EQUITY AND EQUALITY

in irrigation water allocation under basin closure:

CONCEPTS AND MEASUREMENT

Doctoral thesis, Solveig Kolberg

TÍTULO: Equity and equali ty in irrigation water al location under basin cl osure: concepts and measurement

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EQUITY AND EQUALITY IN IRRIGATION WATER ALLOCATION UNDER BASIN CLOSURE: CONCEPTS AND MEASUREMENT

DOCTORAL THESIS

SOLVEIG KOLBERG

Doctoral thesis submitted by Solveig Kolberg in partial fulfilment of the requirements for the PhD degree at University of Cordoba in Spain, Department of Agricultural Economics, Sociology and Policy. The thesis was supervised by Professor Julio Berbel at the Department of Agricultural Economics, Sociology and Policy and Associate Professor Rafaela Dios Palomares Department of Statistics, Econometrics, Operational Research, Business Organisation and Applied Economics, University of Cordoba, Spain.

CORDOBA, JULY 2012

To Javier & Theresa with love

ABSTRACT

This PhD thesis aims to elucidate the conceptual and methodological ambiguities of equity and equality in irrigation water allocation in the context of scarce water resources, high competition and basin closure. Equity and equality are key water policy and management objectives, although they are often poorly understood. Few efforts have been made to clarify their scope, content and measurement within an irrigation water context. A case study approach was chosen to empirically analyse irrigation inequality in the Guadalquivir river basin. It is an example of a Mediterranean river basin where irrigation uses the lion's share of the water, and the pressures on irrigation water are increasing from within and outside the sector. First, the river basins past developments and its gradual anthropogenisation towards basin closure were explained through a Driving Force-Pressure-State-Impact-Response Framework. Then, a-priori hypotheses related to the impacts and responses of this framework were tested using polynomial regressions and other statistical tools. Next, water inequality and distributional effects of water allocation at basin level were analysed using inequality measures such as the coefficient of variation, Gini coefficient, Theil index, Atkinson index, and Lorenz and Pen's Parade concentration curves. Finally, a decomposition analysis of Theil index was used to investigate the structure of inequality. This proved especially attractive due to its axiomatic properties. A new approach was proposed to deal with aggregated data with different scales and levels. The conclusions of this thesis call for the need for a more clearly articulated policy agenda around the issues of equity and equality in the irrigation sector. The findings of the thesis suggest several courses of action for a more equitable irrigation water allocation in the Guadalquivir river basin. These can be summarized in three main points: i) better definitions, ii) more transparency and iii) monitoring. Inequality measures and concentration curves could be used to empower policymakers, researchers and managers with monitoring meaningful and representative information about water allocation related inequalities for a population, geographic area or socially-defined group and over time. More specifically, these tools could be useful to build water policy scenarios, simulate the impact of alternative policies on water and income distribution, rank policy options and monitor water allocation.

RESUMEN

Esta tesis (Equidad e igualdad en la asignación de agua de riego en condiciones de cierre de cuenca: Conceptos y medida) tiene como objetivo aclarar las ambigüedades conceptuales y metodológicas de la equidad y la igualdad en la asignación del agua de riego en el contexto de recursos hídricos escasos, alta competencia por el agua y cierre de cuenca. La equidad y la igualdad son objetivos clave para la gestión y la política del agua, a pesar de que, a menudo, no se entienden de manera apropiada. Se han hecho pocos esfuerzos para aclarar su alcance, contenido y medición en el contexto del agua para riego. Para abordar el análisis empírico de la desigualdad en el riego se eligió el estudio de caso de la cuenca del río Guadalquivir. Es un ejemplo de una cuenca fluvial mediterránea donde el regadío utiliza la mayor parte del agua, y la presión sobre el agua de riego están aumentando desde dentro y fuera del sector. En primer lugar, los últimos acontecimientos ocurridos en la cuenca del río y su antropogeneización gradual hacia el cierre de cuenca fueron explicados a través de un marco Fuerza Motriz-Presión-Estado-Impacto-Respuesta (FPEIR). Posteriormente, las hipótesis relacionadas a priori con los impactos y las respuestas de este marco se analizaron mediante regresiones polinómicas y otras herramientas estadísticas. A continuación, la desigualdad en el reparto del agua y los efectos distributivos de la asignación de agua a nivel de cuenca se analizaron mediante medidas de desigualdad como el coeficiente de variación, coeficiente de Gini, índice de Theil, el índice de Atkinson, y las curvas de concentración de Lorenz y el desfile de Pen. Por último, se utilizó un análisis de descomposición del índice de Theil para investigar la estructura de la desigualdad lo que resultó especialmente atractivo debido a sus propiedades axiomáticas. Fue propuesto un nuevo enfoque para tratar los datos agregados con diferentes escalas y niveles. Las conclusiones de esta tesis instan a desarrollar una agenda política más claramente articulada en torno a los temas de la equidad y la igualdad en el sector del riego. Las conclusiones de la tesis sugieren varias líneas de actuación para una asignación del agua de riego más equitativa en la cuenca del río Guadalquivir. Estas se pueden resumir en tres puntos principales: i) mejores definiciones, ii) mayor transparencia y iii) mayor control. Los indicadores de desigualdad y las curvas de concentración podrían ser utilizados para capacitar a políticos, investigadores y gestores con información significativa y representativa para el control de las desigualdades en el reparto del agua a una población,

un área geográfica o un grupo social definido, a través del tiempo. Más específicamente, estas herramientas podrían ser útiles para construir escenarios de políticas para el agua, simular el impacto de políticas alternativas para el agua y en la distribución de la renta, priorizar las opciones políticas y controlar la asignación del agua.

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Solveig Kolberg, Cordoba, June 2012

ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AREDA	Asociación de regantes de Andalucía
AU	Aggregation Unit
CAP	The Common Agricultural Policy
CBA	Cost-benefit analysis
CEA	Cost-effectiveness analysis
CEDEX	El Centro de Estudios y Experimentación de Obras Públicas
CENTA	Fundación Centro de las Nuevas Tecnologías del Agua
CHG	Confederación Hidrográfica del Guadalquivir
CU	Crop unit
DAINET	Development Alternative Information Network
DAP	Empresa Pública Desarrollo Agrario y Pesquero, Junta de Andalucia
DEA	Data Envelopment Analysis
DOI	Digital Object Identifier System
DPSIR	Driving force-Pressure-State-Impact-Response
DSR	Driving force-State-Response
EEA	European Environment Agency
EC	European Commission
EASYPol	EASYPol-Resources for policy making, FAO
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FERAGUA	Asociación de Comunidades de Regantes de Andalucía
FWR	Foundation for Water Research
GDP	Gross Domestic Product
GHBP	The Guadalquivir Hydrological Basin Plan
GVA	Gross Value Added
GWP	Global Water Partnership
HBP	Hydrological Basin Plan
ICDRP	International Commission for the Protection of the Danube River
ICWE	International Conference on Water and the Environment
IWMI	International Water Management Institute
IU	Irrigation Unit

IWRM	Integrated Water Resource Management
M	Mean
MAP	Mediterranean Action Plan
MCA	Multi-Criteria Analysis
MIMAM	Ministerio de Medio Ambiente
OECD	Organisation for Economic Co-operation and Development
PoM	Programme of Measure
RB	River basin
RIS	Relative Irrigation Supply
RUW	Rational use of water
SD	Standard deviation
SEMC	Southern and Eastern Mediterranean countries
SEMIDE	Système Euro-Méditerranéen d'Information sur les savoir-faire dans le Domaine de l'Eau
SIWI	Stockholm International Water Institute
SPSS	Statistical Package for the Social Sciences
SWM	Sustainable water management
TAC	Technical Advisory Committee
UN	United Nations
UNCSD	United Nations Conference on Sustainable Development
UNEP	United Nations Environment Programme
WCED	World Commission on Environment and Development
WFD	The European Water Framework Directive
WP	Water productivity
WSM	Water Strategy Man
WTO	World Trade Organization
WUE	Water use efficiency
WWAP	World Water Assessment Programme
WWF	World Wide Fund for Nature

UNITS OF MEASUREMENT

1 hectare (ha) = 10,000 square meters (m^2)

1 cubic meter (m^3) = 1,000 litres (L)

1 cubic hectometre (hm^3) = 1,000,000 cubic metre (m^3)

Rainfall of 100 mm is equal to 1,000 $m^3 ha^{-1}$ or 1,000 tonnes per hectare

STATISTICAL SOFTWARE

R, SPSS, Statgraphics (statistics), Access (database) and Excel (spreadsheet).

THESIS DEFINITIONS OF KEY CONCEPTS

Basin closure: A river basin is said to be closed when there is no longer enough water to meet both the social and environmental needs, and the demand exceeds the amount of water available (Falkenmark and Molden, 2008).

Concentration curves: Curves to chart and examine inequality, Lorenz curves and Pen's Parade are applied in this thesis.

Efficiency: Refers to global technical efficiency and is defined as the product of the application-, conduction-, and distribution-efficiency.

Equality: The state of being equal (Oxford University Press, 2008)

Equity: Refers to being fair, impartial or right judgment (Oxford University Press, 2008).

Fair: Equitable, honestly, impartial, justly; according to rule (Oxford University Press, 2008).

Formal equity: In this thesis formal equity is defined as the distributional criteria that the law and legislation have established as fair, through a public participation process.

Formal water right: The amount of water that an entity is entitled to use or take or divert out by law.

Governance: Defined as 'a neutral concept comprising the complex mechanisms, processes, relationships and institutions through which citizens and groups articulate their interests, exercise their rights and obligations and mediate their differences' (UNDP, 1997).

Groundwater: Groundwater is all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.

Inequality measures: Measures that are either descriptive (focus of this thesis) or normative. Descriptive inequality measures evaluate the dispersion in water allocation by descriptive statistic. Normative measures are derived from some underlying social welfare function (Tsur and Dinar, 1995).

Irrigation: The artificial supply of water to supplement or substitute natural precipitation for agricultural production (Bazza, 2006).

Precipitation: All deposits on the earth of hail, mist, rain, sleet, snow, dew, fog, frost, and dust.

Productivity: Water productivity (apparent) refers to the gross income divided on the gross water allocation (this is also called Water use Economic Efficiency).

Seniority: The seniority of a water right or entitlement as determined by its appropriation date (here: appropriation year).

Surface water: All waters on the surface of the earth found in streams, rivers, ponds, lakes, marshes or wetlands, and as ice and snow.

Water allocation: The process in which an available water resource is distributed (or redistributed) to legitimate claimants (ADB, 2009).

Water scarcity: The relative shortage of water in a water supply system that may lead to consumption restrictions and can be caused by drought or human pressures such as population growth, water misuse and inequitable access to water (SEMIDE, 2012).

Year or period of appropriation: Refers to the year or the time period that the water was first put to irrigation use.

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CHAPTER 1

JUSTIFICATION AND OBJECTIVES

'You won't find a solution by saying there is no problem'

William Rotsler

Chapter 1 gives an overview of the problem and the purpose of the thesis. The chapter is divided in four parts. First, the overall objective is described (1.1), next the justification is presented (1.2), then the specific objectives are given (1.3) and finally, the structure of the thesis is presented (1.4).

1.1 OVERALL OBJECTIVE

'There is enough water for human need, but not for human greed.'

Mahatmi Ghandi

The overall objective of this thesis is to contribute to more fair and transparent irrigation water allocation and to provide decision makers with methodological approaches to measure inequality of benefits and burdens of water allocation in a context of basin closure[1]. This is done through clarification of the concepts related to equitable water allocation and by proposing a way to measure inequality in irrigation water use at basin level with a starting point in perceptions of rational water use and distributional justice.

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[1] *A river basin is said to be closed when there is no longer enough water to meet both the social and environmental needs, and the demand exceeds the amount of water available (Falkenmark and Molden, 2008).*

1.2 JUSTIFICATION

1.2.1 Equity and water allocation under basin closure

'Water is abundant globally but scarce locally.'

Rosegrant (1995)

Equitable water allocation is a major policy and management objective, although it is poorly understood, both, conceptually and methodologically. In a world of emergent scarcity and growing inequality between water 'haves' and 'have-nots', the issues of equitable water allocation and appropriate water management are likely to become two of the most pressing issues in the 21st century (Boelens et al., 1998). Water use is a frequently studied topic that has gained increasing importance in the period since 1990, as some regions, economies and communities ran out of water permanently or temporarily, at least for some uses (Allan, 1996). The last 50 years, the world's population has doubled while the water extraction has tripled. Until the 1990s, and continuing in some countries, there were very little interaction between water use sectors. Instead, the sectors worked independently, with specialists in water supply and sanitation, hydropower, irrigation, flood control and so on (WWAP, 2009). Demographic, economic and social pressures on water ('water drivers') bring more and more basins near closure. Issues of access, including the use and transfer of water between and within sectors, have been subject to a great deal of public attention in recent years. Therefore many of the world's river basins (RBs) are either 'closed' or are 'closing'. At a global scale, about 1.2 billion people live in closed basins, and another 500 million in basins approaching closure (De Fraiture and Perry, 2007).

The irrigation sector is often considered to waste and get a disproportionate share of the water. Nevertheless, irrigation is losing out to other sectors in the competition for water (Molle et al., 2010a). Food production needs immense amounts of water and land and is, by far, the largest consumers of water worldwide. Crops consume about 7,130 km^3 of water annually to meet global food demand. This corresponds to more than 3,000 L per person per day; where of 78% comes directly from the rain and 22% from irrigation (De Fraiture and Perry, 2007). Lack of water constrains food production for hundreds of millions of people (Comprehensive Assessment of Water Management in Agriculture, 2007). When water becomes a major constraint to agricultural production, farmers are likely to respond by intensifying agricultural production, changing cropping patterns and/or introducing more efficient crops, or irrigating crops that previously only were rain fed. The intra-sectorial allocation criteria for irrigation become crucial, as they eventually define who gets what, and consequently, if distribution is equitable and economic efficient. Allocation of deficit water resources is a complex issue that normally increases the potential for conflicts among farmers, between rural areas and cities, and between upstream and downstream. As a result the pressures for fair allocation criteria from both outside and within the sector are increasing. The perceived inefficient use of irrigation water has become less tolerable, and so has its adverse impact on water quality. Many consider that the agricultural sector could contribute more to combat both the water quantity and quality challenges in arid RBs. Water restrictions are overwhelmingly imposed on irrigation, while other activities and domestic supply are only affected in cases of very severe shortage. In closing basins, irrigators have to respond to the challenge posed by both short- and long-term declining water allocations (Molle, 2010a).

Equity in water management appears to be important at all levels. However, the interpretation of the term is often ambiguous, and its impact on water management is not discussed in the professional debate (Wegerich, 2007). Perceptions of basic liberties and procedural and distributive justice are frequently at the core of numerous water conflicts throughout the world (Tisdell, 2003). During the past 15 years there has been a number of studies on community perceptions of fairness and justice in water management and the development of fairness principles (Ibid.). There is currently no system or standard methodology in place to measure water allocation related inequality in terms of inputs and outputs, especially in irrigation water management, and above all at basin level. At the same time, efficient water use is increasingly central to the economic well-being of individual regions and countries facing water scarcity (Livingston, 1995). Equitable and economic rational uses of water are key objectives of most water policies. A rational use of irrigation water, as will be discussed in the next chapter, becomes increasingly important as irrigation water becomes scarce and competition is increasing.

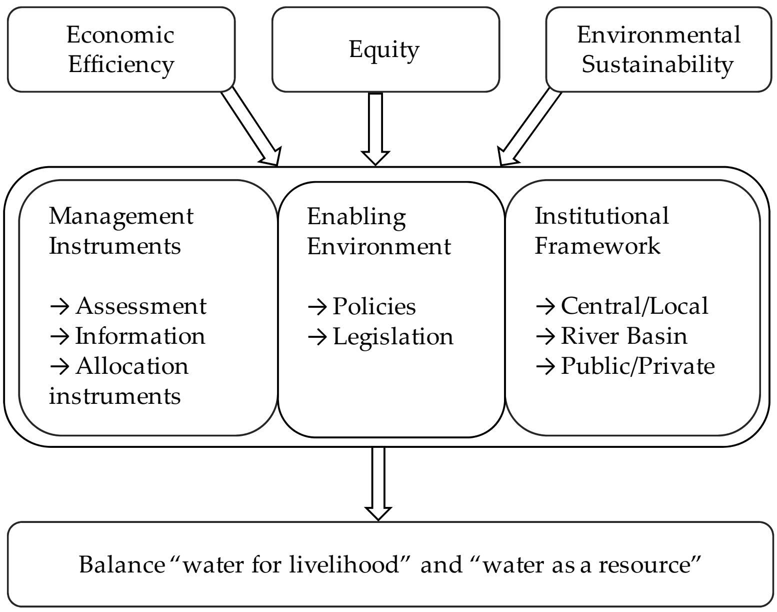
1.2.2 The need to define and measure equity and equality

'IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.'

Definition adopted by The Global Water Partnership, 2001 (Mediterranean Region).

Management of water resources is of vital importance for people's lives and livelihoods, and for society's wealth and economic development. During the 1990s water management was extended to include efficient water use, equitable sharing of benefits, and environmental sustainability. This is referred to Integrated Water Resource Management (IWRM). In 2002, the World Summit on Sustainable Development in Johannesburg the goal was to develop integrated water resources management plans for all countries by 2005 (WWAP, 2009). Equity is the least understood of the 3 E's (equity, economic efficiency and environmental sustainability) in the concept of integrated water resources management Figure 1). It remains a nebulous concept, and little efforts have been made to clarify its scope or content within the water context (Peña, 2011).

Figure 1 The three pillars of Integrated Water Resources Management.



Source: Adopted from UNESCO (2009) cited in the East Asian Seas Congress (2009).

As water scarcity increases and potential conflicts loom, it is crucial to define equity-related concepts at different levels of water management to increase transparency and to facilitate dialogue and water negotiations. The research to date, including the that has been done so far for the implementation of The European Water Framework Directive (WFD), has tended to focus on economic efficiency and environment, rather than equity. Expanding and improving irrigation water use to provide economic benefits to society but it may not necessarily imply that the benefits and costs are distributed equally and/or equitably to all sections of society.

Equity and equality are often used interchangeably, but they are not the same. Equality can be defined as the state of being equal and equity refers to being fair, impartial or right judgment (Oxford University Press, 2008). To date there has been little agreement on the intrinsic meaning of these concepts in the context of irrigation, and the concepts are sometimes used interchangeably in the literature. Water shortage in arid RBs demands achieving 'fair' sharing of available water resources in order to avoid social tensions. Several authors have proposed measures and attempted to measure inequality in irrigation management (see e.g. Sampath, 1988). However, to date there are no standard methods to measure equity in water management. Most of these studies are irrigation scheme level analysis (Table 8, p. 63), different from the current study that takes a basin level approach. Sivramkrishna and Jyotishi (2006) stress the importance of addressing both the distribution of inputs and of outputs. Cullis and van Koppen (2007) argue that there is a need for more case studies on specific basins to develop a better understanding of the relationship between equality in the use of water, the benefits of water use [economic output] and equity under different RB conditions. This case study is basin level analysis of a closed basin, the Guadalquivir RB in Southern Spain.

There is an increasing literature on basin closure (Molle, 2004a; Falkenmark and Molden, 2008; Venot et al., 2007; Smakhtin, 2008; Molle, 2008; Molle et al., 2010b). Most basin closure studies are conceptual and descriptive. They focus on the current situation, and do not provide a detailed picture of 'how we got there' (Molle, n.d.). Moreover, no empirical research has been found that studies basin closure and who has access to the water when closure occurs. This thesis do not only provides a detail picture of how a basin reached basin closure, but it also provides an empirical dimension to basin closure literature (access to water and its outcomes). A Drivers-Pressures-State-Impacts-Responses (DPSIR) framework, a causal system view for describing the interactions between society and the environment, is adapted to a basin closure context to describe the Guadalquivir RB, and to put the results of the hypothesis tested in context. This analytical approach goes beyond the use of indicators that is the most common approach for the DPSIR.

Inequality is related to several mathematical concepts, including dispersion, skewedness, and variance (Hale, 2003). This will be further explained in the following chapters. To date, few studies have applied these measures irrigation inequalities at RB scale. Hereto, inequality measures and concentration curves have mainly been used for income inequality studies, mainly in the field of development economics, though it is applicable to the distribution of whatever resource for a defined population, given that the 'individuals' represents uniform units e.g. irrigators, regions, countries etc. There are few studies of basin closure in a European context, despite the fact, that several basins experiences water scarcity, especially in southern Europe. Often, as in Europe and the Eastern United States, basin closure has come with by severe pollution, because increasing effluent and declining flows have affected the dilution capacity of many rivers and led to wider ecosystem degradation (Molle et al., 2007).

During the last 15 years, areas in the European Union (EU) have faced long lasting drought periods, affecting significantly more people and causing considerably more harm to the environment and the economy than in previous decades. Water scarcity, especially in the Mediterranean, as in the case study of the thesis, is often not only caused by a lack of precipitation. Trends in most European countries, including Southern Spain, where the case study basin is located, indicate that the supply of water to the population is threatened by human pressures, with the result that water ecosystems are undergoing severe processes of quality deterioration (EC, 2002). Water deficits occur as a result of a combination of factors, with overexploitation of water resources a major contributor (Estrela et al., 2000). Typically, the overall water demand in the Mediterranean exceeds the available water resources.

The Guadalquivir RB is located in southern Spain and serves as a case study for the empirical analysis of this thesis. This basin is an example of a closed basin with a typical Mediterranean climate. Agriculture is by far the major water user, accounting for 87% of the water extracted. Moreover, the Guadalquivir RB contains 25% of Spain's irrigated land and the largest river in southern Spain, thus can be considered one of the most important basins in Spain (Giannoccaro et al., 2009; Berbel et al., 2012). The surface of the basin is 57,527 km^3, almost the double of Belgium, and populated by 4.1 million inhabitants, almost the size of the population in Ireland. In the next section the specific objectives of the thesis is presented.

1.3 SPECIFIC OBJECTIVES

This PhD thesis aims to elucidate the conceptual and methodological ambiguities of equity and equality in irrigation water allocation. It aims to present the first empirical analysis of access to water in a closed RB by studying benefits and burdens of prior appropriation[2] in a closed RB. Moreover, it proposes a way to measure and chart basin level irrigation water inequality and distributional effects of water allocation using aggregated data with different scales and levels.

Objective one is generic and objective 2 and 3 are related to the case of the Guadalquivir RB. Hence, the specific objectives are to:

Objective 1: Review the antecedents of rational water use (Chapter 2), and to examine the concepts and the measurement of irrigation equity and equality (Chapter 3).

Objective 2: Describe basin closure through a DPSIR-framework (Chapter 5), and assess empirically the impacts and responses as a function of prior appropriation in access to water in a closed RB (Chapter 6).

Objective 3: Propose an approach to deal with aggregation units of different levels and scales to measure water allocation inequality (Chapter 4). Measure and chart irrigation

[2] *Prior appropriation can be defined as 'whoever first exploits the resource has the right to continue to do so' (Sivramkrishna and Jyotishi, 2006).*

inequality for two water planning scenarios, and study the structure of water allocation inequality (Chapter 7).

