tool, in form of a model of the conflict, was constructed, allowing the achievement of the second objective.

The following part of the study was then devolved to the development and validation of this tool. It combines a hydrological model of the processes related to third-phase implementation, and an optimization algorithm to reconcile conflicting dynamics between agricultural needs of Carracillo farmers and ecosystem services provided by Cega river, which were analytically modelled.

The resulting tool, though far from being a definitive one, presents some interesting characteristics:

- *interactivity and ease-of-use*, which makes it ideal for being used in work tables and in participatory processes. Moreover, its versatility, flexibility and the immediacy of results make it easily usable even by non-experts;
- *modularity*, which allows it to be applied to other case studies. Each part of the software can be modified, new modules can be added and the tool can be developed with the hope that it could be used in as many cases as possible;
- *openness of the source code*: this means that anyone can modify it and make it better. Moreover, it can be used also where there is no possibility to access proprietary paid software.

The model was applied to assess the implementation of the third phase of the recharge project in Carracillo region. This required the acquisition of a large amount of hydrological, meteorological and agricultural data from various sources.

A huge problem encountered during this work is in fact related to data availability. Cega basin is "mysteriously" devoid of a consistent and updated historical flow data series, and years for which there are available flow data upstream the derivation point do not match the years for which data is available downstream. Moreover, there has been no effective monitoring of the derived water, so that it is impossible to know the exact amount of water diverted since the beginning of the project. For what concerns underground water, data related to hydrogeological preliminary studies performed by *Tragsatec* (contractors responsible for the design and realization of the recharge project) are not public. Underground water level monitoring has being carried out by the *Confederacion Hidrografica del Duero* since 2003 through the *Red de control del nivel de las Aguas Subterráneas de la cuenca del Duero*, but the only point present in the Carracillo region only has data for 2011.

Thus it is impossible, for a researcher outside of *Tragsatec*, to have a precise knowledge of the evolution of the aquifer from the beginning of the recharge project as well as of project effectiveness. It is scandalous that a basin affected by such an invasive and important project is left without monitoring infrastructure and that the existent technical data are not open and available to all interested parties.

An environmental impact assessment was carried out by ITACYL in order to evaluate the feasibility of the third phase of the recharge project, due to start its operations in 2023. In it, no mention was made of ecosystem services provided by Cega river, nor an estimate of damages that the implementation of the third phase could cause on pines (which play an important role in local economy) was performed.

The model was then employed to perform an optimization that could lead to a critical assessment of the problem. In particular, optimum values for concession rules, in the form of minimum flow to be guaranteed downstream the derivation and maximum instantaneous intake were investigated. Here a question relative to weight attribution during the optimization problem arose. The objective was then shifted towards an analysis of weight influence, and of eventual results independent of weights.

From the optimization process an interesting result emerged, in the form of an optimum value for the minimum flow to be guaranteed downstream the derivation that is almost three times as large as the one prescribed by third-phase concession rules ($1.60 m^3/s$ against a prescribed value of $0.60 m^3/s$). Moreover, environmental flow values provided by the *Confederacion Hidrografica del Duero* for the hydrologic planning cycle 2015-2021, are less than 10% of average monthly flow, the threshold that, according to Tennant, defines the limit for a riverine ecosystem to be considered alive. Finally, optimization performed involving environmental flow values provided by *Confederacion Hidrografica del Duero* also shows higher results than values prescribed by the concession.

For what regards the continuation of this study, a fundamental step should be represented by a statistical analysis able to provide predictions about impacts that climate change will have on hydrology and hydrogeology of Cega basin.

This information could be included in the model in order to render it even more realistic. In fact, climate change will probably impact deeply the availability of water in the region, so that conflicts could escalate even further. At the same time, atmospheric phenomena will have different behaviours, and this will make it necessary to look for new solutions as well as to improve sustainable land and water management practices.

Furthermore, more ecosystem services should be involved in the model, starting from the ones provided by pines. At the same time, different methods could be tried in order to quantify ecosystem services, also from an economic point of view.

The data collected during this work and related considerations will be offered to local administration in order to facilitate the mediation of the ongoing conflict, by furnishing scientifically based data.

There is hope that this tool encourages participatory management of water resources in the region, while sustaining mediation processes between conflicting parties by facilitating the visualization of the effects of different choices.

Part VI

APPENDICES

A OPTIMIZATION SOFTWARE CODE

A.1 LIBRARIES AND CONSTANT DECLARATIONS

A.2 FIXED DATA

This section comprises import of weather data (rain, evapotranspiration, deep percolation), river data (Cega river daily flow) and data about agricultural water needs. The imported data is then organized into a pandas DataFrame. The function "`makeFixedDF`" calls upon single import procedures to produce such a DataFrame. The import procedures are separated in order for it to be possible to substitute one (for example to account for a different input format) without loss of functionality.

A.2.1 *Cega river daily flow*

A.2.2 *Rain, evapotranspiration and deep percolation*

A.2.3 *Water for Carracillo agriculture*

The water need for agriculture in the Caracillo region is calculated using a table of cultivated species together with their extension, and a table of water needs for each species during different times of the year.

A.2.4 *Creation of the fixed DataFrame*

To speed up calculation, the pandas DataFrame containing imported data has been saved to a hdf5 file, so that there's no need to create it anew each time the notebook is started. When working in Jupyter notebook, the following cell, calling the function to create the DataFrame with imported data and saving it to the hdf5 file, has to be activated (via Cell–>Cell Type–>Code) and then run only if the raw input files have been changed. Otherwise, the cell after that is sufficient, as it loads the fixed DataFrame from the hdf5 file. The same applies to the creation (and loading) of the pandas DataFrame corresponding to no recharge being performed.

A.3 RECHARGE-DEPENDENT DATA

This section comprises functions to compute the lens recharge, the resultant daily flow in the river Cega and the daily value of the utility function for the Caracillo farmers.

A.4 CONCESSION RULES

A.5 CARRACILLO UTILITY AND SERVICE PROVISION INDEX

A.6 GRAPHING

A.6.1 *3D Service curves*

A.6.2 *Functions vs Parameters*

A.6.3 *Functions vs Years*

A.7 OPTIMIZATION

COLOPHON

This thesis was formatted using LaTeX, with the style from package `classicthesis` developed by André Miede and Ivo Pletikosić.