Data were taken from the database of the latest irrigation inventory of the Guadalquivir RB (CHG, 2010a), and contained both estimates and survey data for irrigation related variables for year 2008 and predictions for 2015. These data make the baseline for the hydrological planning of the draft Guadalquivir Hydrological Basin Plan (GHBP) (CHG, 2010b) and for aiding in the implementation of the WFD.

1.4 STRUCTURE OF THE THESIS

The thesis is organized to lay out the problem and methods of addressing it.

Chapter 2: A conceptual analysis of rational water use.

Chapter 3: The antecedents of the concepts and measurements related to equity and equality in irrigation. The two chapters are based on theory and literature review.

Chapter 4: The data and the statistical methods for the empirical analysis. Introduction of the statistical methods, polynomial regressions (for Chapter 6) and inequality measures and concentration curves (for Chapter 7) applied. Moreover it discusses validity and reliability of the data and ethics.

Chapter 5: Context and analysis of how the Guadalquivir RB (case study) has reached basin closure using a DPSIR framework for water management at basin level.

Chapter 6: Hypotheses relating access to water in the Guadalquivir RB to the impacts and responses parts of the DPSIR-framework, analysing the importance of seniority in water use.

Chapter 7: Selected inequality measures and concentration curves are applied to explore water allocation and its distributional effects and structure.

Chapters 8: Major findings, implications and recommendations of the thesis.

CHAPTER 2

RATIONAL USE OF IRRIGATION WATER

'Would you tell me, please, which way I ought to go from here?'
'That depends a good deal on where you want to get to,' said the Cat.
'I don't much care where—' said Alice.
'Then it doesn't matter which way you go,' said the Cat.
'--so long as I get SOMEWHERE,' Alice added as an explanation.
'Oh, you're sure to do that,' said the Cat, 'if you only walk long enough.'
Alice's Adventures in Wonderland, Lewis Carroll (1832-1898)

Rational use of water (RUW) is a catch-all term that includes a wide variety of water use dimensions, including equity. It is frequently referred to in water planning, science and the public debate. In spite of this general adoption, the term lacks a unitary conceptual foundation. The aim of this chapter[3] is to provide a conceptual starting point, in order to develop a practical working-definition of RUW in the context of Mediterranean irrigation. A better understanding of commonly used concepts could contribute to facilitating dialogue and water negotiations. In particular, the different levels and dimensions of rationality are given, including equity that will be discussed more in depth in Chapter 3. The chapter is divided into five parts. First, a background on Mediterranean water resources and irrigation is given (2.1). Second, a review of the historical-philosophical background of the concept of rationality is presented, followed by an analysis of the dimensions of RUW on, respectively, a micro-, meso- and macro-level (2.2). Third, several methods and indictors that could be used to define the rational use of irrigation water in terms of efficiency and productivity are presented (2.3). Fourth, and last, a summary is given (2.4).

[3] *This chapter is adapted to this thesis from: Kolberg S., Berbel, J., 2011. Defining rational use of water in Mediterranean irrigation. Options Méditerranéennes, N° A 98, p.11-27.*

2.1 SCARCITY AND IRRIGATION IN THE MEDITERRANEAN REGION

'It is not the quantity of water applied to a crop, it is the quantity of intelligence applied which determines the result - there is more due to intelligence than water in every case.'

Alfred Deakin (1856-1919)

The Mediterranean region comprises the countries surrounding the Mediterranean Sea[4]. The Mediterranean Sea literally means the 'sea between lands'. It is the largest of the semi-enclosed European seas, with shores on three continents (Europe, Africa and Asia). It is surrounded by 22 riparian countries and territories. In 2008, these countries and territories accounted for 5.7% of the world's land mass; 7% of the world's population with 460 million people out of which two thirds are urban; 60% of the population of the world's 'water-poor' countries; 12% of world Gross Domestic Product (GDP); 30% of international tourism with 275 million visitors; and 8% of global CO_2 emissions. Currently, there are 180 million 'water-poor' Mediterranean people (with less than 1,000 m^3 per capita per year of renewable water resources (Morocco, Egypt, Cyprus and Syria). Sixty million are faced with 'water shortage' (less than 500 m^3 per capita per year) (Malta, Libya, Palestinian Territories, Israel, Algeria and Tunisia). These countries to the south and east need 160% of their renewable water resources to meet the 1,700 m^3 per capita per year, deemed to be the minimum threshold of water required to meet, fully, the peoples' needs (UNEP/MAP-Plan Bleu, 2009). The Mediterranean water demand has doubled since 1950 reaching 280 km^3 per year in 2007 (Ibid.). The region includes the most water-scare regions of the world, the Middle East and North Africa. Most aquifers are overexploited; water quality is worsening, and water supply is often restricted affecting human health, agricultural productivity and the environment.

Water scarcity is defined as the relative shortage of water in a water supply system that may lead to consumption restrictions. It can be caused by drought or by human pressures, such as population growth, water misuse and inequitable access to water (SEMIDE, 2012). Water scarcity leads to tensions within communities and migration in search of better opportunities. As the population grows in this region, per capita water availability is

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[4] *Jordan and Portugal are often also considered part of the region though it is not bordering the Mediterranean sea.*

expected to decrease by 50% by 2050, and climate change is predicted to result in more frequent and severe droughts and floods (The World Bank, 2007).

The countries or territories in the region share many common features, including: arid and semi-arid climate with hot summers, mild winters, and wet falls and springs; limited water resources, agricultural development limited by water availability and high socio-economic value of water. In recent years, there has been a growing concern throughout the Mediterranean region regarding drought events leading to water scarcity problems. Here, the semi-arid/arid climate enhances water scarcity and rainfall is the main source of recharge. The competition between various uses, especially agriculture and tourism, is high in this area that relies on both for its GDP. Hence, conflicts over water are increasing, and they are complex, involving competition among alternative uses, among geographical regions with disparate water endowments, and between water resource development and other natural resources lost due to that development. The challenge of water use and allocation is already a major political concern and will most likely amplify in coming years. IWRM is high on the policy agenda and affects people in their daily life. As the water resource is becoming scarce and/or is deteriorating, it becomes clear that plentiful water of good quality can no longer be free to all who desire to use it, and a more in-depth understanding of water resource use and its consequences is needed.

In the Mediterranean region agriculture accounts for 64% of total water use, followed by industry (including the energy sector) at 22% and the domestic sector with 14%. Irrigation water demand varies from 5,000 m^3 ha^{-1} per year in the north to almost twice that much (9,600 m^3 ha^{-1} per year) in the south and east (UNEP/MAP-Plan Bleu, 2009), depending on irrigation techniques, water use efficiency and climate conditions. Irrigation water accounts for over 50% of water use in all countries in the region, apart from those in the eastern Adriatic and France, reaching almost 90% in Syria and Morocco (Annex 1). Crop production is particularly vulnerable to climate change due to predicted deficits in available water resources and threats of farm land degradation. In April 2009, the European Commission (EC) published the White Paper: ‘Adapting to climate change: Towards a European framework for action’ (EC, 2009). This policy paper presents the framework for measures and policies to reduce the European Union’s vulnerability to the impacts of climate change, including specific strategies aimed at agriculture. Most of these measures, at national, regional or local levels, address the regional variability and severity of climate change impact. Several studies show that the efficiency of water use in agriculture is low[5], though some locations and crops have high efficiency and productivity (Berbel et al., 2011a). Still, improvement in water use is crucial for the Mediterranean irrigation. Although RUW is a term that is frequently referred to in water planning, science and the public debate during water scarcity, it continues to be an ill-defined catch-all term that takes in a wide variety of water use dimensions as it lacks an unitary conceptual foundation. The concept is further explained in the next sections, and it is shown how this concept is related to efficiency and equity. Equity will be further explored in Chapter 3.

2.2 RATIONALITY

'The irrationality of a thing is no argument against its existence, rather a condition of it.'

Friedrich Nietzsche (1844 - 1900)

2.2.1 What is understood by rationality?

Rationality normally refers to human or institutional behaviour or situations where decisions are involved. If a chosen action, or mean, is favourable to accomplish a purpose or goal, they are then considered rational, otherwise, irrational. Behaviour, which is arbitrary or random, is normally judged as irrational. Nevertheless, purposes and goals can themselves be judged rational or irrational, with reference to other relevant means-ends relationships.

In economics, sociology and political science, a decision or situation is often considered rational if it is considered optimal, and individuals or institutions are often called rational if they tend to act somehow optimally in achieving their goals. To regard rationality in this manner, the individual's goals, or motives, are taken for granted, and not made subject to criticism, ethics, fairness and so on. Hence rationality simply refers to the success of goal realization, whatever that goal consists of. Sometimes, rationality is equated with behaviour

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[5] *See e.g. Wallence 2000, Rockstrom and Falkenmark 2000 (rain-fed), and Wallace and Gregory 2002 (irrigated agriculture).*

that is self-interested to the point of being selfish. It can be claimed that because the goals are not important in the definition of rationality, it really only demands logical consistency in choice making.

2.2.2 Economic rationality

In a neo-classical economy, individuals' preferences are revealed by the choices they make and efficiency; consistency of choice reflects rational behaviour. The criterion of social interest is usually expressed in terms of the Pareto criterion where a Pareto optimum situation is one where it is impossible to make any individual better off ('more preferred') without making someone else worse off ('less preferred'). Critics to neo-classical theory of self-interested rationality argue that individuals are capable of altruistic acts and that an extended notion of rationality is necessary (Pearce and Turner, 1990). Extended rationality could be understood in terms of multiple preferences rankings by a single individual – one self-interested and the other altruistic (group interested). As a result, moral considerations will then determine a 'meta-ranking' of alternative motivation, where the individuals possess a sense of community reflected by their willingness to view assets and resources as common pool. This extended rationality also generates a strong commitment to abide by particular laws, which are seen by the individual as endorsing an individual's meta-preferences, despite a potential conflict between the law and the narrow-self interest (Ibid.). Thus, a choice is rational if it is consistent with the objectives and preferences of those making the decision, given the available information.

An allocation choice is economically rational if it is seen as yielding a benefit that exceeds the opportunity cost. In other words, when a choice is made among competing options that are anticipated to yield net benefits that exceed the opportunity cost. When a scarce resource, a good or a service is allocated to one use, the opportunity cost of that allocation represents the value of the best alternative that was foregone. From an economic perspective, individuals are usually considered having perfect or at least bounded rationality. That is, they will always act in a rational way and are capable of complex deductions towards that end. That is to say, they will always be capable of thinking through all possible outcomes and choosing the best possible thing to do (full information).

Economic rationality is closely related to economic efficient use of water. Herbert Simon introduced the term bounded rationality in the 1950s to designate rational choice that takes into account the cognitive limitations of both knowledge and cognitive capacity (See Simon, 1982). Hence, theories of bounded rationality relax one or more assumptions of classical utility theory. Bounded rationality is an important theme in behavioural economics, and it is related to how the actual decision-making process influences decisions. Kahneman and Tversky (1979) developed the prospect theory, which can be seen as an alternative to expected utility theory and aims at modelling real-life choices, rather than optimal decisions. In summary, this theory claims that people's attitudes toward risks concerning gains may be quite different from their attitudes toward risks concerning losses. Though this is not necessarily irrational, it is important for analysts to acknowledge the asymmetry of human choices.

2.2.3 Rational use of irrigation water

'The largest single consumer of water is agriculture – and this use is largely inefficient. . . As much as half of all water diverted for agriculture never yields any food. Thus, even modest improvements in agricultural efficiency could free up huge quantities of water. '

Gleick (2001)

Water demand management under scarcity is challenging. Improved performance in water use and water saving is key to meet the general objectives of economic efficiency, environmental conservation and equity in terms of community/consumer satisfaction. Socially, efficiency looks after the interests of future generations; environmentally, sustainable use of water ensures good ecological status and minimum flows; and economically, water efficiency reduces business costs and defers costly investment in water supply development and sewage treatment capacity expansions. Water policy should be designed in a way that reduces the conflict level between competing uses and ensures environmental sustainability. RUW's operalization depends upon academic field, stakeholder groups, level of operation and the interdependence between these levels.

To define RUW for the irrigation sector, three different levels of analysis are considered critical:

- Micro-level (household, farm and community);

- Meso-level (infrastructure, institutions, RB); and
- Macro-level (legal, national and international policy).

On a micro-level, which includes household, farm and community, the main objective entails water productivity and efficient use of water; on a meso-level (infrastructure, institutions, RB), the main goal to achieve territorially and socially efficient and equitable allocation of water and to reduce conflicts among competing uses, while on a macro-level (legal, national and international policy) sustainability, regional development and food security are core objectives. Table 1 attempts to give an overview on rationality at different levels for the sector of irrigated agriculture, and the next section give more in depth analysis of each level.

Table 1 Micro-, meso- and macro-levels of rational use of water (RUW) in irrigated agriculture

	Type	Field of Research	Rationality	Research objective
MICRO	Crop	Physiology/agronomy	Optimal use of water	Water efficiency & productivity, drought tolerance
	Plot or Field	Agronomy/hydrology	Maximize resources productivity	Efficiency of irrigation systems & crop management, i.e. minimising losses, maximize technical efficiency
	Farm & household	Agronomy/crop level economy/social science	Optimal crop management plan, individual households preferences & capabilities in the allocation of productive assets	Livelihood strategies, especially profit maximization & risk minimization.
MESO	Scheme	Agricultural Engineering	Technical and economical	Irrigation efficiency & cost minimization
	Basin	Socio-economic & environmental science	Economical, social, environmental, territorial, cultural (water rights) & regional.	Efficient & equitable water allocation, hydrological models (basins and aquifers), conflicting environmental & socio-economic objectives
	Institutions	Social science	Social efficiency	Maximize the present value of stakeholders benefits, public choice models, conflict resolution
MACRO	Country	Socio-economic policy	Economic & social allocation	Transfer conflict alleviation, food security, maximize economic & social welfare, regional development
	International	International policy	Political consensus	Fairness, ethics
	Planet	Sustainability/climate change	Ethics & comparative advantages	Global sustainability

Source: Author's elaboration.

Many vital socio-cultural and environmental benefits cannot be monetized, and these would have to be taken into account in order to judge what Barbier (1990) calls the 'social efficiency' of the system.

2.2.3.1 Micro-level

At field and community level, many consider water to be a main production factor, and RUW is often closely linked to the efficiency and productivity of water. *Efficiency* generally refers to the condition of minimal waste (Hackett, 1998) and *productivity*, is a ratio referring to the unit of output per unit of input (Kijne et al., 2002). The term water efficiency was probably first introduced by Viets (1966). In economic terms, a ratio between a desired output (yield, economic returns) and a parameter estimating input use is considered. However, because of the different connotation attached to the term 'efficiency', some authors claim that it has outlived its usefulness (see e.g. Seckler et al., 2003). Economists refer to total factor productivity as the value of output divided by the value of all inputs. However, the concept of partial productivity is widely used by economists and non-economists alike. Water productivity can be expressed in general physical or economic terms as follows (Seckler et al., 1998):

- Pure physical productivity: quantity of the product divided by the amount of water depleted or diverted.
- Combined physical and economic productivity: either the gross or net present value of the crop divided by the amount of water diverted or depleted.
- Economic productivity: gross or net present value of the product divided by the value of the water diverted or depleted, which some authors define in terms of its value or opportunity cost in the highest alternative use.

Zoebl (2006) argues that the term water productivity is not always meaningful or appropriate to use and should be reserved for genuine production factors such as labour, land and capital. Furthermore, in contrast to fertilizers, pesticides and animal feeds, irrigation water is generally not a purchased input provided by individuals or corporations (Zoebl, 2002). He claims that irrigation efficiency and water use efficiency still are useful and meaningful terms, under the condition that they are well defined, and used at the level of individual farmers (Zoebl 2006). Alternative concepts have been introduced in recent years, e.g. consumed fraction (Willardson et al., 1994); beneficial and non-beneficial depleted or consumed fractions (Perry, 1996; Clemmens and Burt, 1997; and Molden, 1997). These new terminologies are used in the context of water accounting relating to the engineers' view of 'efficiency', though the definition and interpretation of these new terminologies still remains to be widely understood.

Areas of arable land and permanent crops stabilized, if not declined, from 1961-2005. The annual average growth rate for irrigated land remained unchanged, thus increasing the proportion of crop land irrigated. The total irrigated area in the Mediterranean countries has doubled in 40 years and exceeds 26 million hectares in 2005, corresponding to more than 20% of all land under cultivation. Albeit total agricultural production in the Southern and Eastern Mediterranean countries (SEMCs) has made a huge progress over the past 40 years through improved forms of production; yet, these countries are more and more dependent on secure food supplies (UNEP/MAP-Plan Bleu, 2009).

According to the neoclassical definition of externalities, most irrigation sector-related water problems stem from situations where clear misalignments exist between farmers' private objectives and more general social objectives. The presence of divergences between private and social objectives is manifested by various trends. One is the widening of the divergence between farmers' low water marginal productivity in irrigated commodity production (except for the case of high-value crops) compared to the industry and the costs incurred by society for making the resources available to them. Another is the issue that the water costs of competing users (urban, industry, aquaculture etc.) may be rising as a result of farmers' water use or polluting practices. The manifestation of adverse incentives is perceived through time and not with snapshots. This implies that policy judgments should preferably be based on whether observed trends show improvements or are worsening, however, consistent time-series data are often difficult to obtain.

2.2.3.2 Meso-level

At meso- or intermediate-level, structures, institutions and RB are considered. Irrigation systems in many countries will more and more need to find ways to improve performance as the pressure on available water resources increases. The need to improve irrigation and drainage sector is driven by several factors (Malano et al., 2004):

- Population growth leading to a need for higher yields in agricultural production
- Increasing water scarcity within RBs leading to a need for irrigated agriculture to produce 'more crop per drop'
- Higher expectations from farmers and their families to improve their livelihoods
- Higher expectations by farmers of the level of service provided by the irrigation and drainage agency
- Changing perceptions, attitudes and practices within government on the provision of public services.

In addition, the increased emphasis by society on environmental and sustainable goals demands higher RB quality standards. Farmers engage in irrigation for securing their basic needs, which include earning income. However, their activities depend greatly on their access to land, labour, water, markets, knowledge and capital, which are the main resources in irrigated agriculture. Within any given culture, access to resources varies according to gender, age, wealth, caste and ethnicity, and so does livelihood.

When water is locked into uses that are no longer high-value, inefficiency abounds; when the distribution of the resource use cannot adapt to changing economic conditions, conflicts increases. Many parts of the world treat water as a free resource. Accordingly, no charge is imposed for withdrawing water from a surface or groundwater source. The users only pay costs that occur from the source to the place of use (including storage, distribution and management costs), and occasionally for the treatment of the water, and disposal of the return flows. Traditionally, restrictions in many areas have limited or banned the possibilities of water users to trade or sell their water rights. Water rights systems in many places have allocated water rights based on historical claims. Traditional water rights systems often gave many water users a low incentive to increase their water use efficiency, particular for those with historical rights. The introduction of water markets could allow water users to sell the unused share of their water rights to another user, providing an incentive to improve the efficiency of their water use (Schoengold and Zilberman, 2004).

The empirical part of this thesis (Chapter 6 and 7) will particularly address the meso-level, i.e. basin level water allocation. Water allocation can be defined as the process in which an available water resource is distributed (or redistributed) to legitimate claimants (ADB, 2009).

2.2.3.3 Macro level

'Let not even a small quantity of water that comes from the rain go to the sea without being made useful to man.'
King Parakramabahu of Sri Lanka (1123-1186)

At the macro level, international and national policies determine resource availability and distribution, such as water resource policies; international funding and loan agreements; legal arrangements, etc. A policy can be Pareto efficient compared to the status quo when it makes some people better off and nobody worse off. In contrast, a proposed policy is potentially Pareto efficient compared to the status quo when it generates net social benefits that could potentially be used to compensate those made worse off. In year 2000, the European Union[6] adopted the WFD as a response to the numerous, and increasing, pressures on European water resources (EC, 2000). The WFD is probably the most ambitious effort for a common integrated management of natural resources in the EU (Berbel and Gutiérrez, 2004), because it urges that 'good ecological status' must be achieved for all European waters by 2015. WFD proposes regulating the use of water and associated areas on the basis of their capacity to withstand different kinds of pressures and impacts. It thus intends to promote and guarantee a responsible, rational and sustainable exploitation and use of the environment (EC, 2000 - L327/2):

> *As set out in Article 174 of the Treaty, the Community policy on the environment is to contribute to the pursuit of the objectives of preserving, protecting and improving the quality of the environment, in prudent and rational utilisation of natural resources, and to be based on the precautionary principle and on the principles that preventive action should be taken, environmental damage should, as a priority, be rectified at source and that the polluter should pay.*

Other international agreements include The Millennium Development Goals (safe and sufficient water); and Agenda 21 as follows:

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[6] *Norway and Switzerland have also committed to the WFD.*

…to plan for the sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of national economic development policy.

In most international agreements, rationality is strongly linked to sustainability. A community's control and prudent use of natural, human built, social, and cultural capital fosters economic security and vitality, social and political democracy, and ecological integrity for present and future generations. Ecological sustainability more narrowly focuses on maintaining and enhancing ecological integrity and biodiversity, and generally on protecting the life-support and waste-sink functions of the earth. The most often quoted definition of IWRM has been developed by the Global Water Partnership (GWP) (GWP-TAC, 2000):

…a process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

This definition has been criticized as very limited for practical guidance to present and future water management practices, though all encompassing and impressive (Biswas, 2004). To improve the theoretical framework for policy considerations and methodology on water use, analytical frameworks such as the logical framework analysis and sustainable livelihoods analysis could potentially be used. The logical framework approach is a management tool mainly used in the design, monitoring and evaluation of international development projects, while livelihoods analysis provides a framework for research and policy that takes into account the complex and multidimensional relationships between the social and physical environments.

2.3 MEASURING IRRIGATION EFFICIENCY AND PRODUCTIVITY

'Efficiency is intelligent laziness''
Unknown

2.3.1 Irrigation and hydrological cycle concepts

'In truth, the story of water almost everywhere involves abuse, waste and even tragedy.'
Peet John, The Economist (2003)

'Irrigation' can be defined as, the artificial supply of water to supplement or substitute natural precipitation for agricultural production (Bazza, 2006). 'Precipitation' can be defined as the release of water from the atmosphere as rain, snow or hail (FWR, 2012). Generally the rainy season over the Mediterranean Sea extends from October to March, with maximum rainfall taking place November to December. The average rain rate is ~1–2 mm day^{-1}, but during the rainy season, there is 20% more rainfall over the western than that over the eastern Mediterranean Sea (Mehta and Yang, 2008). Precipitation is also a critical variable to evaluate regional and global water supplies and time variability. It characterizes the input of water into the entire hydrological system that is important for a variety of models, including climate, weather, ecosystem, hydrological and biogeochemical models.

The 'renewable water resources' can be estimated on the basis of the water cycle. They represent the long-term average annual flow of rivers (surface water) and groundwater, while non-renewable water resources are groundwater bodies or deep aquifers that have a negligible rate of recharge on the human time-scale and thus can be regard as non-renewable. 'Surface water' can be defined as inland waters, except groundwater, which are on the land surface (such as reservoirs, lakes, rivers, transitional waters, coastal waters and, under some circumstances, territorial waters) which occur within a RB. 'Groundwater' can be defined as all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil. This zone, commonly referred to as an aquifer, is a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow a significant flow of groundwater or the abstraction of significant quantities of groundwater (FWR, 2012). The transpiration ratio, applicable to crop production, was introduced by Van Helmont (1579-1644). The transpiration ratio represents the amount of water a crop use to reach a certain weight, and it is the term that later led to the concept of water productivity, or the 'crop per drop' slogan (Zoebl, 2002). Potential transpiration, introduced by Penman in 1948 (Ibid.), is the water loss from an extended surface of a short green crop actively growing and completely shading the soil, and never short of water. This is applicable to crop and field level. Evaporation is the transition from a liquid to a vapour state. The actual and potential evapotranspiration is the net water loss (in vapour form) per unit area of land, both directly from the land surface, and indirectly through transpiring leaves. Evapotranspiration is applicable to crop and field level and is the sum of evaporation and plant transpiration. The term was introduced by Thornthwaite in 1944 in response to irrigation engineers who did not distinguish between actual and the so-called potential evapotranspiration. However, this difference became less important from the 1960s onwards, after Penman's formula became the established way to calculate crop water needs by irrigation engineers globally (Ibid.).

In order to develop standards, it is important to take into consideration: i) examination of long time series of past-to-present hydrological data (including palaeodata and proxy data, especially for droughts and floods); ii) projections into the future (running hydrological models fed by scenarios resulting from climate modelling, and in particular regional climate models, via downscaling); and iii) extreme hydrological events such as floods and droughts, which must be monitored. In view of population growth and the immediate impacts of changes in the water cycle, it is estimated that by 2050 about 290 million people in the SEMC could end up in a situation of water scarcity (Blue Plan, 2008). When considering uncertainty, it is necessary to identify critical gaps in knowledge related to climate change and water, as well as interlinked issues of the global environment change. According to Kundzewicz and Mata (n.d.) the existing gaps include, among others:

- Scarcity of geophysical data, with sufficient accuracy and spatial and temporal coverage;
- Scarcity of socio-economic information;
- Poor validation and integrated interpretation of proxy data;
- Low credibility and accuracy of hydrologically-relevant outputs from climate models;
- Low credibility and accuracy of downscaling schemes;

- Lack of development of climate models for hydrological forecasting; and uncertainty in results related to extremes - floods and droughts (frequency, intensity, persistence, spatial extent).

Available water resources are those stored in lakes and reservoirs and those extracted directly from wells and streams and rivers (dependent on climactic variability) minus several constraints imposed according to basin specific conditions mainly related to environmental demand and safety storage in reservoirs.

2.3.2 Methodological approaches and measurement

Most governmental agencies, international bodies (e.g. Food and Agriculture Organization of the United Nations, FAO) and research institutions set efficient management of water in the agricultural sector as the main target for irrigation. Efficient management is measured as 'more crop and value per drop' and recently 'more jobs per drop'. These targets are based upon measuring water use efficiency as a ratio of the desired output (physical, economic or social) compared to consumed input. Nevertheless, the application of this intuitive concept should be done with precaution. The terms 'water use efficiency' (WUE) and 'water productivity' WP) has been loosely used to describe a number of water use indicators, and irrigation efficiency ratios. Irrigation is frequently said to have a high potential to achieve efficiency gains in the Mediterranean region. This is due to current low efficiency of use compared to the generally high value of water that should lead to investment in water saving technologies. However, improving efficiency in irrigation to alleviate meso- and macro- level water scarcity may not be as significant as one might have thought. The explanation is that many of the frequently used concepts of water use efficiency systematically underestimate the true efficiency (Seckler et al., 2003). For example, not all water allegedly 'lost' from a farm or irrigation district, in fact, represent a loss to the hydrological system, as the water returns to the hydrological system, either surface or groundwater. Losses to the system are strictly losses to the sea, losses through evaporation from e.g. canals, transfers or water being severely polluted. Therefore, how water is defined and at what scale is referred to is critical to management and decision making. In general terms, irrigation efficiency is defined as the ratio of water consumed to water supplied, and water productivity is the ratio of crop output to water either diverted or consumed, the ratio being expressed in either physical or monetary terms or some combination of the two.

Seckler et al. (2003) distinguish between 'classical' and 'neoclassical' concepts of irrigation efficiency. Classical irrigation efficiency can be defined as the crop water requirement (actual evotranspiration minus effective precipitation) divided by the water withdrawn or diverted from a specific surface water or groundwater source. The classical concepts of irrigation efficiency ignore the reuse and recycling of water and thus tend to underestimated real basin efficiency while the newer neoclassical concepts such as e.g. net efficiency, effective efficiency and fractions (see e.g. Seckler et al., 2003) aim to take into account real water losses. The level at which efficiency is measured is quite a relevant decision. Table 2 shows definitions of water productivity by crop, farm and basin level.

Table 2 Crop, farm and basin level water productivity definitions

Water productivity	Definitions
Crop water productivity	Crop water productivity or 'crops per drops' can be defined for different crops by comparing the output per unit of water input(*). 'Output' may either be in physical (usually measured in kg) or monetary terms. The amount of water depleted is usually limited to crop evapotranspiration (measured in m^3). Two examples: (i) Smith (2000): Yield (tc) / Transpiration (mm); (ii) Kassam and Smith (2001): Crop yield/water consumptively used in evapotranspiration. Here, crop water productivity may be quantified in terms of wet or dry yield, nutritional value or economic return.
Farm productivity	The use of water in a farm as a system implies a different level of productivity compared to individual crop productivity as the considerations of other constraints (land, labour, machinery, financial, risk) may influence the optimal allocation of water in a crop mix. Water may be a constraining factor during some months and may not be scarce in others.
Basin productivity	Takes into consideration beneficial depletion for multiple uses of water, beyond crop production, including the environment. Here, the problem lies in allocating the water among its multiple uses and users. Priority in use involves the value judgement of either the allocating agency or society at large and may be legally determined by water rights.

Note(*): Some authors define 'total water productivity' by including also effective precipitation water, but this research focus on apparent irrigation productivity and the discussion on 'green' and 'blue' water is outside the scope of this thesis. Source: Authors elaboration.

The use of physical measures of the output is easier to apply than economic definitions of 'value'. Young (2005) criticizes the frequent use of 'value added' or 'total production' for measuring socio-economic benefits of water use, opposing OECD (Organisation for Economic Co-operation and Development) recommendations (see Bergmann and Boussard, 1976, p. 59). The concept of added value (or total value of production) may lead to misleading results since 'value added' comprises of several factor incomes (labour, capital etc.). Hence, the choice of the economic indicator, should be taken with precaution corresponding to the level of analysis (micro, meso, macro) and that, in general, the selected variable should be a value generated by the water use.

When economic analyses are done at a meso- and macro-level, priorities in use may include objectives of rural development or social or territorial equity that may be in conflict with maximizing economic efficiency and diverting water to the most productive location and sectors against more traditional crops and less favoured areas. Therefore, the macro level concept of efficiency may consider social targets (such as more jobs per drop) that are not necessarily compatible with the pure economic definitions (more value per drop). The key issue in defining efficiency and productivity indicators is related to answering the following questions, which are closely related to the level of analysis (micro, meso or macro-level):

- Who is the decision maker (the farmer, the public administration, etc.)? What are the decision making objectives (profit, employment, risk reduction, etc.)?
- What are the limiting resources (land, labour, capital, water, etc.)?
- How is the decision making model put together (data quality and availability, time-span, etc.)?

Generally, water efficiency and productivity are defined in the literature in relation to micro- and meso-level. These definitions are single dimensional, and the authors give a list of output ratios (economic, physical, etc.) versus inputs (water, fertilizer, etc.). This thesis makes use of ratios that are generally used to measure irrigation efficiency and apparent productivity. Nevertheless, there are more complex definitions and methods that take into account more than one objective, e.g. multi-criteria analysis (MCA), and analysis based upon the combination of various inputs in order to give one or more outputs, such as the Data Envelopment Analysis (DEA). For a complete review of MCA in irrigation economics, see Gomez-Limon et al. (2007), regarding DEA, see e.g. Malano et al. (2004). Other attributes of the problem, such as irreversibility, equity, minimising uncertainty, etc. may also be introduced in the analysis. Cost-effectiveness analysis (CEA) and cost-benefit analysis

(CBA) could also be considered. The cost-effectiveness approach is in WFD considered an instrument for management and planning, when formulating the program of measures, to be implemented in the European RBs (Berbel et al., 2011b) and could be relevant to all scales (local, RB, national).

All the above mentioned methods (MCA, DEA, CEA, and CBA) imply further complexity of the analysis of efficiency. For these methods, the concept of bounded rationality (Simon, 1982) may be set as a common ground, so that instead of an 'optimum' solution, the aim is to find a 'satisfactory' solution between different and conflicting objectives. A farmer, when deciding on water allocation to crops, may be interested in maximizing profits and minimizing risk, or minimizing cost of labour. A solution to this multi-criteria problem needs to be analysed under multi-attribute utility. The result may be that the revealed solution may look non-optimal (non-rational) from the single profit maximizing hypothesis. Consequently, the practical definition of rational choices is more complex. Nevertheless, one should go beyond this problem in order to find practical definitions of RUW. These methods are outside the scope of this research. This thesis, however, focuses on single dimensional ratios, such as gross (apparent) water productivity which can be defined as gross income (€) divided on gross water use (m^3).

2.3.3 Other aspects related to water use efficiency in Mediterranean systems

An important issue in Mediterranean systems is the use of 'deficit irrigation', which can be defined as a water application below full crop-water requirements. This is a crucial strategy to maximize water productivity and efficiency. Generally, the farmer's adaptation to water supply limitations in water scarce regions, imply cultivating crops with supplementary or deficit irrigation. This is a strategy that is expected to be used more frequently as in the future irrigated agriculture will probably take place under increasing water scarcity. Therefore, to maximize food production under soil and water constraints, irrigation management will focus more towards maximizing the production per unit of water consumed (water productivity), against the old strategy of intensive water use in some areas maintaining the rest under rain fed conditions. Deficit irrigation is widely practiced over millions of hectares for a number of reasons - from inadequate network design to excessive irrigation expansion relative to catchment supply. A review can be seen Fereres and Soriano (2007), which concludes that there is a potential for improving water productivity of many field crops; there is sufficient information for defining the best deficit irrigation strategy for many conditions; and the level of irrigation supply under deficit irrigation should be relatively high in most cases. This is a strategy that increases the efficiency of the use of water by crops, but can be applied only to certain crops at some growth stages; not all crops are able to adapt. The single dimensional indicators (ratios) presented could potentially be used to aid measuring RUW. Still, it is important to carefully define the economic terms, as the measured 'value' depends on the decision-level or policy context in which the estimate is developed (Young, 2005, p 221). For example, subsidies to production are an income for the farmer but an expense for the government. Additionally, most of the measures do not specify if they refer to depleted water or to diverted water. At crop and field-level, much of the 'apparent losses' remain inside the hydrological system and do not represent losses at a meso level as most of the water returns to the basin. This consideration is an argument that supports the notion that rationality depends on the scale of analysis. In view of the diversity of definitions on WUE and WP indicators there seems to be considerable confusion around the interaction between the hydrological cycle and these concepts, which again could produce confusing results for planners and policymakers involved in addressing issues of water scarcity. Even irrigation professionals use various terms interchangeably and without due regard to the clarity of their recommendations (Perry, 2007). For calculating productivity, it seems adequate to use biomass, edible crops, dry matter, profit, water value, income in case of an economic target, or job creation in the case of social objectives. The economic value should take into consideration the level of analysis, as the private farm measure of success (profit) is different from the global public measure of value (where e.g. taxes or subsidies are considered differently than from the private viewpoint).

2.4 SUMMARY

Chapter 2 shows that the concept of RUW is increasingly relevant to irrigation as water scarcity and pressures on water are escalating. At a micro-level, (household, farm and community level), the definition includes maximizing profit, water use efficiency and productivity; at a meso-level (institutions, RB, infrastructure) it includes achieving an equitable and economic efficient allocation that does not increase the conflict level between competing uses; while at a macro-level (legal, national and international policy) sustainability and food security appear to be core aspects of RUW. Although multi-dimensional indicators have advantages, they are also rather complex. The chapter, therefore, presented a number of single dimensional indicators that can potentially be used to measure RUW. In the next chapter, the antecedents of the concepts and measurement of equity and equality dimensions in irrigation is presented.

CHAPTER 3

EQUITY AND EQUALITY IN IRRIGATION

'The arguments against existence [of equity] take three different forms. The first is that equity is merely a word that hypocritical people use to cloak self-interest – it has no intrinsic meaning so therefore fails to exist. The second – is that even if equity does exist in some notional sense, it is so hopelessly subjective that it cannot be analyzed scientifically – it fails to exist in an objective sense. The third argument that there is no sensible theory about it – thus it fails to exist in an academic sense. '

Young (1994)

Despite almost every water management system in the world have equity as a fundamental policy objective, there are misconceptions and lack of understanding of what equity and equality means in irrigation water management that make it difficult to measure and monitor its implementation at all scales and levels. Chapter 2 defines levels and dimensions of Mediterranean irrigation and shows that as water resources become scarce in Mediterranean irrigation, equity becomes an increasingly important objective of rational irrigation water management, especially at basin level (Chapter 2). Chapter 3 consists of three parts: First the institutional perspectives (3.1) of irrigation water management are presented, next the concepts of equity and equality (3.2) are explained, and finally a chapter summary (3.3) is given.

3.1 INSTITUTIONAL PERSPECTIVES

3.1.1 Natural and human distribution of water resources

'…coping with water scarcity [is] the challenge of the 21st century'.

FAO Director-General Dr Jacques Diouf, the World Water Day celebration, 2007

The natural and renewable water resources in the Mediterranean countries are by nature unequally distributed between, the 'rich' North and the 'poor' to 'extremely poor' South and East. As much as 81% of the water resources in Spain are located in the Northern half of the country (Kayamanidou, 1998). In addition to water resources being naturally unequally distributed within each country, human intervention also unequally distributes water between and within sectors. Irrigated agriculture accounts for a large share of total water withdrawals in the Mediterranean countries (83% in Greece, 68% in Spain, 57% in Italy, and 52% in Portugal), while it represents less than 10% in Northern European countries (Berbel et al., 2007). Widespread water resource withdrawal and droughts could exacerbate the water supply variability as a result of the drier warmer climate due to the impacts of climate change. States and the local stakeholders' adaptation to growing scarcity implies (Molle et al., 2010a):

- Supply responses; by augmenting the supply from existing sources, as well as tapping additional sources;
- Conservation responses; or 'efficiency in use' by making better use of existing resources, without increasing the supply or the number of sources of water; and
- Allocation responses; by reallocating water from one user to another, either within the same sector (e.g. agriculture) or across sectors.

The increase of supply based on building water control structures (dams, polders, drainage ditches etc.) often change water regimes, with consequences for the distribution and allocation of water resources among different stakeholders (Chowdhury et al., 1997). The technical, economic and environmental costs related with continued development of new sources during scarcity are high, and makes this approach undesirable, for meeting future demand. Conversely, the allocation of water for irrigation is, in many countries, considered as a low priority (Gorantiwar and Smout, 2006). Accordingly, more recently, irrigation has received a reduced share of the total supply due to increased demand from higher valued uses, such as industrial, domestic and recreational (Ibid.).

3.1.2 The importance of water institutions

'I am convinced that, under present conditions and with the way water is being managed, we will run out of water long before we run out of fuel'

Peter Brabeck-Letmathe, The Economist (2009)

In the water sector is increasingly recognizing the importance of institutions in development, because the policy prescriptions based on the neoclassical approach and the public choice theory have proved equally inadequate in many contexts. In natural resource management, with all its many forms of externalities, neither the price mechanism nor the creation of property rights can provide a permanent solution (Saleth and Dinar, 2004). As a result, much of the policy design, which have moved from 'getting the prices right' to 'getting the property rights right,' now centre on 'getting institutions right' (Williamson, 1994). Often, erroneously, 'institutions' are regarded only as 'organizations' (Bandaragoda, 2000). Moreover, no standard definition is established, either within or across the various social sciences (Box 1). This is due to the dealing with different interpretations of behaviour (Vatn, 2005).

Box 1 Different definitions of an institution

Veblen (1919): '[Institutions are] settled habits of thought common to the generality of man' (p. 239).

Berger and Luckmann (1967): 'Institutionalization occurs whenever there is a reciprocal typification of habitualized actions by types of actors. Put differently, any such typification is an institution' (p. 72).

Bromley (1989): '[Institutions are the] rules and conventions of society that facilitate coordination among people regarding their behaviour' (p. 22).

North (1990): 'Institutions are the rules of the game in a society or, more formally, are the humanly devised constraints that shape human interaction' (p. 3).

Scott (1995a): 'Institutions consist of cognitive, normative, and regulative structures and activities that provide stability and meaning to social behavior. Institutions are transported by various carriers – cultures, structures, and routines – and they operate at multiple levels of jurisdiction' (p. 33).

Gunderson et al., (1995): Institutions are 'the sets of rules or conventions that govern the process of decision making, the people that make and execute these decisions, and the edifices created to carry out the results' (p. 497).

Source: Adapted from Vatn (2005)

Formally written laws, rules, and procedures, along with informally established procedures, norms, practices, and patterns of behaviour, form part of the institutional framework (Bandaragoda, 2000), 'they are patterns of norms and behaviours which persist because they are valued and useful' (Merrey, 1993).

Although institutions function as a system, it is useful to make a distinction between institutions and organizations (North, 1990) and between the institutional environment and institutional arrangements (Davis and North, 1970; North and Thomas, 1970). The institutional environment comprises of the rules of the game, while the institutional arrangements; include the governance structure and its evolution within, and interaction with the institutional environment (Saleth and Dinar, 2004). Governance can be defined as 'a neutral concept comprising the complex mechanisms, processes, relationships and institutions through which citizens and groups articulate their interests, exercise their rights and obligations and mediate their differences'. According to the UNDP (1997), good governance addresses the allocation and management of resources in order to respond to collective problems. Moreover, it is characterized by participation, transparency, accountability, rule of law, effectiveness and equity. Water management institutions have long been seen promoting efficient and socially just distribution of the available resource (Tisedell, 2003).

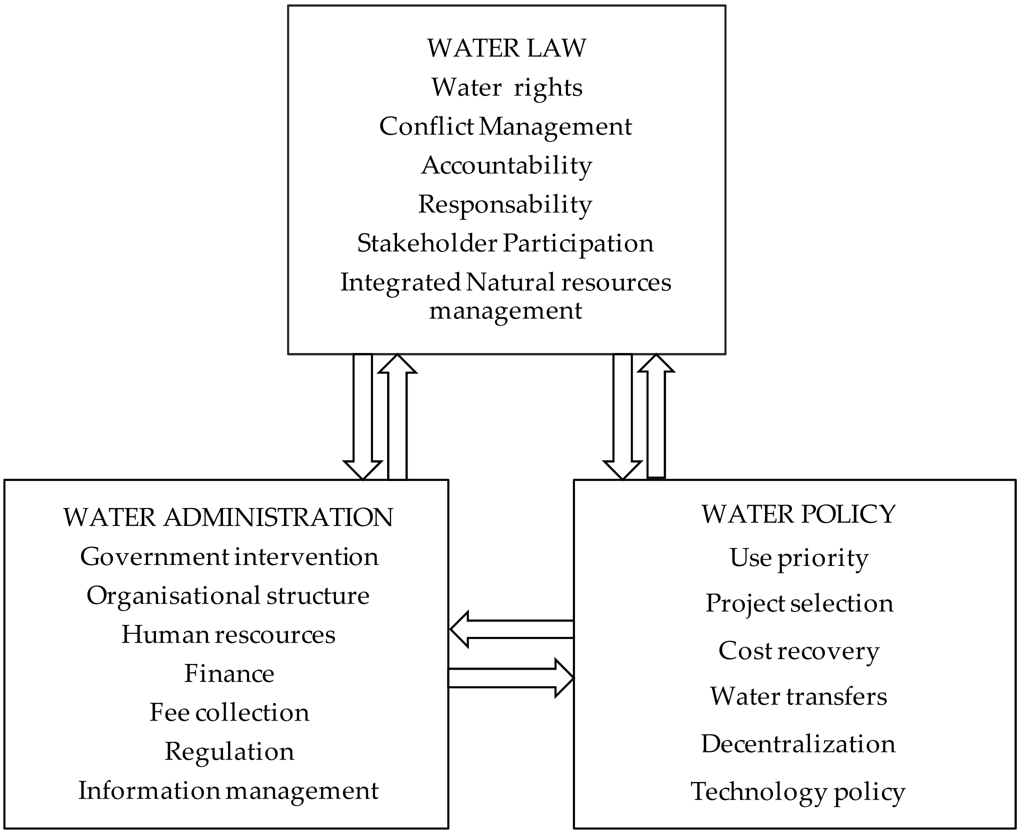
3.1.3 Water law, policy and administration

'The form of law which I propose would be as follows: In a state which is desirous of being saved from the greatest of all plagues -- not faction, but rather distraction -- there should exist among the citizens neither extreme poverty nor, again, excessive wealth, for both are productive of great evil. Now the legislator should determine what is to be the limit of poverty or of wealth.'

Plato (427-347 BC)

Management of water resources has the primary scope of balancing water availability (quantitatively and qualitatively) and water demand in space and time, at a reasonable cost and with acceptable environmental impacts. The bulky nature and physical characteristics of water resources constitute a significant challenge for institutional design. Consequently, water resources are vulnerable to market failures that must be addressed by institutions in order to provide efficient allocation and use (Livingston, 1995). Bandargoda (2000) propose a comprehensive institutional framework for water resources management in a RB context that consists of 'established rules, norms, practices and organizations that provide a structure to human actions related to water management'. The framework is considered in three broad categories: i) *Policies:* National policies, local government policies and organizational policies; ii) *Laws:* Formal laws, rules and procedures; informal rules, norms and practices; and Internal rules of organizations; and *Administration:* Organizations at the policy level for resource management; and Organizations at the implementation level for delivery management. The performance of water management depends upon the how well the interlinkages (Figure 2) between these institutional components function.

Figure 2 Interlinkages between institutional components.



Source: Adopted from Bandaragoda (2000)

The institutional framework aims to reduce the uncertainty of human actions and thus aid in stabilizing society. For example, conventional water allocation rules tend to bring about equitable distribution of water if these rules are compatible with other related rules and norms, for instance mechanisms to monitor water-delivery systems and laws regarding breach of commonly accepted allocation practices (Bandargoda, 2000).

A number of arguments that have been launched to legitimize government intervention (Stiglitz, 1987). These interventions could be classified by efficiency or non-efficiency oriented interventions as described in Table 3.

Table 3 Rational for Government Intervention

Efficiency oriented interventions	Non-efficient oriented interventions
- Public goods - Externalities - Economy of scale - Market power - Transaction costs & imperfect information	- Sustainability and intergenerational equity - Welfare (poverty reduction & income distribution) - Security (food and other aspects)

Source: Adopted from Sadoulet and Janvry (1995); and Stiglitz (1987).

When it comes to equity related interventions, many more dimensions could be relevant (see Table 7). Intergenerational equity, as mentioned in the table above, is related to the definition of sustainable development (see Chapter 3.1.4). The institutional arrangements implemented by the local and national governments set the ground rules for resource use. These institutions may in some cases facilitate implementation of economic efficiency and equity, but, if not regularly revised, they could create an impediment to equity and efficient resource use due to obsolete or poor design.

The causes of socioeconomic inequality have been disputed since the time of Plato. Wilkinson (2005) claims that the main practical argument in favour of reducing economic inequality is because economic inequality weakens society, hinders social and economic development, and could affect social and political stability (Box 2).

Box 2 How greater inequality leads to poorer social relations

Greater income inequality
⇓
Increased social distances between income groups, less sense of common identity
More 'them' and 'us'
⇓
More dominance and subordination, superiority and inferiority, snobbery and downward discrimination, hierarchical and authoritarian values
⇓
Increased status competition, shift to more anti-social values, emphasis on self-interest and material success, carelessness of other's welfare, aggressive exploitation of society for individual gain
⇓
Others as rivals: poorer quality of social relations

Source: Wilkinson (2005).

Molle (2004b) refer to formal equity in water management, however, he does not provide any explicit definition. Throughout this thesis, the term '*formal equity*' is proposed to be used to define the distributional criteria that the law and legislation have established as fair, through a public participation process.

3.1.4 Equity in international agreements and commitments

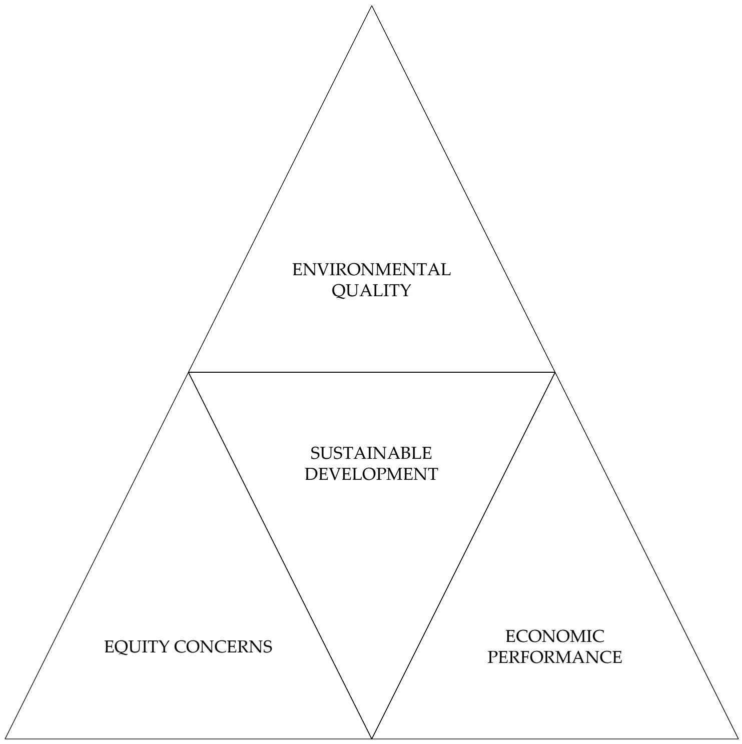
'If water is so fundamental a biological requirement in agriculture, if irrigation water (or other outstream flows) is now widely recognized to be an economic good, and if irrigation water constitute about 70 per cent of all diversions, then there is a need for an economics of irrigation.'

Merrett (2002)

Not only regional and national institutions set the agenda for water management. Centrally or externally mandated multilateral institutions such as the United Nations (UN) and World Trade Organization (WTO) build on, homogenize and reproduce standard expectations worldwide, stabilizing international order (Bandargoda, 2000). Thus, new paradigms and management approaches have emerged. The 1987 report of the World Commission on Environment and Development, also referred to as The Brundtland Commission, defined Sustainable Development as 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). Five years later, the Rio Earth Summit concluded that: ‘the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.’ (UN, 1992). Meanwhile, Sustainable Development has become one of the most prominent catchwords on the world political agenda.

The majority of governments and multinational firms has committed themselves to the overall concept of Sustainable Development. Hitherto, Sustainable Development, which is not just about the environment, but about the economy and the society, has proven hard to define (Böhringer, 2004). One reason for this is that Sustainable Development explicitly incorporates a (normative) equity dimension, which is ‘so hopelessly subjective that it cannot be analyzed scientifically’ (Young, 1994). Another reason is that the scope of the concept seems prohibitively comprehensive to make it operational in concrete practice (Böhringer, 2004). Nonetheless, societal policy is being challenged to come up with pragmatic approaches to Sustainable Development and to this end requires practical advice from the scientific community. Inherently, the three dimensions of Sustainable Development, i.e. environmental quality, economic performance (gross efficiency) and equity concerns, are intertwined and subject to tradeoffs (Figure 3).

Figure 3 Dimensions of sustainable development.



Source: Author's elaboration

Levite and Sally (2002) argue that equity in water allocation involves a fair access for all water users to the water needed for their activities and that attention should also be paid to efficient and beneficial use in order to achieve sustainability. While similarly, Gleick (1998) claims that equity overlaps with sustainability when defining what is to be sustained, for whom, and who should decide. Sustainable water management (SWM) implies managing water in a holistic way, taking into account the various sectors affecting water use, including political, economic, social, technological and environmental considerations. SWM has been high on the international agenda since the Mar del Plata Water Conference, hosted by the UN in 1977 (DAINET, n.d.), and it has been redefined several times since then. Current understanding of SWM is founded, above all, upon the principles develop during the International Conference on Water and the Environment in Dublin in 1992 (ICWE, 1992) (Box 3).

Box 3 The Four Dublin Principles

These principles recommend action at local, national and international levels (in this thesis micro, meso and macro level) to reverse the trends of overconsumption, pollution, and rising threats from drought and floods.

Principle No. 1:
Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment. An holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer.

Principle No. 2:
Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels. Raising awareness of the importance of water among policy-makers and the general public. Decisions to be taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

Principle No. 3:
Women play a central part in the provision, management and safeguarding of water. Positive policies required to address women's specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

Principle No. 4:
Water has an economic value in all its competing uses and should be recognized as an economic good. Access to clean water and sanitation at an affordable price is a basic right of every person. Past failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.

Source: (ICWE, 1992)

The interpretation of the concept 'water as an economic good' has taken two directions: i) water should be priced through the market by ensuring it is allocated to the highest valued uses and ii) the process of integrated allocation decision making of scarce resources, which does not necessarily involve financial transactions (See e.g. McNeill, 1998; Perry et al., 1997 cited in Van der Zaag and Savenije, 2006). The WFD (EC, 2000) and other policy documents acclaim the need of economic analysis to assist in sustainable management of water resources, especially in arid areas where competition and conflicts over water are more prevalent. Most of these economic analyses seems to focus on economic productivity and efficiency as an end in itself and ignore the larger social and equity aspects of water resources.

3.2 INTERPRETATION OF EQUITY AND EQUALITY

3.2.1 Confused concepts

Despite attention over several decades, the concept of equity has proven difficult to define. Often the concepts of 'distribution', 'equality' and 'equity' are used as if their meanings are obvious, and at times, they are used interchangeably. Occasionally, 'equality' and 'equity' are also applied interchangeably when qualifying some other concept, such as 'access' which represents another unhelpful lack of distinction (Williams and Doessel, 2006). Equality and Equity are not necessarily the same. *Equality* can be defined as the state of being equal and can be measured with descriptive inequality statistics. *Equity* refers to being fair, impartial or right judgment and is characterized by conflicting perceptions. Equity is such a complex idea that is strongly shaped by cultural values by precedent, and by the specific types of goods and burdens being distributed (Young, 1994). Water can be defined as a good that is homogeneous[7] and divisible (Young, 1994) and the supply of it may be fixed or variable. Water is also considered as an economic good (ICWE, 1992). In economics, the simplest problem of fairness is that of dividing a homogeneous commodity among a group of agents with equal claims on it. A distinction is made between horizontal and vertical equity, where horizontal equity implies that equals should be treated equally and vertical equity implies that unequals should be treated unequally (Elliot, 2009).

In irrigation, equity does not necessarily mean that every irrigator receives the same, equal amount of water. It rather implies that each irrigator gets an amount that is fair (Laycock, 2007). The question arises, 'What is a fair water allocation?'. Though equality can be a key component of equity, the relationship between equity and equality depend very much upon how the concepts are defined (Cullis and van Koppen, 2007). In practice, large-scale irrigation systems' water entitlements are almost always based on equality, rather than

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[7] *For agriculture the quality of water is probably of less relevance than for domestic water use.*

equity, because it is difficult to accurately determining what a society considers to be a fair way to share water. Further, many larger irrigation systems are constructed in areas that have previously not been irrigated, covering several different communities which may have varying views on fairness, and where there is ineffective communication between system designers and potential water users. In addition, some irrigators may use a larger share of water than others, either due to prior rights (prior appropriation-a focus of this thesis), in compensation for more input in system construction, or maintenance. The result is that it is much easier for irrigation system designers to develop systems based on an assumed concept of equality, which later is assumed to be equitable.

In irrigation systems, the most frequent form of division is by area, implying that each unit area of land is given the same water allocation (Murray-Rust et al., 2000). In some smaller systems managed entirely by the local community, a water share may be assigned to each person irrespective of the area of land they own or cultivate, and can include landless members of the community. Also, and more difficult to estimate and systematically measure, equality of water distribution may be based on the expected potential productivity of land resources, giving more water to more productive land or that soils with high water holding capacities receive less water than soils with lower water holding capacity (Murray-Rust et al., 2000).

3.2.2 Distributional justice and dimensions of equity

'Justice is the tolerable accommodation of the conflicting interests of society, and I don't believe there is any royal road to attain such accommodation concretely'.

Judge Learned Hand (1872-1961)

Bojer (2003) describes the main theories of distributional justice (distribution of rights and resources), from utiliraisme and welfare economics, moving to Rawls´s social contract and Sen/Nussbaum capability approach, and she also describes empirical methods of inequality measurement. She claims that there is a gap between what philosophers write and what is studied in empirical analysis. Some examples of important moral philospohers that seem quite unconcerned with how their concepts can be made operational for empirical analysis are Roland Dworkin, Martha Nussbaum, John Rawls and Amartya Sen. These are philosphers that are not at all concerned with welfare, but with opportunities, resources, rights and capabilities. According to them, achieveing individual welfare and happiness is the person's own responsability, while the state is responsable to further the means to and remove constraints on the pursuit of happiness. Since the end of 1980s, there has been a number of studies exploring community perceptions of fairness and justice in water management (Tisdell, 2003). Syme et al. (1999) and others has developed social psychological theories of justice, equity and fairness, which again have explored the adequacy of equity and procedural justice in explaining individual water allocation decisions. These approaches, however, enters into *perceptions* of what is fair, and that is beyond the scope of this thesis.

Rasinski (1987) and Syme et al (1999) show, in the context of social welfare policy, that equity comprises two components, 'proportionality' and 'egalitarianism'. *Proportionality* implies that resources should be distributed according to efforts or needs (as in the Marxist mantra 'from each according to their abilities to each according to their need'), while in the case of egalitarianism; the term suggests that everyone should be treated equally. Boelens et al. (1998) distinguish five levels of equity in irrigation and water management at local levels. These comprise:

- Equitable water distribution and allocation among different water users and uses,
- Equitable distribution of services involved in irrigation development,
- Equitable distribution of the added agricultural production and other benefits under irrigation,
- Equitable distribution of burdens and obligations related to functions and positions.
- Equitable distribution of the rights to participate in decision making processes, since this relates to the fundamental issue of whether or not every farmer has rights to speak, vote, claim an entitlement of irrigated land and enjoy equality of status in leadership elections, etc.

Phansalkar (2007) further divides two of the above mentioned levels, namely equity in access to and use of water, and the distribution of the impacts of water resource development intervention, into four categories:

- Social equity: equity between different groups of people living in the same location.
- Spatial equity: equity between people living in different regions (Saleth and Dinar, 2004).

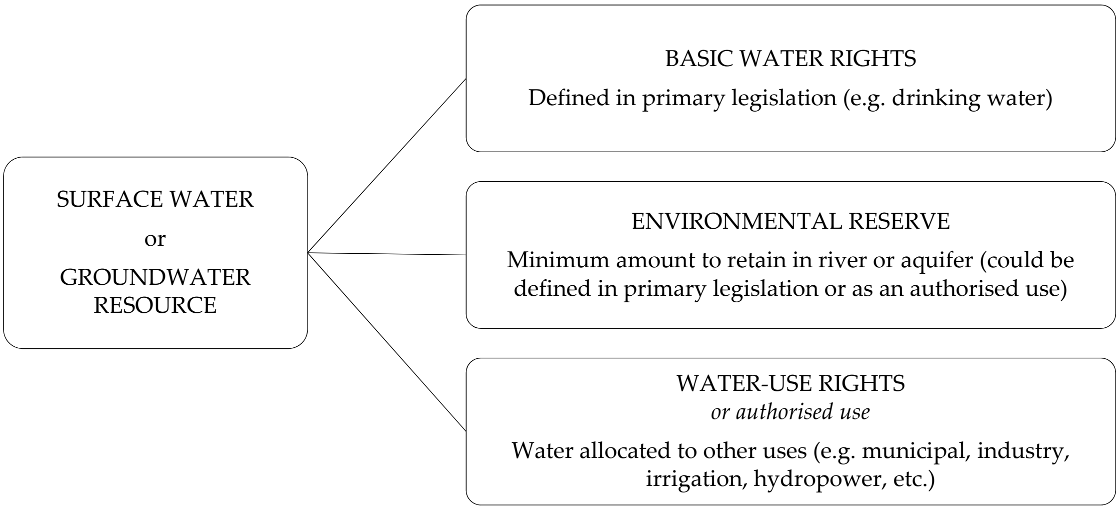
- Gender equity: equity between men and women in sharing labour costs, efforts to access and use water, and its benefits.
- Inter-generational equity: equity in the enjoyment of natural resources, including water, across generations of people (Divan and Rosencranz, 2005).

There has been an increasing focus on the concept of social equity or distributive justice as one of the guiding principles of contemporary people-centered development paradigm. Social science literature on developmental practices defines social equity as social justice in benefit sharing or the fair distribution of benefits (Uprety, 2005). Moreover, Syme and Fenton (1993) affirm that the concepts of equity and procedural justice (fair process) have greater significance as competition for water resources augments. For further reading on equity related concepts and social justice see Young (1994).

3.2.3 Equity and water rights

Water rights and equity are among the most debatable water issues (AbuZeid and Elrawady, 2008), especially when water resources gets scarce. In arid climates, such as the Guadalquivir RB where irrigation is necessary, problems of water scarcity and levels of rainfall are matters of public interest and concern. There is no universally agreed definition on the term 'water right' (Hodgson, 2006). The term used in different contexts and jurisdictions, and has come to mean somewhat different things. Water law, and therefore water rights, reflects economic, social and cultural perceptions of water. These in turn are formed by factors including geography, climate and the extreme variability in the water availability and the uses to which water is put. Figure 4 shows that a distinction can be made between 'basic' water rights (defined in primary legislation), from 'allocated' water-use rights or usufruct rights (decided through a defined administrative process). In addition, environmental reserves retained in the river or aquifer for environmental or other sustainability related downstream purposes may either be legislated as a basic right (ADB, 2009) or decided administratively through the water resources planning process.

Figure 4 Water Rights, environmental reserve, and water-use rights.



Source: ADB (2009).

Water rights are closely linked to land rights, as well as rights to the use of irrigation infrastructure. This could include reservoirs and canal systems, tanks, energised tube wells and mechanised pumps. These play a critical role in ensuring access to water. *Access to water* may be defined as the availability of water in the right quantity and quality, at the right moment, and in the right place. Water rights play a critical role in defining who has access to water and who do not (Hodgson, 2006). Water rights have been defined as a type of property right that aims, along with other water institutions and 'landed property rights', to assign access, use, liability and control over water from some persons and social groups to others (Wescoat, 2002). Uncertainty regarding water quantity and location, in addition to demand for specific amounts of water at specific times and locations, makes water rights a highly complex and controversial issue.

3.2.4 The need to link equity and efficiency in irrigation

Tsur and Dinar (1995) defines an efficient allocation of water resources as an allocation that maximizes the total net benefit that can be generated by the available quantity of the resource. According to Marsh and Schilling (1994), costs, burdens and amenities, 'efficiency' and 'effectiveness' are the most important criteria in decisions on the allocation of resources.

However, generally these criteria are not sufficient for generating acceptable and implementable decisions, and another criterion is required – is the allocation fair? (Ibid). Water management approaches may be clear on their objectives regarding equality or equity in distribution of input (e.g. water rights and annual allowances of water) without realizing the full implications of such policies on output or outcomes (e.g. economic return, water productivity and employment). In the end, social welfare, however, ultimately depends on the distribution of outcomes, whether equitable or equal. Whether equity of income, ought to be a target of irrigation management is uncertain as it goes against the idea that people who work harder than others deserve more income than others. Also, equity is difficult to ensure because the decisions should be fair and free from bias and should ensure social justice in the distribution of social costs and benefits of water management projects. It is often assumed that the equity objective conflicts with the efficiency objective (e.g. Msangi and Howitt 2007; Molle 2009; and Shah et al. 2009). Sampath (1992) argues that this does not necessarily have to be the case as, under certain conditions the promotion of efficiency can be compatible with improved equity (Sampath, 1984; 1988a; 1990b; cited in Sampath 1992), while policies introduced to promote equity have sometimes resulted in a simultaneous decrease in efficiency and equity. Dinar and Tsur (1999) investigate efficiency and equity performance of various irrigation water pricing methods, and conclude that the extent to which water pricing methods can affect income redistribution is rather limited. They claim that farm income disparities are due mainly to such factors as farm size and location, and soil quality, but not to water (or other input) prices. Small and Rimal (1996) analysis several irrigation systems in Asia, and found that efficiency and equity trade-offs becomes more important with increasing water scarcity. In Chapter 7, water allocation inequality and efficiency will be analysed for the Guadalquivir RB that is an example of a water scarce basin.

3.2.5 Measuring inequality

'All happy families are alike, but every unhappy family is unhappy in its own way'

Opening sentence from the book Anna Karenina by Leo Tolstoy (1828-1910)

Inequality measurement is an attempt to give meaning to comparisons of distributions in terms of criteria which may be derived from ethical principles, mathematical constructs, or simple intuition (Cowell, 2000). Inequality measures are most frequently used for dynamic comparisons (comparing inequality measures across time), and for policy analysis (e.g. to compare inequality across regions or by population sub-groups) (Vecchi, 2007). The methodology of inequality measurement is not novel, as it has been widely applied in many settings. The empirical application of this methodology to water allocation, however, is relatively novel. However, there is a lack of standard approaches to select relevant variables, the unit of analysis and choice of measurement, not bridging criteria for inequality with, nor what measures are more suitable at different levels and scales. The paucity of studies and agreed upon approaches to apply this methodology justify its further exploration, considering alternative approaches of measurement that allow comparing outcomes of water allocation on not only efficiency, but also equity in water allocation at basin level. Often there are confusions in the use of terminology. While there is only one way a distribution can be equal, there are infinitely many ways for it can be unequal, and unequal distributions, like Tolstoy´s unhappy family (see quote above), are all unequal in their own way (Bojer, 2003). Frequencies, mean, and variance, are well-known statistical measures to describe a distribution. In addition, explicit methods have been developed to describe and measure the inequality of a distribution. There are several established methodologies on how to measure productivity and efficiency (See Chapter 2); however, currently there are neither standard methods, nor monitoring systems in place to reliably measure the impact of a water allocation on e.g. social, temporal and territorial equity in water use at basin level.

Despite vast and rapidly expanding empirical research on inequality measurement, to date, few studies have applied inequality measures to quantify how irrigation water is allocated within a RB. The most common, next to standard measures of dispersion, are the coefficient of variation, the Gini coefficient and the Lorenz curve. Yet there are few empirical studies on water use allocation applying inequality measures and concentration curves. Cullin and van Koppen (2007) use Gini coefficient and Lorenz curve to measure water use inequality and indirect benefit among domestic water users in Olifants water management area in South Africa, and Sun et al. (2010) use environmental Gini coefficient and Lorenz curves to study an allocating wastewater discharge permit in Tianjin, in China. Lorenz curve and Gini coefficient have also been used to assess yield inequality within Paddocks (Sadras and

Bongiovanni, 2003). The coefficient of variation has been used by several authors. For example, Akkuzu et al. (2007) used this measure on water delivery in irrigation systems in irrigation areas in Gediz, Turkey; and Murray-Rust et al. (2000) used it to study water distribution equity in Sindh Province, Pakistan. Gorantiwar and Smout (2005) list equity considerations and indicators for irrigation used by different authors, including statistical measures of dispersion and inequality measures (Table 8, p. 63). Inequality measures and concentration curves do not measure equity in water allocation unless equal sharing is the purpose. Charting and measuring inequality could be of assistance to determine if water or related variables are more or less distributed for example over time and or between different water planning scenarios. Inequality simply indicate the differences in the resource without regard to the desirability as a system of reward or undesirability as a system running counter to some ideal of equality (Kuznets, 1953). Descriptive inequality measures will be described in more detail in Chapter 4.

3.3 SUMMARY

How water is shared, becomes critical when productive activity becomes constrained. Utilizing different arguments from the public sector, management, and psychology debates, it is argued that the concept of equity is often undefined and ambiguous. Equity in irrigation does not necessarily mean that every irrigator receives the same amount of water; it rather implies that each irrigator gets an amount that is fair. Equality can be an important part of equity, but not necessarily the same. This thesis proposes that the term 'formal equity' could be defined as the distributional criteria that the law and legislation have established as fair through a public participation process. Descriptive inequality measures do not measure equity, but has the potential to do so. Currently there are no standard methods to assess or monitor equity and equality in irrigation water allocation.

CHAPTER 4

METHODS AND DATA

'By three methods we may learn wisdom: First, by reflection, which is noblest; Second, by imitation, which is easiest; and third by experience, which is the bitterest.'

Confucius (551-479 BC)

This chapter presents the methods and data applied for the empirical analysis of the thesis. It comprises four parts. First the approach and the data are presented (4.1); next the methods for analyzing consequences of basin closure are described related to Chapter 6 (4.2); then the methods to assess and monitor inequality related to Chapter 7 is presented (4.3), and finally a chapter summary (4.4) is given.

4.1 APPROACH AND DATA

4.1.1 Linking the theoretical and the empirical realm

One of the primary goals of a researcher is to link the empirical and theoretical worlds by using theory to make sense of evidence and evidence to refine and sharpen theory (Jelstad, 2007). According to Halvorsen (1987), methodology is a systematic way of reaching reality and is in itself just a tool to help the researcher do research. On the other hand, methodology can also be viewed as a science on its own of how to collect, organize, analyze and interpret data and information. According to Ragin (1992), social scientists face two main problems: 'the equivocal nature of the theoretical realm and the complexity of the empirical realm.' There are two main methodological approaches or research methods in social science, qualitative and quantitative methods. Both methods aim to contribute to a better understanding of the society and how persons, groups and institutions act independently and act together within the society. The main difference between the two methods is that when using quantitative methods, the researcher performs statistical analysis based on numerical, measured amounts, while, in qualitative methods, the researcher's understanding and interpretation of information is central, as in the interpretation of frames of opinion, motives, social processes or relationships (Holme and Solvang, 1991). This thesis measures inequality by applying quantitative methods.

4.1.2 Basin level approach and analytic framework

The RB is increasingly accepted as the appropriate entity for the analysis and management of water resources, especially as basin level water availability becomes the most important constraint to agriculture (Pretorius et al., 2005). Empirical studies of RB management systems could provide opportunities to examine the consequences of claims made for basin-level water resources, factors that appear to affect the implementation of integrated water management, and the outcomes of water allocation and hydrological planning.

However, some issues are either irrelevant or difficult to address at basin level due to the lack of data or poor quality of data, whereas site-specific situations might create the need for investigating other aspects. Kundzewicz and Mata (n.d.), claim that a major challenge in RB study is the paucity of data with sufficient accuracy and spatial and temporal coverage. More specifically the challenges include:

- Scarcity of socio-economic information
- Lack of validation and integrated understanding of proxy data
- Low credibility and accuracy of hydrology-relevant outputs from climate models
- Low credibility and accuracy of downscaling schemes
- Little development of climate models for hydrological forecasting
- Uncertainty in results related to extremes - floods and droughts (frequency, intensity, persistence, spatial extent).

Water sharing and usage tend to be historically grounded, and the past evolution of the basin, in terms of its gradual anthropogenisation, should be taken into the consideration for the analysis of both the current situation and future prospects. Therefore an in-depth approach, like in this study, is preferred to an in-breadth analysis of a high number of RBs (Molle, n.d.). All EU countries apply a RB approach for water management since the adoption of the WFD (ICDRP, 2011). This thesis takes a RB level approach to the empirical analysis in the following chapters.

In the literature, there are several approaches to structure and describe the state and the response of a natural system. The Pressure-State-Response (PSR) approach exerts that human activities cause a pressure on the environment affecting its state, such as the quality and quantity of water. The pressure causes a response by the society in terms of environmental, economic and sectoral policies. Pressures include both direct and indirect pressures. The approach can be applied at the national, sectoral, community, or individual firm (farm) level. The PSR approach was first introduced by OECD in 1994 and has since been modified and adjusted. Two examples are the Driving force-State-Response (DSR) model that was used by United Nations Conference on Sustainable Development (UNCSD) in the past or the Driving force-Pressure-State-Impact-Response (DPSIR) model that is currently used by the European Environment Agency (EEA) (WSM, 2004).

The evolution and context of the Guadalquivir RB is presented in Chapter 5, using a DPSIR-system view, and serves as a background for the empirical analysis in the two consecutive chapters. An adaptation of The DPSIR model to a closing RB is presented in Figure 11, p. 83 in Chapter 5. The source of the data is presented in next the chapter.

4.1.3 The 2008 Irrigation Inventory of the Guadalquivir river basin

'Data! Data! Data! I can't make bricks without clay.'

Sherlock Holmes. The Adventure of the Copper Beeches, by Sir Arthur Conan Doyle (1855-1930)

4.1.3.1 Data collection

The data was taken from the Irrigation Inventory of the Guadalquivir RB (CHG, 2010a). This Access database was made as a result of a large-scale irrigation survey across the entire Guadalquivir RB, for the development of the draft Hydrological Basin Plan (HBP)[8] for the basin as required for the implementation of the WFD. The survey was conducted by eight trained fieldworkers from Empresa Pública Desarrollo Agrario y Pesquero, Junta de Andalucia (DAP). Most of the survey (94%) took place in 2007 and 2008 (Table 4). The

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[8] *A draft was presented for public hearing in December 2010 (CHGb). The final version is pending approval of the new government.*

database is owned by the Water Agency of the Guadalquivir RB, called 'Confederación Hidrográfica del Guadalquivir' (CHG).

Table 4 The year the survey was conducted

Year	n	Percentage	Cummulative percentage
2006	87	5.4	5.4
2007	566	35.3	40.7
2008	945	58.9	99.6
2009	6	0.4	100.0
TOTAL	1,604	100,0	

Source: Author's calculations based on data from CHG (2010a)

The survey covers a total of 1604 aggregation units (AU) with sub-aggregated units reflecting aggregated information by crop types. The data covered the entire irrigated area of the Guadalquivir RB. This will be further explained in the next section. There are several arguments for using secondary data, as this irrigation inventory, to make basin level analyses. Basin level analyses require a large investment of time and money. Due to the lack of budget and the time constraint, it was not feasible to collect additional primary data. Moreover, additional data collection was unnecessary and outside the scope for this research.

4.1.3.2 Aggregation level and unit of analysis (Irrigation entities)

'Do not throw away information'

James Tobin (1918-2002)

The AUs shared some common characteristics including geographical proximity, origin of water, water right status, and year of appropriation (the year first put to irrigation use). However, the way the data were aggregated in the database posed an initial challenge in terms of statistical analysis due to scale and level of AUs. Table 5 shows the frequency of the three levels of AUs found in the database.

Table 5 Type of aggregation unit (AU)

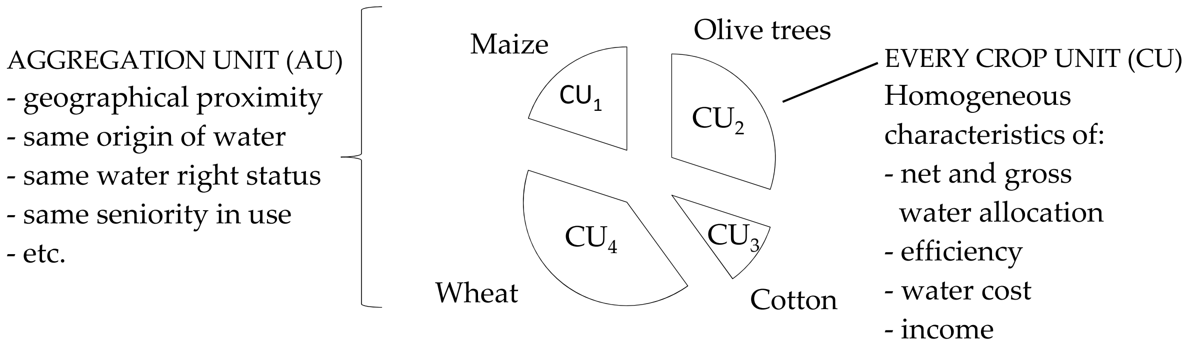
Type	n	Percentage	Cummulative percentage	Aggregation level
Individual irrigator	460	28.7	28.7	Individual irrigators
Irrigation community	635	39.6	68.3	Communities
Irrigation zone	509	31.7	100.0	Mixed aggregation levels
TOTAL	1,604	100.0		

Source: Author's calculations based on data from CHG (2010a).

'Individual irrigators' are physical persons. 'Irrigation communities' consist of aggregated individual irrigators of a community or groups of communities (>200 ha). 'Irrigation zones' are units that consist of either aggregated individual irrigators, or irrigation communities, or a combination of both (<200 ha). The number of members of the community is given, but these data are highly uncertain because of the possible double counting with other AUs and uncertainty whether all irrigators are using their water allocation (CHG-staff, personal communication, 2010). Hence, proper individual irrigator data at basin level could not be obtained, as a physical person could be represented in one or more irrigation entities at the same time, leading to both double counting and problems of scale. In addition, every AU had detailed crop production data information categorized by a number of, what will be referred to as, *crop units* (CU). Each CU represents a crop type[9] with strictly identical characteristics, in terms of water allocation, efficiency, water costs and income (Figure 5).

[9] *Note that one AU can contain the same crop type more than once if they have different characteristics in any of the related variables.*

Figure 5 An example where an Aggregation Unit (AU) consist of four Crop Units (CUs).



Source: Author's elaboration based on the data base of CHG (2010a).

In total, there were 4,159 CUs in the data base[10]. In order to not lose data, to homogenize the unit of analysis (in terms of level and scale), and to reduce the estimation error, analyses were made at the lowest level of aggregation. The unit of analysis for this thesis will thus be referred to as an irrigation unit (IU). After weighting, the sample consisted of N = 845,998 IUs (1 unit= 1 ha) for 2008, and 881,568 IUs for 2015. These numbers correspond, approximately, to the number of hectares in the entire basin for the two years. To solve the issue of aggregation and the large variation in irrigated area (ha), every CU was weighted by the irrigated area (ha) it occupied for the empirical analysis presented in Chapter 6, while the data was disaggregated with the help of a macro in Access for the inequality measurement analysis in Chapter 7.

The database consisted of both field data and estimates on irrigation volumes for the entire basin for a 'normal year'. CHG defined a typical year as a 5 years average value, represented by and referred to as year 2008. In addition, and in line with current water planning, the estimated irrigated area (ha) and gross and net water allocation scenario (m^3) for year 2015 developed by the CHG and partners, was made available for this research. The 2015 scenario correspond to the management plan to be implemented by 2015 in line with

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[10] *This implies that one AU can have two or more CUs for e.g. olive if there are some difference in any of the variables, e.g. efficiency.*

the WFD. The original database also contained GIS-maps to locate the AUs; however, these were not permitted used for this research.

Chapter 3 stressed that equality is an objective or quantitative term and is taken to mean equal shares of the whole related to 'a directly measurable parameter' (Murray-Rust et al., 2000). In the context of water distribution, this measurable parameter can be the size of landholding (m^3 ha^{-1}) or the individual irrigator (m^3 per person). In the latter case, every member of the society irrespective of e.g. landholding size, gender and/or occupation gets an equal share of water. The most frequent type of water allocation is by area and equality implying that each unit area of land is given the same water allocation (Ibid.).

$$\frac{G_1}{A_1} = \frac{G_2}{A_2} = \cdots = \frac{G_n}{A_n}$$

G: Gross water allocation (m^3), *A:* irrigated area (ha)

Such division would make more sense in an irrigation scheme, where equal sharing is the objective, than on a RB scale that has much larger heterogeneity due to e.g. different climate and soil conditions and other allocation criteria to take into consideration. In this basin the water right is attached to land right and not to individuals. This is also a reason why it makes more sense to analyse land or a spatial unit more than irrigators.

4.1.3.3 Variables and period of appropriation groups

There are two water planning scenarios in the database: 2008 (current) and 2015 (future). The management scenario for 2015 takes into account the planned measures as indicated in the draft GHBP. The changes reflected are mainly due to increased supply (building of infrastructure); improved efficiency (modernization); change in crop pattern; and modest expansion of irrigated land. The latter is in line with management planning conformity prior to 2005 on not expanding irrigated area. Therefore, the Guadalquivir RB has been defined as closed institutionally, as the expansion observed is only due to prior agreements.

For 2008 and 2015 it is important to mention that there were three types of water use/allocation variables in the database: 1) the reported water use, 2) the estimated net water allocation and 3) estimated gross water allocation. The CHG considered the reported water use to be of too poor quality due validity and reliability issues in reporting. Therefore, the net water allocation (N) (the amount of water the plant is estimated to consume) and gross water allocation (G) (the water extracted from the basin), was estimated by the CHG and partners using hydrological and agro-technical models. For 2008, these data had been aligned with socio-economic data in the database in order to produce consistent results when calculating ratios etc. consisting both estimated and surveyed data. This thesis therefore only considers estimated gross and net water allocation. It was decided to use the word allocation, instead of use or consume, as the thesis uses the data that refers to actual public water allocation planning, which are supposed to be quite close to real water use.

The difference between G and N is defined as the loss or return of water due to transport; distribution and conveyance (Annex 3 in CHG, 2010b). For each aggregation unit the relationship between total gross and net water allocation can be given by the following equation:

$$\mathrm{G} = \frac{\mathrm{w} * \mathrm{A}}{E} = \frac{\mathrm{N}}{E}$$

Where N is the product of estimated net irrigation supply by crop (w) multiplied by the irrigated area (A) divided on global technical efficiency, in this thesis only referred to as efficiency (E), where E is given by the product of the application, the conduction, and the distribution efficiency estimated for every CU in the database.

The data base also contains information on *reported water right status* (license, applied for license and no licence). This is a politically sensitive issue and could not be a main focus of the analysis, though it is of interest from an equity perspective. A descriptive analysis, using contingency tables is presented at the beginning of Chapter 6. Furthermore, variables such as socio-demographic data (e.g. age, sex, household size) were not available, though, they could have been interesting to research. The key original database variables that make basis for the calculations are given in the next table.

Table 6 Base variables found in the inventory for the empirical analysis in Chapter 6 and 7

Variable	Unit	Symbol	Definition of original variable as found in data base
Water cost	€ ha^{-1} & € m^3	C	Represents the farmer's water extraction costs.
Efficiency	n.a.	E	The global efficiency given by the product of the estimated application, conduction, and distribution efficiency.
Gross water allocation	m^3	G	The estimated gross water allocation (water extracted from the basin)
Gross income	€ ha^{-1}	I	Average income.
Irrigated area	ha	A	Number of hectares irrigated.
Net water allocation	m^3	N	The amount of water the plant is estimated to consume.
Origin of water	%	S	The origin of water (surface water, groundwater and recycled water) was given as the percentage of total water use per AU.
Year of appropriation	Year	t	Traditional irrigation is older than 1947 and undated and modern irrigation is from 1947 or later and are given by year by AU
Water right status	n.a.	n.a.	Reported water right status: 1) Formal water right; 2) Pending water right; and 3) No formal water right

Source: Author's elaboration based on data from CHG (2010a).

Seniority of water use refers to year of appropriation and had a dual treatment in the analysis in Chapter 6 because of its nature: traditional irrigation (categorical variable, <1947) and modern irrigation (continuous variable; >1947). This is further explained under the models in Chapter 6. Moreover, further explanations of the variables, together with the hypothesis and research questions, are in the empirical analysis chapters (Chapter 6 and 7) for easier reference. The descriptive analyses of the key variables used in the empirical analysis are found in Chapter 6 and Chapter 7 and in Annex 2.

For some of the analysis, however, the year of appropriation had to be divided into periods of appropriation, e.g. when no polynomial model could explain a phenomenon using continuous variables, ANOVAs and contingency tables were applied to determined groups of period of appropriation. The four groups were identified as: 1) traditional water use before 1947; 2) 1947-1966, 3) 1967-1985; and 4) 1986-2008. The traditional appropriation group consisted of all units that started to irrigate before 1947. These data were undated, but stem back from the earliest Arabic and Roman irrigation. The period 1947-1966 was defined by the introduction of the Franco regime's large irrigation schemes policy, where surface water was the main source. The period, 1967-1985, with 1947 to 1966 represent modern irrigation before the 1985 water law (See Section 5.2.2). The last period of appropriation corresponding to 1985-2008, represent modern irrigation after the 1985 law, i.e. the most recent irrigation appropriation. The three modern appropriation periods were made as homogeneous as possible in terms of number of years in each group.

4.1.3.4 Data validity and reliability

'That which cannot be done perfectly must be done in a manner as near perfection as may be.'

Daniel Webster (1782-1852)

Validity is related to researcher's specification of the study (accuracy), and validity is related to systematic errors in the data material (consistency) (Hair et al., 1995). In this study validity is related to how the information was gathered and if the findings relate to the hypothesis or problem. Reliability is related to how consistent the information is with information from other reputable sources. The assessment of irrigation water use and performance variables in an entire RB requires significant efforts of collection of physical and socioeconomic data. Secondary data are data collected [by individuals or agencies] for other purposes, and thereby, promptly available at a low cost. The main drawback of using secondary data, however, is that they may not be tailored to the research needs in the same way as primary data may in terms of sampling design and validity (Arriaza, 2006).

Census data and irrigation inventory data often lack homogeneity and comparable aggregation units, or the units could be aggregated into ways that are not suitable for the analysis. Sometimes there are differences in collection methods and sample size between years, complicating the analysis further. Nevertheless, large scale survey (or censuses) conducted by governmental bodies could often produce more accurate data than that obtained through primary research with custom designed and executed surveys when these are based on relatively small sample sizes (Crawford, 1997). The irrigation inventory data applied in this study has been considered sufficiently appropriate and adequate to draw conclusions and answer to the research questions proposed in this thesis. Moreover, the time involved in searching secondary data is a much less than that needed to gather primary data.

One of the main weaknesses of this database is that it only gives a snap shot of water use and allocation for two specific 'normal' years and crop mixes. The reliability of published statistics may vary over time. To compare the data of this inventory with previous census and or irrigation inventories is not straight forward. The problems are related to level and scale of aggregation, definition of geographical boundaries (e.g. administrative counties are not always the same as agricultural counties), and change in the management area. The latest inventory covers a much larger proportion of the RB than previous basin level surveys, as satellite pictures were used to identify irrigated areas (CHG-staff, personal communication, 2010).

Survey data could be subject to errors in reporting. Therefore, before receiving the database, it was screened and cross-checked by technical officers at the CHG and partners. For the case of water allocation they estimated two new variables, gross and net water allocation. Moreover, before conducting the analysis for this thesis, the PhD candidate checked all relevant variables for consistency in recording. An inconsistency in data related to the irrigated area for year 2015 was found and reported to the owners of the database. Only units that reported as irrigating were included in the sample, independent upon reported water right status. The CHG and partners were consulted in cases there were doubts about how a variable was measured or defined.

Uni-dimensional outliers (extreme values) were checked for both for estimated and reported variables through frequency tables. After consultation with experts and review of literature, it was decided that the values could be defined within the possibility range for every variable, even though these could be defined statistically as outliers. This could be explained by the fact that the basin is large and diverse. An example of extreme values is water allocation by crop type. Irrigated land of traditional olive orchards, which account for the largest share of the irrigated area (almost half), has an average net allocation of 1,500 m^3 ha^{-1}, versus rice with 10,400 m^3 ha^{-1} (Annex 3). Nevertheless, outliers are more of a problem with small sample sizes.

4.1.4 Ethical considerations

Ethical considerations in this study are related to the use of data, the analyses and the writing process. The data were mostly aggregated, but in some cases, individual irrigators could be identified. Thus, it was necessary to ensure anonymity in line with the law of protection of data and the requirement of the database owner. The anonymity of the participants in the survey and the staffs' personal opinions were ensured by providing information that could not be traced back to individuals. The analyses in this study are mainly related to statistical approaches. The rationale for each statistical step is described as thoroughly as possible. Statistical analyses and choices connected to the research is expert opinion driven. This means, when expert opinion and good statistics were not fully compatible, the choices were based on literature review or expert opinion, resulting in slightly weaker statistical results in the regression models. During the write-up of the thesis, it was essential to ensure that the analysis and interpretation of the results reflected, in the most accurate way possible, the true situation in the RB which is ethically relevant towards both the survey respondents and the readers of the thesis.

4.2 METHODS FOR ANALYSING BASIN CLOSURE

'My ideal is equal distribution, but so far I can see it is not to be realized.
I therefore work for equitable distribution'

Mohandas Karamchand Gandhi (1869-1948)

4.2.1 Polynomial regression models and correlations

The Statistical Package for Social Science (SPSS) was used to analyze the data in an attempt to fit statistical models to explain impacts and responses and the interactions between the impacts and responses in the Guadalquivir RB depending upon seniority in water use (Chapter 6). More specifically, it was studied if those senior irrigation units had different characteristics in terms of origin (H1), water costs (H2), gross water allocation (H3), efficiency (H) and productivity (H5). Then possible correlations (two sample t-tests) between impacts and responses are postulated H6-H7. For H1-H5 the difference between modern (1947-2008) (categorical variables) and traditional irrigation (older than 1947) was contrasted with independent-sample t-tests and then polynomial regression functions were fit for modern irrigation (scale variables), taking the general form:

$$y = a_0 + a_1x + \ldots + a_mx^m + \varepsilon$$

4.2.2 Assumptions

The normality assumption, a requirement for most of the polynomial regressions, implies that all variables follow a normal distribution. When the assumption of normality is fulfilled, also the residuals are normally distributed. All RB have a certain degree of heterogeneity. For examples, the upper part of the basin usually has different hydrological, climatic and soil characteristics compared to the lower basin. This is also the case of the Guadalquivir RB that will be studied in more detail in the following chapters. In this basin, the differences translates into differences in crop water needs of rice (downstream) versus olive (upstream), and substantial difference in water productivity (see Chapter 6). This heterogeneity leads to non-Gaussian distributions of the majority of the selected variables for the empirical analysis. The central limit theorem states that parametric tests work well with large samples, even if the distribution of population variables is non-Gaussian. This implies that parametric tests are robust to deviations from Gaussian distributions, under the condition that the samples are large (Motulsky, 2010). Moreover, none of the statistical software packages available could perform non-parametric analysis using weighted data. Hence, it was decided to use parametric tests and regressions. The possible existence of heteroscedasticity is a concern in the application of regression analysis, because its presence can invalidate statistical tests that assume the effect and residual (error) variances are uncorrelated and normally distributed. Residuals plots were made to check for heteroscedasticity and log transformations were applied to correct for it. Under each of the hypothesis stated in Chapter 6, the variables and the model specification are explained for easy reference.

4.3 METHODS TO ASSESS AND MONITOR INEQUALITY

4.3.1 Measurement dimensions and transformation of data

Evaluating equity and equality usually involves a comparison of the impact or effect of an action on two or more individuals or groups. March and Schilling (1993) organize groups along four dimensions as provided in the Table 7.

Table 7 Group dimensions for evaluating inequality

Group dimension	Description	Examples
Spatial	Jurisdictional boundaries or unit areas that partition a spatial surface into mutually exclusive groups	States, counties, square kilometers & legislative districts
Physical	Geologic, biologic, or geographic features that may divide a spatial surface, or may be distributed throughout the surface.	Land use, forest type & habitat
Demographic	Social or human characteristics that are typically distributed over a spatial surface.	Population, income, ethnic group & age.
Temporal	Time; any category above may also be defined over a period of time.	Years, decades, generations

Source: Adopted from March and Schilling (1993).

This thesis will mainly analyze physical dimension in terms of water resource allocation, demographic dimension in terms of water costs and income, and temporal dimension in terms of prior appropriation and a two year scenario (2008 and 2015). The population analysed is defined as the sum of all IU amounting to the total irrigated area (A) of the RB. Most studies of irrigation and inequality use a physical irrigator, an irrigation entity or spatial area as a unit of analysis (Table 8). In this thesis, the data is disaggregated so that one hectare is the unit of analysis. This is referred to as Irrigation Unit (IU), and the sum of all hectares, all IUs, is the total area of the RB. The justification is that the data are aggregated in units of different levels (e.g. irrigators and schemes); and because water rights and water allowances are associated with land. Since the irrigation inventory data base had AU aggregated into non-comparable units, a transformation of the data was needed to apply the inequality measures and the concentration curves. The estimation error was reduced through a disaggregation until the lowest aggregation level possible, under the assumption that each crop type in each AU receives the same per hectare water use. One hectare is the unit of analysis. The data were ordered, from low to high, with the help of a macro built for Access. Accordingly, every hectare was given its own record so that water allocation for 2008 had 845,998 rows and water allocation of 2015 had 881,568 rows; one record for each hectare (rounded due to the disaggregation). First, a comparison was made to see if the distributions have conflicting rankings for selected variables for 2008 (gross water use, gross income and water costs). Then inequality in current and future water use (gross and net water allocation) was compared. The types of inequality measures and concentration curves applied, and decomposition analysis are described in the next sections. Normative measures are also explained, though they do not directly form part of the analysis (except that Atkinson index can be used as a normative measure).

4.3.2 Inequality tools

Tsur and Dinar (1995), discuss two main categories of inequality measures, descriptive and normative. The descriptive measures can evaluate the dispersion in water allocation by descriptive statistic, while normative measures are derived from some underlying social welfare function (Ibid.). The inequality measurement and charts in this thesis were made with the R-software.

4.3.2.1 Inequality measures

A descriptive inequality measure can be defined as a statistical measure of the deviation from equality of a distribution and gives a complete ordering over the set of possible distributions of the resource (Bojer, 2003). Cowell (2009) defines an inequality measure to be a scalar numerical representation of the interpersonal differences in resources within a given population. The use of scalar indicators implies that all the different features of inequality are compressed into a single number. Coulter (1989) has collected about 50 inequality measures, but probably there exist a few more. Table 8 shows an overview of some inequality indicators proposed for irrigation schemes, by different researchers.

Table 8 Irrigation performance indicators related to equity by author

Author	Indicator
Abernethy (1986)	Christianson coefficient (Christianson, 1942), standard deviation (Till and Bos, 1985), interquartile ratio (Abernethy, 1984), Gini coefficient and Shannon-Wiener. However preferred modified interquartile ratio (the average depth of water received by all land in the best quarter, divided by the average depth received in the poorest quarter).
Sampath (1988)	Relative mean deviation, the variance, the coefficient of variation, the standard deviation of logarithms, the Gini coefficient and Theil's information measure (Theil, 1967). Preferred Theil's information measure.
Molden and Gates (1990) and Kalu et al (1995)	Coefficient of variance (CV) of spatial water distribution to field plots as a measure of inequity and thus (1 - CV) as measure of equity.
Steiner (1991)	Relative mean deviation, coefficient of variation, inter-quartile comparison and Gini coefficient.
El-Ewad et al (1991)	Absolute average deviation.
Bird (1991)	Inter quartile ratio
Goldsmith and Makin (1991)	A normalized equity index called interquartile ratio (Abernethy, 1986).
Kaushal et al (1992)	Christiansen uniformity coefficient, coefficient of variation, modified IQR and Theil index.
Bhutta and Van der Velde (1992)	Inter quartile ratio (Abernethy, 1986) .
Bos et al (1994)	Modified interquartile ratio (Abernethy, 1986) for overall equity and Head:Tail equity ratio (Vander der Velde, 1992) for looking at the difference between head and tail of the canal.

Source: Gorantiwar and Smout (2005). Note: The references are included in the reference list for easy reference.

The measures that will be applied in this study are explained more in depth in the remaining of this section. And, different from above, they will be applied to measure basin level inequalities, not irrigation scheme inequalities.

A common inequality measure is the *coefficient of variation (CV)* that is the ratio of the *standard deviation (σ)* to the *mean ($\bar{y}$)* (adapted from Cowell, 2009): $\mathrm{CV} = \frac{\sigma}{\bar{y}} = \frac{\sqrt{v}}{\bar{y}}$

The CV is independent of measurement unit, and is more relevant than e.g. the variance (v) as inequality analysis requires comparisons. When all resources are equal then CV = 0, because v= 0 (Bellù and Liberati, 2006a). There is no upper limit. The CV, measures the relative variation independently of the mean resource level. The *Gini coefficient* (*GI*) is one of the most widely used inequality measure and it is defined as the area between the line of perfect equality and the observed Lorenz curve. There are various formulas for artimetic calculation of the Gini coefficient. This is one of them (Bojer, 2003):

$$GI = \frac{2\sum_j Y_j}{n^2\bar{y}} - \frac{n+1}{n}$$

Given that resources Y are ranked according to size, and j is the ranking number and $\bar{y}$ is the mean. The advantage of GI is that it is a widely known measure and easy to explain and interpret in a non-technical way. Though it is often claimed that the Gini coefficient tends to give greatest weight to the middle part of the distributions, this is incorrect, as it emphasizes that part of the distribution where the density is greatest (Bojer, 2003). The *basic Theil index* has higher resolution for changes to higher resource and is given by (Ibid.):

$$T = \frac{1}{n}\sum_{j}^{n} \frac{Y_j}{\bar{y}} \ln\left(\frac{Y_j}{\bar{y}}\right)$$

Atkinson's index is a welfare-based inequality measure; that quantifies the social deprivation involved in unequal water distribution, in terms of shortfalls of equivalent water allocation. The Atkinson index can be turned into a normative measure by imposing an inequality aversion parameter, ε, to weigh water use. Greater weight can be placed on changes in a given portion of the water distribution by choosing the level of inequality aversion. The Atkinson index becomes more sensitive to changes at the lower end of the resource distribution as ε approaches 1. Conversely, as the level of inequality aversion falls (that is, as ε approaches 0) the Atkinson index becomes more sensitive to changes in the upper end of the resource distribution. The Atkinson index is defined as (Bojer, 2003):

$$AI = 1 - \left[\frac{1}{n}\sum_{j}^{n}\left[\frac{Y_j}{\bar{y}}\right]^{1-\varepsilon}\right]^{\frac{1}{(1-\varepsilon)}} \quad \text{for } \varepsilon > 0 \; and \; \varepsilon \neq 1$$

This study compare two inequality aversion parameters, i.e. ε = 0.20 and for ε=0.80. The higher value of ε the more society is concerned about inequality (Atkinson, 1970).

The coefficients applied in this thesis (except CV) ranges from 0 to 1. The closer an inequality measure is to zero, the less inequality. All measures applied in this study are *ordinal measures*, except the Atkinson index. Inequality measures can also be selected on the basis of axioms. The axiomatic approach allows us to obtain a mathematical formula that delivers a class of inequality measures that satisfy a set of *elementary properties (axioms)* that we think inequality measures ought to have. The most common are (Cowell, 2009.):

- Anonymity (or symmetry): it does not matter who the high and low water receiving hectares are.
- Population independence: inequality does not change by changes in the size of the population.
- Scale independence means that if each IU's water allocation changes by the same proportion, then inequality should not change.
- Normalization: if all individual hectares have the same water use, there is no inequality.

4.3.2.2 Decomposition by sub group

Decomposable inequality indexes can provide an analytic and practical method to understand the origin or structure of inequality. Inequality may stem from different groups or sectors of population with different intensities (e.g. senior and junior water use claimants). Hence, decomposability is a very important attribute to inequality measures, and it implies the possibility of calculating the contribution of each group to total inequality (Bellù and Liberati, 2006b). The decomposability of inequality measures requires a consistent relationship between overall inequality and its parts. More specifically, the within groups element captures the inequality due to variability of the resource within each group, while the between group element captures the inequality due to the variability of income across different groups (Bellù and Liberati, 2006b).The Theil index allows for a perfect and complete decomposition of the total level of inequality into the inequality within sub-groups of the population (Conceição and Ferreira, 2000) the within-group contributions, and the between groups contribution. If units of a population can be classified into mutually exclusive and totally exhaustive groups, then *Theil's T statistic* is made up of two components, *the within group element* (T_w) and *the between group element* (T_b) (Hale, 2003): $T = T_w + T_b$ The IUs were divided into the four population groups: explained in Section 4.1.3.3. The within element identified the contribution to inequality of the variability of these four groups taken separately. Assuming m groups, its decomposition takes the following form (Bellù and Liberati, 2006b):

$$T = \underbrace{\sum_{k=1}^{m} \left(\frac{n_k}{n}\frac{\bar{y}_k}{\bar{y}}\right) T_k}_{(T_w)} + \underbrace{\sum_{k=1}^{m} \frac{n_k}{n}\left(\frac{\bar{y}_k}{\bar{y}}\right) \ln\left(\frac{\bar{y}^k}{\bar{y}}\right)}_{(T_b)}$$

The 'within' part of the decomposition, is weighted average of the Theil inequality indexes of each group (T_k), with weights represented by the total resource share (the product of population shares and relative mean incomes). The 'between' part of the decomposition use subgroup means $\bar{y}_k$ instead of actual resource. This is due to replacing the e.g. water allocated in each group with the average water allocation level of the same group. These calculations were made in Excel.

4.3.2.3 *Concentration curves*

Parade of Dwarfs also called Pen's Parade (Pen, 1974) and Lorenz curves (Lorenz, 1905) are used as a way of visualizing the distribution of selected variables. *The Parade of Dwarfs is the inverse distribution function, $F^{-1}(u)$,* and plots the ranked variable of interest; this study just refers to it as the resource against the cumulative population. The dominant distribution's Parade lies nowhere below and at least somewhere above the others (Litchfield, 1999).

The Lorenz Curve, L(u), is one of the most common ways of representing resource distributions in empirical works due to its immediate comparability with the equality-line, representing the most egalitarian distribution. It is a graph representing for every *u* between

0 and 1, the proportion of resources accruing to the poorest fraction, u, of the population. The Lorenz curve is the plot of cumulative resource shares against cumulative population shares. If one of the Lorenz curves lies nowhere below, and at least somewhere above, the Lorenz curve of distribution is Lorenz dominant to the other one. Any inequality measure which satisfies the anonymity and the Pigou-Dalton transfer principle will rank two distributions the same as the Lorenz curves (Atkinson, 1970). If we plot the slope of the Lorenz curve against the cumulative population proportions, *F*, then we are back precisely to the Pen’s Parade (scaled so that mean resource equals unity) (Cowell, 2009). For further reading, Cowell (2009) and Bojer (2003) have written comprehensive overviews of inequality measurement, concentration curves and axioms. Moreover, an array of peer reviewed methodological papers with empirical examples on inequality measurements can be found at the FAO EASYPol-Resources for policy making website[11].

4.3.2.4 Types of normative measures

There is a trade-off between ranking distributions by choosing a specific Social Welfare Function (SWF) or by looking for Lorenz dominance. The advantages of choosing a specific Social Welfare Function are the possibility to calculate the levels of welfare for any given resource distribution, and the possibility to reduce any resource distribution to a single number, thereby generating a ‘complete ranking’. (However, to do this, a mathematical relationship between individual resources and social welfare has to be specified). There are several difficulties in choosing a specific Social Welfare Function. Issues includes the choice among many functional forms and lack of guarantee that the same ranking holds for alternative functional forms of SWF, even if all of them satisfy the two general requirements that the SWF should be increasing in resource and concave (Y’>0 and Y’<0). In many cases, however, in order to recognize the best distribution in terms of welfare it is enough to identify the Lorenz dominating distribution and apply the Atkinson’s theorem. In this case, it is not necessary to specify the functional form of the SWF (Bellù and Liberati, 2005). Ranking distributions on the basis of their Lorenz dominance is a way to rank resource distributions on welfare grounds assuming the point of view of an inequality adverse decision maker, and using some properties of the Lorenz curves. This study will not

[11] *www.fao.org/easypol*

consider SWF: Social Welfare Functions, which provide the basis for making inequality judgments deriving inequality measures consistent with judgments.

4.4 SUMMARY

The chapter describes the approach, data and methods applied in the empirical part of the thesis (Chapter 6 and Chapter 7). The secondary data applied in the study were derived from the data base of the latest irrigation inventory for the Guadalquivir RB that makes the basis for the draft GHBP in line with the implementation of the WFD. The database included both field data and estimates for irrigation water management for the entire basin for the management scenario of year 2008 and year 2015. These data were used to make the draft GHBP. Individual irrigator data were not available. Hence, the variables were analyzed at the lowest level of aggregation adapted to regression modelling (frequency weighting) and inequality measuring (disaggregation) to cope with issues of scale and level. The polynomial regression models could be applied to analyze impacts and responses to basin closure depending upon year or period of appropriation. The specific models will be presented in Chapter 6. The dimensions for analyzing inequality and a selection of descriptive inequality measures and concentration, and decomposition analysis of Theil index were presented. These were applied in the empirical analysis presented in Chapter 7.

CHAPTER 5

THE GUADALQUIVIR RIVER BASIN: A CLOSING BASIN

'Among the many things I learnt as a president, was the centrality of water in the social, political and economic affairs of the country, the continent and the world'

Nelson Mandela (b. 1918), World Summit on Sustainable Development, 2002

Equity should be characterized according the contextual details in order to understand what the concept of equity means in a given situation (Young, 1994). Consequently, the aim of this chapter[12] is to present the contextual setting of the Guadalquivir RB. Moreover, the chapter attempt to explain how basin closure has envolved, emerging from natural and man-made factors. The chapter comprises four sections. First an overview of the 'basin characteristics' (5.1) are given, next the 'basin management´ (5.2) is described, then the 'basin trajectories' (5.3) are outlined following a DPSIR logic, and finally a chapter summary (5.4) is presented.

5.1 THE RIVER BASIN

'The Guadalquivir comes from the Arabic word wadi al-Kabir (large river)', while the Romans named it Betis.

Wikipedia

5.1.1 Geography

The Guadalquivir RB is located in the southern part of the Iberian Peninsula draining 57,527 km^2, traditionally it has been supposed that it is born in the Sierra de Cazorla in Southeastern Spain, and flowing south-west past Córdoba and Seville into the Gulf of Cadiz near Sanlucar de Barrameda in the Atlantic Ocean. The Guadalquivir river is the longest in

[12] *Parts of this chapter has been published: Berbel, J., Kolberg, S., and Martin-Ortega, J., 2012. Assessment of the Draft Hydrological Basin Plan of the Guadalquivir River Basin (Spain). International Journal of Water Resources Development. DOI: 10.1080/07900627.2012.640875.*

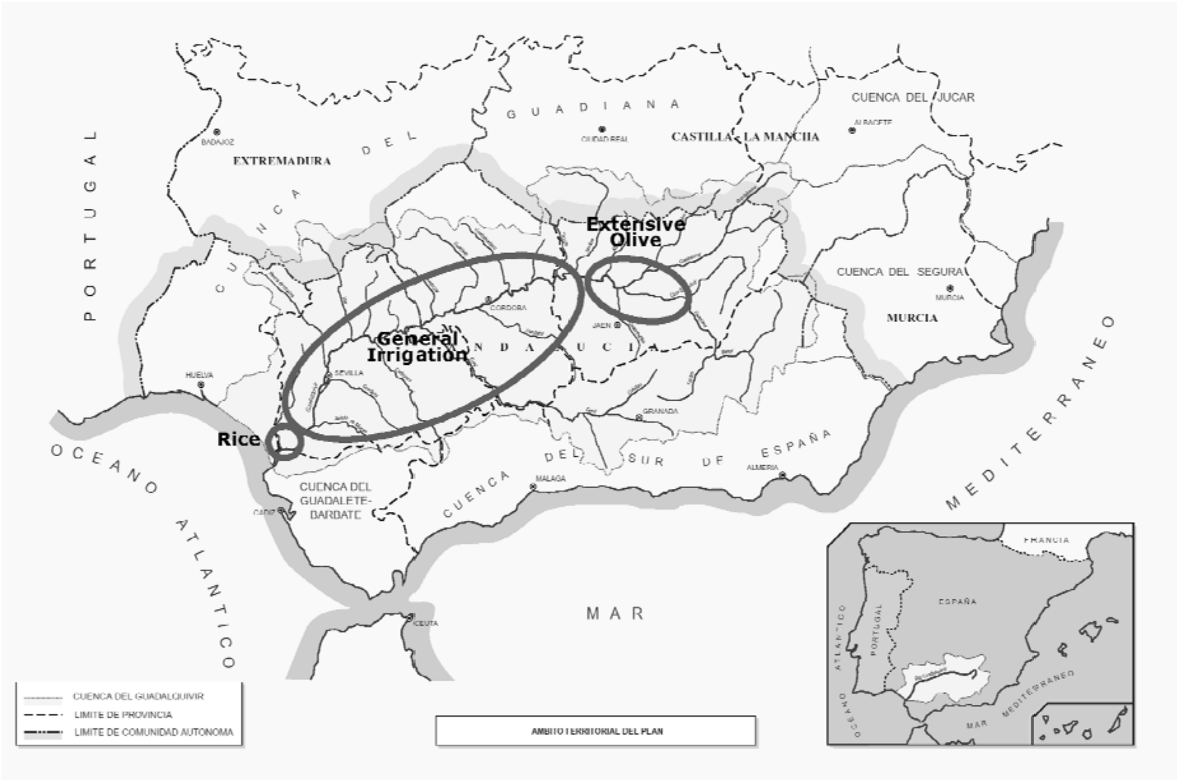
Southern Spain, with a length of around 650 km. The total length of the river and its tributaries add up to around 10,700 km. Its middle reaches flow through a populous fertile region at the foot of the Sierra Morena, where its water is used mostly for irrigation. The lower course of the Guadalquivir river passes through extensive marshlands (Las Marismas) that are used for rice cultivation. The Guadalquivir river is tidal up to Seville, corresponding to 80 km upstream. Seville is a major inland port and head of navigation for ocean-going vessels. The Guadalquivir is accessible for navigation purposes between Seville and the sea. The basin is located in four autonomous communities (Comunidad Autónoma). Most of the basin drains through Andalusia (90.2%), with smaller tributaries draining parts of Castilla-la Mancha (7.1%), Extremadura (2.5%) and Murcia (0.2%) (CHG, 2011) (Table 9).

Table 9 Spatial distribution of basin: autonomous communities

Autonomous communities	Province	Province (km^2)	Basin (km^2)	Basin/province (%)	Basin participation (%)
Andalusia	Almeria	8.774	229	2.6%	0.4%
	Cadiz	7,385	532	7.2%	0.9%
	Cordoba	13,718	11,135	81.2%	19.4%
	Granada	12,531	9,960	79.5%	17.3%
	Huelva	10,085	2,552	25.3%	4.4%
	Jaen	13,498	13,002	96.3%	22.6%
	Malaga	7,276	489	6.7%	0.9%
	Seville	14,001	14,001	100.0%	24.3%
Castilla-la Mancha	Albacete	14,862	800	5.4%	1.4%
	Ciudad Real	19,749	3,300	16.7%	5.7%
Extremadura	Badajoz	21,657	1,411	6.5%	2.5%
Murcia	Murcia	11,317	116	1.0%	0.2%
TOTAL		154,853	57,527	37.2%	100.0%

Source: Adopted from CHG (2011).

Figure 6 Map of the Guadalquivir river basin in Southern Spain.



Source: Adapted from CHG (2009)

5.1.2 Climate

The Guadalquivir RB has a typical Mediterranean climate with high intra-annual and inter-annual variation in discharge. The mean annual precipitation is estimated to be 630 mm, ranging from 260 to 983 mm (SD 161 mm). The summers are dry (rainfall<10mm), and winters are wet (Sabater et al., 2009). The average annual temperature is 16.81°C, with a strong intra-annual variation in extreme temperatures (CHG, 2011). Water and land use

The surface waters of the Guadalquivir have an annual flow of 7,100 million m^3 and groundwater has a flow of 2,576 million m^3. Currently half of these surface waters and groundwater are extracted for use by agriculture (85%), domestic (11%), industry (3%) and tourism (1%). The per capita water consumption in the basin in 2005 was 1,600 m^3 (Martin-Ortega et. al, 2009). The most important land covers in the basin are forestry (49%), agriculture (47%), urban areas (2%) and wetlands (2%) (CHG, 2010b). The irrigated area of the Guadalquivir RB contains 25% of Spain's irrigated land (Mesa-Jurado and Berbel, 2009).

Olive covers the largest number of hectares (more than half the surface), while rice has the highest average water allocation per hectare (Table 10).

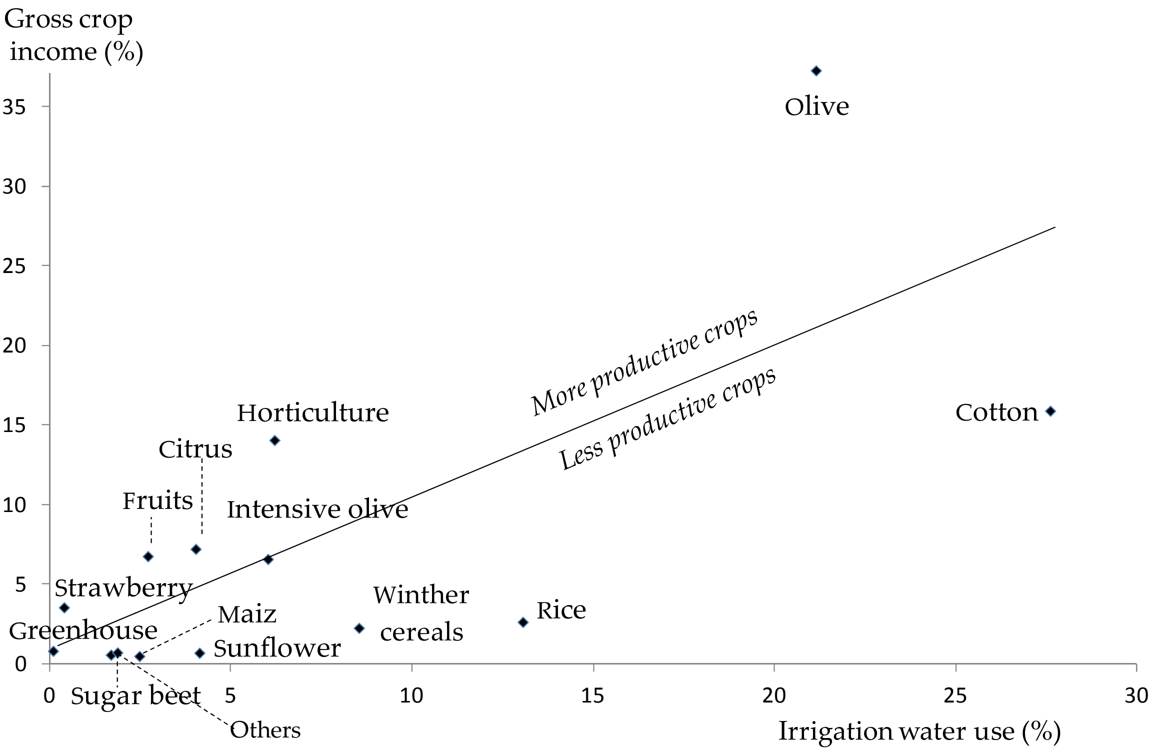
Table 10 Crop type, irrigated area and net allocation in the Guadalquivir RB (2008)

Crop type	Irrigated area (ha)	Net water allocation (m^3 ha^{-1})
Olive	393,520	1,500
Cotton	127,031	4,500
Extensive winter cereals	79,598	2,430
Olive (intensive)	69,568	2,200
Rice	35,530	10,400
Horticulture	34,278	4,500
Citrus	27,677	4,000
Sunflower	25,569	3,510
Fruit trees	17,833	4,000
Others	13,612	4,500
Maize	9,300	5,100
Sugar beet	8,072	4,500
Strawberry and raspberry	3,808	3,000
Greenhouse	591	4,500
TOTAL	845,986	

Source: Author's calculations based on data from CHG (2010a).

Figure 7 shows the estimated total share of irrigation water allocation (m^3) relative to gross income (€) for all crops in the Guadalquivir RB. The estimated gross water productivity and water costs of these crops are given in Annex 4.

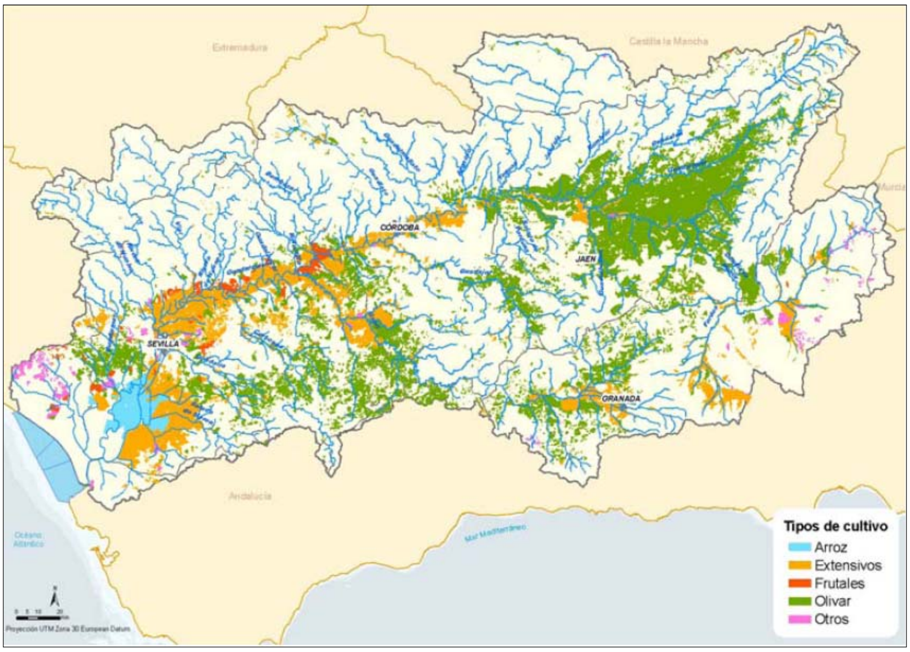
Figure 7 The total share of irrigation water allocation relative to gross income in the Guadalquivir river basin.



Source: Author's calculations based on data from CHG (2010a).

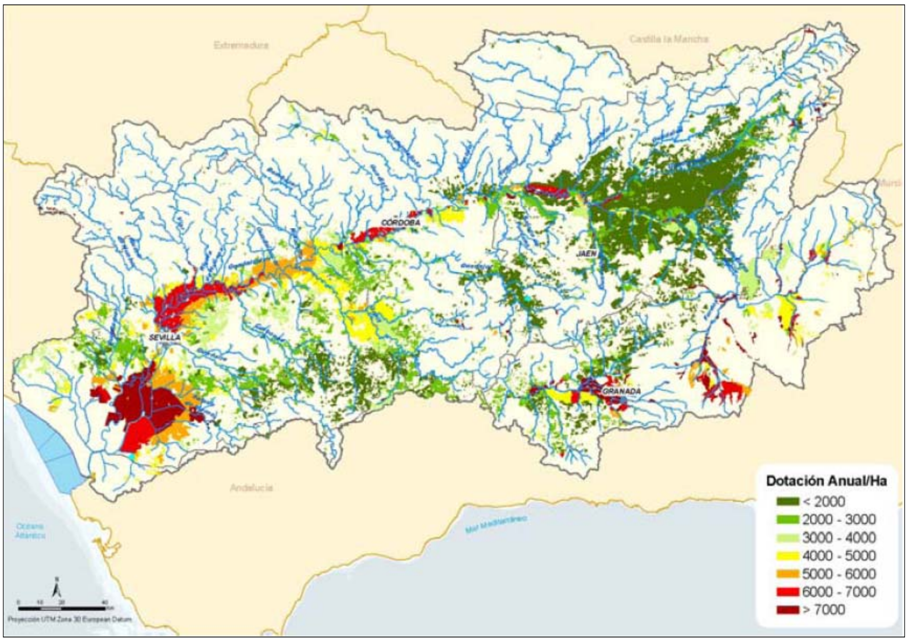
The spatial distribution of crops is given in Figure 8, and spatial distribution of net water allocation ($m^3 ha^{-1}$) is given in Figure 9.

Figure 8 Spatial distribution of crop type in the Guadalquivir RB (2008).



Source: (CHG, 2010b; p. 108).

Figure 9 Spatial distribution of annual water allocation ($m^3\ ha^{-1}$).



Source: CHG (2010b, p.109).

5.2 BASIN MANAGEMENENT

5.2.1 Institutional setting

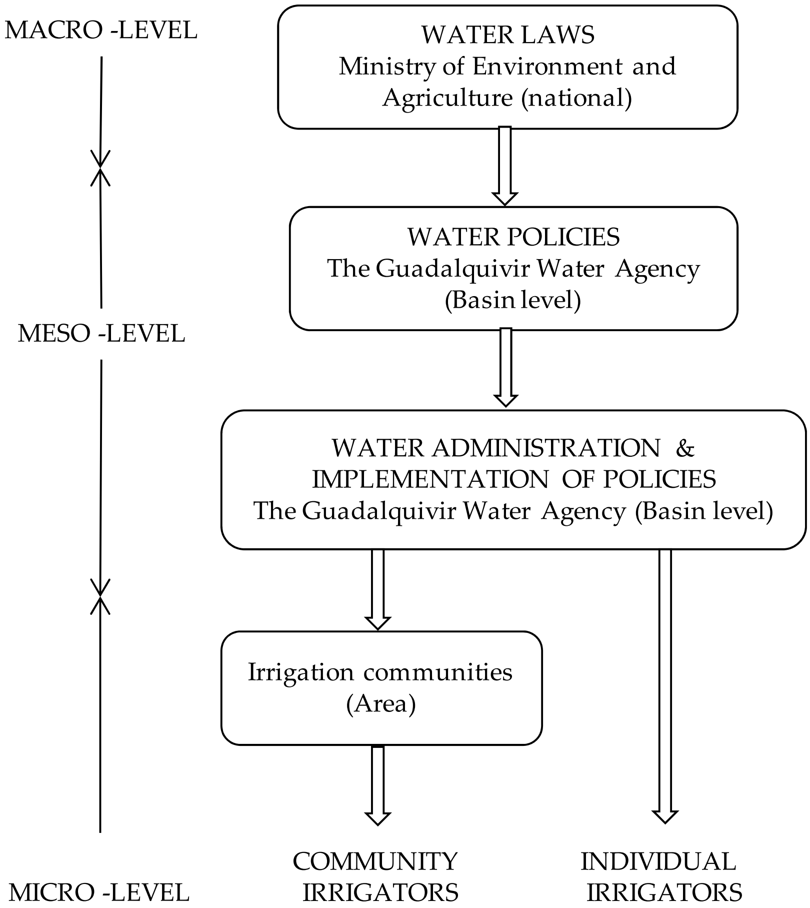
'The primary responsibility for ensuring equitable and sustainable water resources management rests with governments…'

Bonn International Conference on Freshwater, 2001.

Spain has one of the longest histories of any country in developing formal governmental authorities on the RB scale (Bhat, 2004). The first RB authority in Spain, in Spanish called Confederacion Hidrografica (CH), was the Water Agency of Ebro in 1926, followed by the Water Agency of the Guadalquivir RB, *Confederacion Hidrográfica de Guadalquivir (CHG)*, constituted in September 1927 (ALMUDAYANA, 2002). The Guadalquivir Water Agency experienced many changes that have reduced and expanded their responsibilities, and, accordingly, their participatory structures over the years. The current institutional management levels in the basin are illustrated in Figure 10.

Water laws are developed by the Ministry of Environment and Agriculture, while the water policies of the GHBP are designed by the Guadalquivir Water Agency, acting at a basin level. Between 2007 and 2011 the Regional Government through the Andalusian Water Agency (Agencia Andaluza del Agua), was in charge of implementing and monitoring water policies in the Andalusian part of the basin. However, this has been cancelled through juridical procedures, and the whole basin is again to be managed from a basin perspective directly by the Guadalquivir Water Agency. Finally, the main role of formal irrigation communities is to facilitate and to allocate common water resources among its members. Other key institutions are the irrigation associations. FERAGUA (Asociación de Comunidades de Regantes de Andalucía), established in 1994, is the largest irrigation association in Andalusia, claiming to represent irrigators cultivating a total of more than 300,000 hectares of the basins irrigated land. The association defends the interests of its members through dialogue and collaboration with government (FARAGUA, 2012). AREDA (Asociación de regantes de Andalucía), established in 2005, is a similar association claiming to represent more than 207,530 ha of irrigated land, and 48,639 Andalusian irrigators (AREDA, 2012).

Figure 10 Water Management levels in the Guadalquivir RB.



Source: Author's elaboration.

5.2.2 Milestones in legislation and management

In Spain traditional water policy has been based on water supply availability, especially for irrigation (Lopez- Gómez et al., 2008), and there was an intense political debate around the National Hydrological Plan (2001) that makes the idea of 'New Water Policy' a key feature of the Autonomous Region's change in public water policies. The pillars of Spain's new water policy focus on adjustment to new European regulations, modernization of irrigation systems and urban supply and treatment, risk management, inclusion of environmental needs in policy, and stakeholder participation to ensure transparency of information and decisions (Lopez- Gómez et al., 2008). Costejá et al. (2002) analyze how the water regime in Spain has undergone deep transformations regarding property rights and policy design whilst the number of uses of water have increased and the scope of uses regulated has expanded. The main uses of water considered in the 19th century legislation are generally limited to agriculture and population supply. In the 20th century, mainly after the fifties, the number and type of uses noticeably increased because of the rapid development of industry and the tourist sector. In the eighties and nineties, environmental protection and nature conservation became new and important uses, as in the rest of the EU. These tendencies can be observed in Table 11 that shows the Guadalquivir RB´s milestones in legislation and management.

Under the Water Act, the design and implementation of HBPs have been enforced since 1985 and the Special alert and drought management plan since 2000. The Draft HBP includes a Programme of Measures (PoM), as required by the WFD, but it has a wider focus because it attempts to address the need for a detailed analysis of water supply to all economic services including quantity and reliability. The HBP also includes regulation for the prevention and management of drought and floods. The average expected increase in water cost due to the implementation of technical measures included in Draft GHBP are in the range of 60% for urban sector and 160% for irrigators (Berbel et al., 2012). These increases in cost are solely due to cost recovery of the new measures included in the PoM. However, it is important to acknowledge that the PoM also includes the extensive use of volumetric tariffs as the majority of the farms pay flat land tariffs and most of the urban users are connected to collective condominium counters.

Table 1 Milestones in water legislation and management the Guadalquivir river basin

Year	Milestones
1876	Water Act, the first one, amended in 1886.
1957	The Treaty of Rome and the successive creation of the Common Agriculture Policy (CAP) (important reforms in 1992/2000/2003/2010), with the objectives to: - Increase productivity - Ensure fair living standards for the agricultural community - Stabilise markets - Ensure availability of food - Provide food at reasonable prices
1985	The 1985 water law ('la ley de aguas de 1985'), core of current legislation: - Water considered public domain, with exception of groundwater use that was previously registered under the 1876 Law - Water planning principles for national hydrological plans - Consolidated a financial regime for water users - Consolidate the institutional role of basin agency: autonomy, financial resources and personnel to become the actual decision maker - Defined a co-decision making model between direct water users and interested administrations for basin water planning and managements
1998	The Guadalquivir Hydrological Basin Plan (GHBP). Aimed to: - Meet water demands, balance and harmonize regional and sectorial development - Increase the water availability, protect its quality, ensure employment - Obtain a rational water use in harmony with the environment and the natural resources.
1999	Amendment of the 1985 Water Act: - Regulation of voluntarily exchange of water rights through water banks in case of drought and severe scarcity problems. - Public corporations in building water works and recouping the costs by means of sounder financial arrangements. - Desalinized and reused water considered public domain, and the issuance? of special water rights to its users.

2000	EU Water Framework Directive (WFD): - A framework for community action in the field of water policy - Significant changes of focus in e.g. water pricing, ecological objectives, political processes, public participation - Rebalancing of priorities from ensuring water supplies to all economic users to improving the ecological status of all water bodies - Adopted by the Spanish legal regulations in 2003.
2001	The National hydrological plan ('El plan hidrológico nacional'), approved by Law 10/2001, of July 5, amended in 2005: - Sets the basic elements of coordination of Hydrological Basin Plans (HBPs) and transfers of water resources between different territorial areas - Planned changes in use of water affecting domestic and irrigation supply.
2005	Agreement for water in the Guadalquivir river basin ('Acuerdo por el agua en la cuenca del Guadalquivir'): - An unanimous public consensus on the 'new irrigated land moratorium' to not expand irrigated areas, with the exception of legally binding public projects under development previously approved by the CHG in 2005.
2007	Special alert and drought management plan ('Plan especial de actuación en situaciones de alerta y eventual sequía de la cuenca hidrográfica del Guadalquivir'): - Water management strategies in cases of water shortage
2010	The Draft GHMP with a focus on: - Reducing water demand and investing in point pollution (urban sanitation) - Meeting the objectives of the WFD.
2015	The objectives of the WFD to be accomplished

Source: Adopted from Garrido and Llamas (2008); Costejá et al. (2002); FAO (2002).

Accordingly, the GHBP and PoM imply a significant increase in cost of water services for both urban and irrigation sectors. The average per capita income in the basin is 11,250 € per capita per year. PoM supposes an impact of 1.3% of average income. Users will support the total cost directly by paying an increase of 67.4% in water fees (98.8 € per capita per year) through an urban tariff or increase in production cost for farmers and industries (Berbel et al., 2012). Spanish regulation has similar objectives as set out in the WFD, such as the good ecological status of water bodies and similar planning mechanisms (public participation, derogation, cost recovery), the key difference with the WFD is the emphasis on quantity-related issues in the Spanish regulation, next to water quality and reliability. Furthermore, water resource depletion and security are particularly relevant under a Mediterranean climate, thus the objectives for supply guarantee and territorial development while achieving and maintaining good environmental status in all water bodies are essential for Spain. This was a core aspect of the debate during the public participation process ahead of the draft HBP, and where particular attention was given to (a) cost recovery; (b) the definition of the minimum environmental flow; (c) supply guarantee; and (d) demand management (groundwater and surface abstraction control.). The law of 1985 (and its amendment in 1999) refers to equitable sharing of burdens (e.g. costs of exploitation, repair and improvement of infrastructure) and of regional development in harmony and equilibrium. Current law does not make specific reference to equity in allocation of water. Neither does the GHBP. Nevertheless, it makes reference to recuperating costs for groundwater extraction, the actual division of costs, however, is yet to be decided, as the decision on the allocation and impact to users depends on criteria of equity and territorial policy.

5.2.3 Priority in water use

The Water Act of 1985 updates priority preferences from the 1879 Water Act, and by doing so, adapted to the new social and economic realities (Costejá et al., 2002). Examples are the explicit addition of hydropower production and the relegation of navigation. The Law of 1985 states that the priorities set in the respective HBPs should be followed, while 'population supply' should always be first priority Table 12).

Table 12 Order of preference for granting concessions

1879 Water Act	1985 Water Act	Draft Hydrological Basin Plan 2010
- Population supply - Trains supply - Land irrigation - Navigation channels - Water mills, ferries, bridges floating - Fishponds	- Population supply - Land irrigation and agricultural uses - Industrial uses for power production - Other industrial uses - Aquaculture - Leisure uses - Navigation and aquatic transport - Other exploitation	- Supply of population - Irrigation and agricultural uses - irrigation - animal husbandry - Industrial uses for electric energy production - Thermal power stations, nuclear, solar and biomass - Hydroelectric - Other industrial uses - Aquaculture - Recreational Uses - Navigation and water transport

Source: Adapted from Costejá et al. (2002) and CHG (2010b).

Other sectors' water needs are rather fixed. The irrigation sector experiences the largest absolute cuts in times of restrictions, and it is faced with intra-sectorial allocation challenges that are urgent to address. These include: How to respect water rights of established irrigators versus the entrance of new irrigators? How to address demand for expansion of the irrigation area? How to deal with potential conflicts between irrigators upstream versus downstream and basin transfers? What should be the rationale for water use in the sector, taking into account socio-economic priorities for the region as a whole? The level of guarantee is higher for urban and industry users than for agricultural users. However, due to water shortages, the full level of guarantee for any sector is frequently not met (CHG, 2010b). The irrigation sector is particularly affected by extreme events, as other uses (urban industry, environment) are prioritized under the water law in a situation of insufficient water resources when the Special alert and drought management plan are implemented. Lack of guarantee could constrain productive activity and lead to uncertainty in crop planning (e.g. use of less productive buffer crops). The sector is also seen to have the biggest potential for saving water compared to other uses that are less flexible in response to cuts and variations in supply (e.g. domestic and industry).

Water rights are associated with land ownership for irrigation purposes or administrative allocation for non-agricultural purposes. Holders of water rights are required to respect their established entitlement both in quantity taken and usage. Currently, the CHG attempts to achieve equity and equality in the irrigation sector by allocating water in proportion to a farmer's planted area, crop water need, and demand (CHG-staff, personal communication, 2010). In the Guadalquivir RB, there are some minor local conflicts (e.g. Castril river and Doñana strawberry farmers) with different views regarding proposed resources allocation in the Draft GHBP. Moreover, some minor differences about water rights allocation between irrigators whose different views have been enlarged into a political issues by the two main irrigators unions in the basin. In situations of drought, the criteria for allocating water between irrigable lands are not spelled out clearly in any public document. An observed practice, however, is that all irrigators are treated the same in times of restriction, a so-called 'equalitarian' allocation (e.g. all users 50% reduction), despite complaints from some irrigators with old user rights. They claim such restrictions damages their administrative rights, as the current allocation is not respecting allocation rights in a chronological order (i.e. older rights get a priority in allocation). As a consequence, new irrigated areas (most of them olive trees with very low water allocation located in the upper valley) have equal priority to 50 year old irrigation areas (most of them in the medium and low valley). These territorial and sectoral conflicts have not been a pertinent public issue yet. Irrigators have tried to solve this allocation problem internally, but the issue may rise in a near future and consequently result in a legal and economic debate.

Currently there is no complete record on who has legal water rights in the Guadalquivir RB. There are irrigators with legal water rights that do not have their licence registered at the Guadalquivir Water Authorities (CHG-staff, personal communication, 2010). In a workshop on prioritization and allocation of water held by the CHG and CENTA 2008 (CHG and CENTA, 2008), the sectors claimed the following:

- There was an agreement among participants that the current prioritization of water uses is not the most appropriate. All agreed it should be more flexible, but the motivations for flexibility were very different.
- The power industry wants more facilities for water, and argues with Spain's need to produce clean 'green' energy with higher efficiency and value than irrigation.
- Farmers do not refuse to be the first in the list after urban water supply, but want the flexibility to more easily sell water they have granted, forgetting that it is a public good that has been assigned by administration.

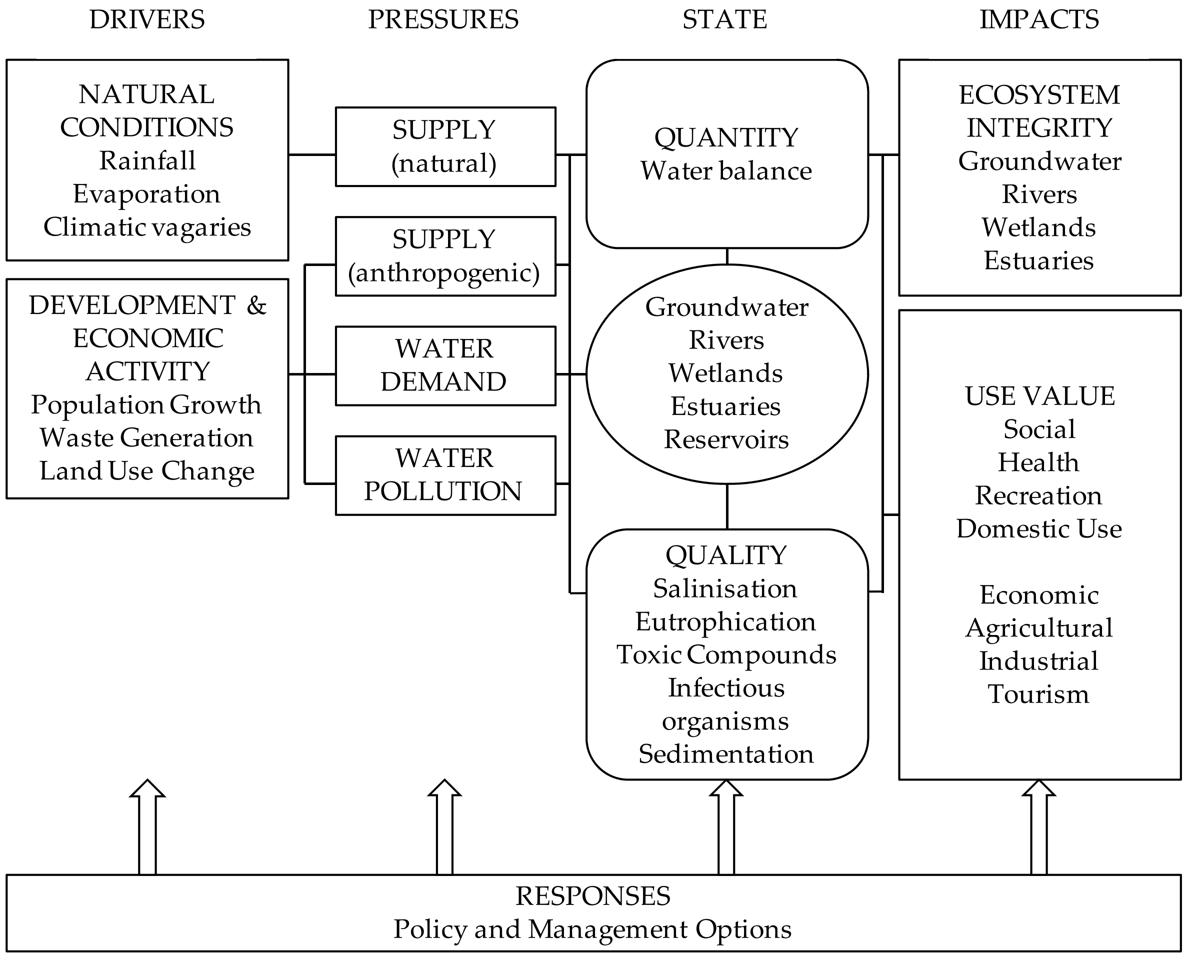
- Environmentalists want each water use be allocated after analyzing costs and benefits, environment and economy, as well as risk.

5.3 DPSIR AND BASIN TRAJECTORIES

5.3.1 The DPSIR system view

To better understand how the Guadalquivir RB has reached basin closure, the evolution of the basin is described through a DPSIR system view.

Figure 11 A DPSIR-framework for water management at basin level.



Source: Adopted from: Walmsley, 2004; Kristiansen 2004; Gabrielsen and Bosch, 2003. Note: The chain of causal links seems to differ in literature. Here a standard EEA approach is taken.

DPSIR framework states that natural conditions and social and economic developments exert pressure (waste, and demand) on the water resource. As a consequence, the state of the water resource changes. This impacts ecosystems that may elicit a societal response that feeds back on the driving forces, on the pressures or on the state or impacts directly, through adaptation or curative action. This model describes a dynamic situation, with attention for the various feedbacks in the system (Gabrielsen and Bosch, 2003).

5.3.2 Drivers

It is considered that the Guadalquivir RB is closing, as there are limited possibilities to increase water supply. Simultaneously the overall water demand is increasing because of a set of drivers: increase in population, competitive agriculture, economic development and increasing demand for environmental protection, including water quality and quantity available for environmental uses. Economic activity and development drivers in terms of agriculture, forestry and mining have a long history in the Guadalquivir RB. The first signs of mining of silver and copper date back to 300 BC and was especially active during the Phoenician and Roman periods, and again in the 19th century. The Romans also tended olives and vineyards. Humans have dramatically impacted the landscape, reducing the natural vegetation to small areas. Large alterations in vegetation and land use can be seen in Cordoba and Jaen, where the natural vegetation of evergreen oaks (quercus rotundifolia Lam.) is now replaced with olive tree and other extensive crops (Sabater et al., 2009).

The region's population has been growing, and its economic base has changed the overall levels of need for production, consumption and trade. The basin's current population is around 4.2 million people divided on 476 municipalities. Seville, Cordoba, Granada and Jaen are the most populated cities. From 1986 to 1996 the basin experienced 5.51% population growth, compared with 3.1% growth for all of Spain. More rapid growth in the RB than in the rest of the country is expected to continue (Bath, 2004). The irrigated are in the Guadalquivir RB has augmented from 142,900 ha in 1904 to 715,000 ha in 2004 (Camacho, 2005). The increase has been particularly rapid in the last decade, around 60% from 1995 to 2004 (Parias, 2007). Moreover, comparing the GHBP of 1998 with the Draft GHBP 2010, the increases in the total area of land irrigated has expanded from 410,000 ha to more than 845,000 ha. Due to this expansion, the demand for water has also increased considerably, and the total consumption of water has increased by 1,5% per year since the 1990s, peaking in 2008. Rising demand for irrigation water, coinciding with a series of dry years and reduced recharge, has undoubtedly increased this water deficit. Water used by cities and industry account for just 12% of total water extraction, compared to 88% by agriculture (as mentioned earlier); urban consumption has grown 0.75% per year. Urban consumption has grown from 297 L/person per day in 1992 to 323 L/person per day in 2008 (CHG, 2010b).

Irrigation in Spain was once considered the engine of economic growth, but nowadays it is subject to increased criticism. There are four major issues among the many observations made about irrigation (Fereres and Ceña, 1997):

- Irrigation uses too much water
- Irrigation is inefficient; (about 50% of the delivered water is wasted)
- Farmers hardly pay for the water they use or they do not pay at all.
- Water pollution problems are often caused by agriculture.

Irrigation assures farmers in the Guadalquivir RB of their summer production and allows them to produce high-value crops that would otherwise be imposible to cultivate. The Guadalquivir RB is one of Spanish zones with highest irrigation water productivity (MAPA, 2002). The contribution to employment of one irrigated hectare in the Guadalquivir RB is estimated to be 3.5 times higher than from one non-irrigated hectare of farm land (Berbel and Gutiérrez, 2004). According Berbel et al. (2011a) the high level of productivity of water in the Guadalquivir RB is a factor that drives demand for irrigation; however, the already existing low average irrigation doses is a consequence of the proximity to the limits of the system and the need for the GHBP in demand management. In particular the high profitability of olive crops led to a considerable expansion and intensification of olive crop cultivation in the Guadalquivir RB in the 1980´s. The marginal net profit of water ranges between 0.50 to 0.63 € m^{-3} (Mesa-Jurado et al., 2010), explaining the intense pressure on water allocation for this use. Consequently, for the Guadalquivir RB as a whole, olive groves have become the largest user of water, despite its low dose (1,500m^3 ha^{-1}, with an average RIS[13]=0.62). The average Gross Value Added (GVA) of water in the basin is 0.50 €$^{-3}$ and the average residual value in the basin is 0.31 € m^{-3} (Berbel et al., 2012). Water resources used for irrigation are summarized in Table 13.

Table 13 Irrigated area and consumption according water origin in the Guadalquivir river basin (2008)

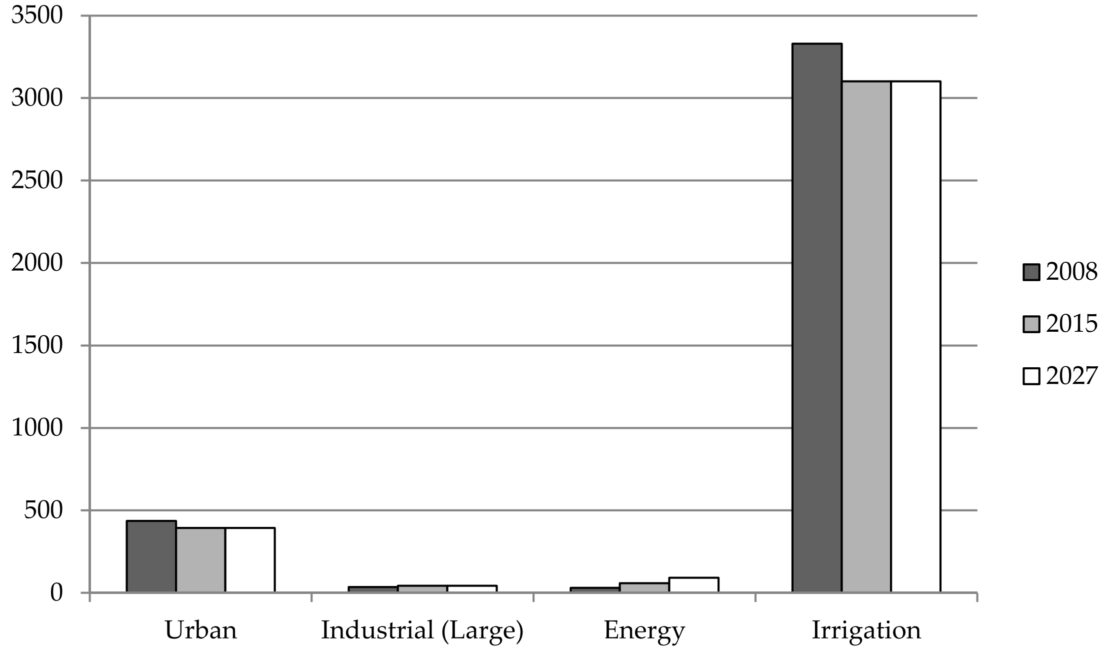
Water source	ha	hm^3	m^3 ha^{-1}
Regulated surface	372,412	2,148	5,666
Non regulated surface	152,398	574	4,118
Groundwater	308,455	726	2,575
Recycled	11,402	36	3,157
TOTAL	845,000	3,568	4,222

Source: CHG (2010b)

Irrigated agriculture is still an important wealth generator and important for the region's rural based economy. As long as water incomes are higher than water costs, farmers seeking increased incomes will be an main driver in the basin. Climate change has raised the stakes, and global warming has been blamed for more frequent droughts. As population grows, the development needed to support it requires increased allocations of water for cities, agriculture and industries. The pressure on water resources intensifies, leading to tensions, conflicts among users, and excessive strain on the environment. There are large spatial and temporal differences in the amount of water available. These differences are expected to change due to climate changes. Assuming a temperature increase of 1°C and a reduction in mean rainfall of 5%, average hydraulic yields are predicted to decrease by 12% in the Guadalquivir RB by 2030, which is above the 8% predicted on average for the whole of Spain (Iglesias et al., 2005). Figure 12 shows the water use scenarios for 2008, 2015 and 2027 as stipulated by the GHBP, indicating that urban and irrigation will decrease its total water use, but still irrigation will be the largest water user by far.

[13] *RIS = Relative Irrigation Supply or the ratio of Irrigation water supply/Maximum ETP.*

Figure 12 Evolution of water allocation in the Guadalquivir river basin by sector (2008, 2015 and 2027).



Source: Author's elaboration based on data from CHG (2010b).

5.3.3 Pressures

The drivers in terms of natural conditions and human activities exert pressures on the water resource in terms of water availability versus demand and pollution. Water demand depends on climate, crop type, soil characteristics, water quality, and cultivation practices. There has been growing pressure on the water resources by the increased cultivation high value irrigated crops (e.g. citrus, olive and vegetables) but at the same time, there have been increases in efficiency of water use per hectare. Irrigation water demand per hectare since 1985 shows a strong tendency to diminish (Camacho, 2005). An in-depth analysis of a representative sample of 22 irrigation districts in the Guadalquivir RB shows that water consumption per unit of irrigated surface has decreased from an average of 7,000 m^3 ha^{-1} (30% of the irrigated area in the Guadalquivir RB) to 5,000 m^3 ha^{-1} in 2004 (Ibid.).

The continuous expansion of irrigated area has in general implied that the total water allocated to each irrigation district has gradually been reduced in recent years, leading to an ad hoc re-allocation of the resources. This reduction in annual allocation will be specified in the draft GHBP. The reductions have been made possible the last years because water saving measures started to be effective and stricter control by the CHG (J. Berbel, personal communication, 2012). Obviously, during years with high pluviometry and accumulated high reserves, water scarcity is not perceived by the population. However, in an average year situation or in drought years, water is scarce and an obvious limiting factor to production.

Projected extraction quantities or 'business as usual scenario' by sector for 2015 are as follows: total demand is 3,969 hm^3, with agriculture consuming 3,402 hm^3, urban 43.4 hm^3 and energy and industry together 58.9 hm^3 (Berbel et al., 2012). It is expected that water extraction by the energy sector will triple if the plans for thermo-solar plants are implemented, while extraction for irrigation and urban development will also increase but at a lower rate. Therefore, the main pressure on water resources comes from irrigation requirements, mainly from high valued horticulture crops such as citrus and strawberries (both in greenhouse and open air) on the Atlantic coast. Crops in the upper Guadalquivir valley such as olives rely on irrigation and rainfall. In the lower valley there is mixed cropping (rice, maize, citrus, cotton) which relies heavily on irrigation, whereas in mountainous areas of the basin only marginal irrigation is undertaken.

5.3.4 State

'Filthy water cannot be washed'
West African Proverb

Irrigation improves crop productivity, reduces risks during dry spells, and makes it possible to grow more profitable crops. However, irrigation is also the source various environmental concerns, including excessive extraction of groundwater, irrigation-driven erosion and increased soil salinity. As a consequence of the pressures, the quantitative and qualitative 'state' of the water resource (rivers, lakes, seas, coastal zones, and groundwater) is affected in terms of physical, chemical and biological conditions. The unpredictability in water resource availability, the increasing demand from different water sectors, and the recurring droughts lead to cyclical scarcity events. The local and seasonal droughts cause aquifer salinisation and environmental stress (CHG, 2010b). Water quality is a major problem throughout the RB. The main pollution sources are urban and industrial wastewater discharge, erosion, nutrients and pesticide runoff from agricultural land (CHG, 2010b). The diffuse pollution from agriculture and urban water use is estimated to contribute elevated levels of nitrogen in water bodies. Therefore water quality as well as quantity is a recognised problem. In fact, in this basin, as in most of Southern Europe, scarcity is a much bigger problem than the quality issues. This study focuses on quantitative water management, in terms of rational use and allocation of water and water saving for irrigation, the number-one user of water user in the Guadalquivir river basin. Natural annual flow levels are 7,100 million m^3 for surface water and 2,576 million m^3 for groundwater. About half of these water flows are used for agriculture (80% of total volume extracted). Currently groundwater constitutes 20% of the total water consumed in the basin. Groundwater abstraction has increased over the last few decades due to increasing demands for the irrigation of olive groves in the upper valley. As of 2008, irrigation systems included drip (64%), sprinkler (14%) and surface (27%) techniques (CHG, 2010b). The water quality and quantity for the Doñana National park, located downstream, is critical. The park is one of the most important wetlands areas in Europe for migrating birds and other ecological habitats. It is critical not only in Doñana wetlands but also for the river where the maintenance of minimum environmental flow implies a constraint for the economic uses.

5.3.5 Impacts

The impacts of over-abstraction of available water include decreases in groundwater levels that in turn can lead to impacts on associated aquatic and terrestrial ecosystems such as wetlands. In addition, over-abstraction of groundwater can lead to the intrusion of saltwater into coastal aquifers. The impact of agricultural activities (deforestation, use of chemical fertilisers and pesticides, intensification) on environment (soil erosion, fertility decline, water pollution, salinisation, depletion of the natural water base of ecosystems) is more and more visible and has not been satisfactorily factored into the analysis of either benefits or costs, or the sustainability of agriculture. It has also been argued that solutions to scarcity and to the water-agriculture related environmental problems can be found in the way water is managed for agriculture.

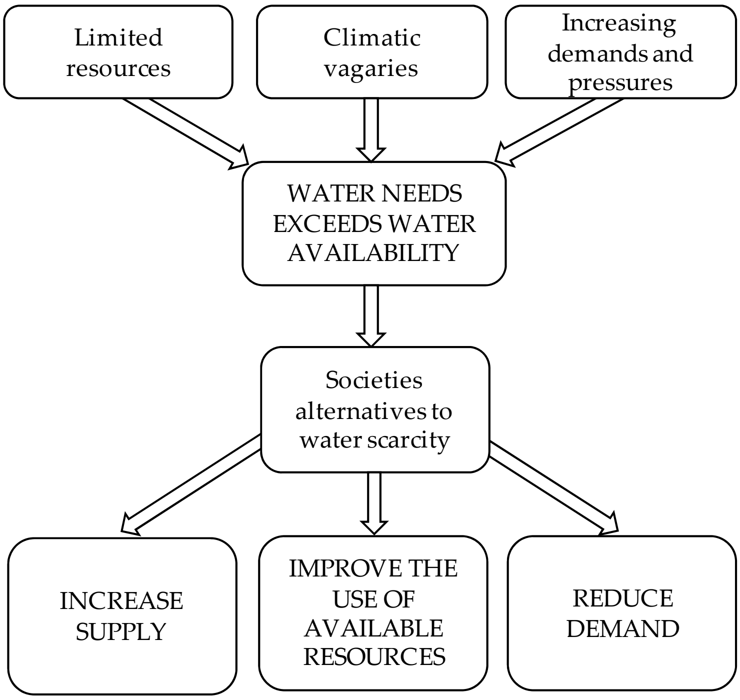
The state of water bodies and the fluctuations and availability of the resources were identified as critical to develop the HBP and PoM. In the Guadalquivir RB there are 443 surface water bodies and 60 groundwater bodies. Surface waters can be further categorised into rivers (392), lakes (35), transitional waters (13) and coastal areas. Among these, 116 are considered heavily modified (reservoirs, and navigation channels). Water shortages are often spatially distributed and may occur during dry spells or in excessively dry years. This prompts stakeholders, managers, and policy makers to adjust their behaviours and strategies, as will be described in the next section.

5.3.6 Responses

'By failing to prepare, you are preparing to fail'
Ben Franklin (1706-1790)

The adaptation from both the State and the local stakeholders to growing RB scarcity can trigger three distinct responses (Molle et al., 2010a) i) Supply responses; augmenting the supply from existing sources, as well as tapping additional sources; ii) Conservation responses; or 'efficiency in use' by making better use of existing resources, withouth increasing supply or the source of water; and iii) Allocation responses; by reallocating water from one user to another, either within the same sector (e.g. agriculture) or accross sectors. Figure 1 illustrate society's alternatives to water scarcity.

Figure 13 Society´s alternatives to water scarcity for irrigation water use.



Source: Authors elaboration.

The key drivers of policy change includes: serious environmental degradation, growing water demand, climatic change, agricultural policy and economic growth (Garrido and Llamas, 2008).

5.3.6.1 Supply responses

The exploitation of surface and groundwater resources in the Guadalquivir RB has reached its limit and with the current situation almost no more reservoirs can be built up. The last large dam constructed was the Breña II that finalized in 2008. The Agreement for Water, states that there should not be any further expansion of land (only those that are already approved, but not implemented, prior to the agreement). This agreement was a movement to stop political pressure from lobbying stakeholders and interest groups claiming additional water rights, especially for new users in the upper basin. Nevertheless, allocation of water for irrigation is still seen as a priority by the general public (Ecobarómetro de Andalucia, 2009).

5.3.6.2 *Improve the use of available resources*

Due to concerns regarding long-term water scarcity, and in order to conserve available supplies, both water authorities and farmers have made great efforts to improve irrigation efficiency during the last years. This process is often referred to as 'modernisation' of irrigation sector and is planned towards year 2015 in the Draft GHBP The net and gross water use for 2008 and 2015 is shown in Table 14 (see Annex 2 for detailed descriptive statistics).

Table 14 Total irrigated area and water use for 2008 and 2015

Year	Irrigated area (ha)	Gross water allocation		Net water allocation	
		Total (hm^3)	By hectare (m^3 ha^{-1})	Total (hm^3)	By hectare (m^3 ha^{-1})
2008	845,986	3,330	3,936	2,463	2,911
2015	881,557	3,105	3,522	2,524	2,863

Source: Author's calculations based on data from CHG (2010a).

In 2012, some of the largest irrigation districts are still in the process of system modernisation. The old open channel networks are being replaced by 'on demand' pressurized networks. The primary aim of these investments is to achieve more efficient conveyance and use of water. As a consequence, nearly half (45%) of the total irrigated area relies on micro (trickle) irrigation, which is now the most common application method in the basin. This tendency is in contrast to 15 years ago when surface irrigation was predominant (61%) whilst trickle (12%) was still regarded as a specialised technique.

Recent studies show how efficiency impacts water savings. For example Rodríguez-Díaz et al. (2011) assesses water savings in the case of Bembezar irrigation district inside the Guadalquivir RB. Even if the results show a reduction of around 40% in the water diverted for irrigation, the consumptive use of water increased considerably, mainly as a result of the adoption of new crop rotations (in particular, increasing the area devoted to citruses). Thus, the majority of the decrease in water consumption corresponds to reductions in return flows and not to proper water savings. Moreover, the total production costs have dramatically increased (four times larger) after the modernization. Energy increased from 10% of the total management, operation and maintenance cost of irrigation before modernization to 30% after modernization. A focus on irrigated agriculture was chosen because agriculture consumes more than 85% of all water extracted and had the biggest potential for water saving, and generally, regions suffering from scarcity and deteriorating situations tend to coincide with regions in which irrigation is major water user (Berbel et al., 2007).

5.3.6.3 *Allocation responses*

While the Northern Spain often has surplus water, southern Spain is often short of water. The process of interfering in this natural imbalance of water by re-allocating between geographical areas, started in the aftermath of the Spanish civil war. The civil war (1936-1939) had left Spain economically and politically isolated. Irrigation was seen as a mean to combat the ailment. Large dams and irrigation channels were constructed and vast areas of dry land were converted into productive land of irrigated crops (Jimenez Torrecilla and Martinez-Gil, 2005). Society adopted the notion that nature and natural hydrological systems were hostile or erroneous and conveyed that believe to Civil Engineers that for the first time had the technology and the public funding to change and 'improve' it. Spanish Hydrology had to be re-balanced to serve human production (Ibid.). Today, the water resources of the RB are highly regulated. This is not only to re-balance natural injustice, but also to store water in case of droughts and floods. There are a total of 65 dams in the RB. These regulate 7,145 hm^3 and will amount to over 7,500 hm^3 when the last dam built start to operate. Additionally there is an important natural regulation capacity, as groundwater can store 2,720 hm^3 per year. There is also an inter-basin transfer (the 'Negratin Almanzora') that transfers water from the Guadalquivir RB to the intensive horticulture in Almeria, located in the Southeast of Andalusia, on the basis of a water market trading and regulated administrative allocation. More flexibility in allocation water systems, which would allow the transfer of water rights from less to more water productive activities, is often demanded. As of the amendment of 1999 of the water act, water markets allow right-holders to trade among themselves through a public water bank set up by the CHG. There is a consensus, reflected in the PoM, that the basin should be closed to any new entrants in the irrigation sector. Further details on the water planning of the Guadalquivir RB can be found in the GHBP (CHG, 2010b) of the Guadalquivir Water Agency. The next chapters presents the first empirical analysis of access to water in the Guadalquivir RB, focusing on the impacts and response parts of the DPSIR-framework, and seniority in water use.

5.4 SUMMARY

This chapter aimed to provide a detailed picture of how this RB has reached basin closure. It is argued here that legislation and management at all levels, how they are shared and used, are historically grounded and that the past development of the basin, and its gradual anthropogenisation, affect the present situation and future prospects. The Guadalquivir RB represents a typical water scarce Mediterranean RB, with increasing pressures and demands for water resources, especially for irrigation, the major water user. Consequently the overall water demand exceeds the water resources available, as supply has reached its limit. Competition for water tends to generate conflicts; thus, how water is shared becomes crucial. Conflicts over water will probably increase. Such conflicts are complex, involving competition among multiple users and among geographical regions with disparate water endowments. As governments are searching for ways to increase water security for rural and urban water uses, the need to articulate water rights and improve water allocation practices is rapidly becoming important.

CHAPTER 6

ACCESS TO WATER IN A CLOSED BASIN

'We forget that the water cycle and the life cycle are one.

Jacques Cousteau (1910-1997)

This chapter[14] addresses objective 2 of the thesis (See Section 1.3) to obtain a better understanding of how the irrigation sector has adapted to basin closure in the Guadalquivir RB. The chapter has eleven sections. First the analytic framework is presented (6.1), next formal and informal water access is described (6.2), followed by model description and results for each a-priori hypothesis stated in the analytic framework (6.3-6.7), and then the correlations between impacts and responses at basin level are given (6.8). Next, a descriptive analysis of coping strategies for restrictions in supply is presented (6.9). The results are then discussed (6.10) and summarized (6.11).

6.1 ANALYTIC FRAMEWORK

'Agriculture's role in generating water scarcity and degrading high quality surface and groundwater for marginal output – is not disputed'

FAO (2007)

A DPSIR-framework served to describe the contextual setting of the Guadalquivir RB in Chapter 5 (Figure 11, p. 83). In this chapter, the framework is adapted and used to present the a priori hypothesis to be tested and to put the empirical results in context for discussion of the results. Data were taken from the Guadalquivir RB irrigation inventory as described in Chapter 4. The unit of analysis is referred to as an Irrigation Unit (IU)[15]. Table 15 presents the descriptive statistics of the key variables analyzed in this chapter.

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[14] *Preliminary results this chapter was presented at an international congress: Kolberg, S., Dios-Palomares, R., and Berbel J., 2011: 'Determinants for access to irrigation water in Guadalquivir river basin, Spain'. The 7th Symposium for European Freswater Sciences. Girona, 27 June to 1 July – 2011. Oral presentation and proceedings in abstract book.*

[15] *The variables were frequency weighted to homogenize the level and scale of the aggregation units in the database as described in Chapter 4. Therefore 1 IU = 1 ha.*

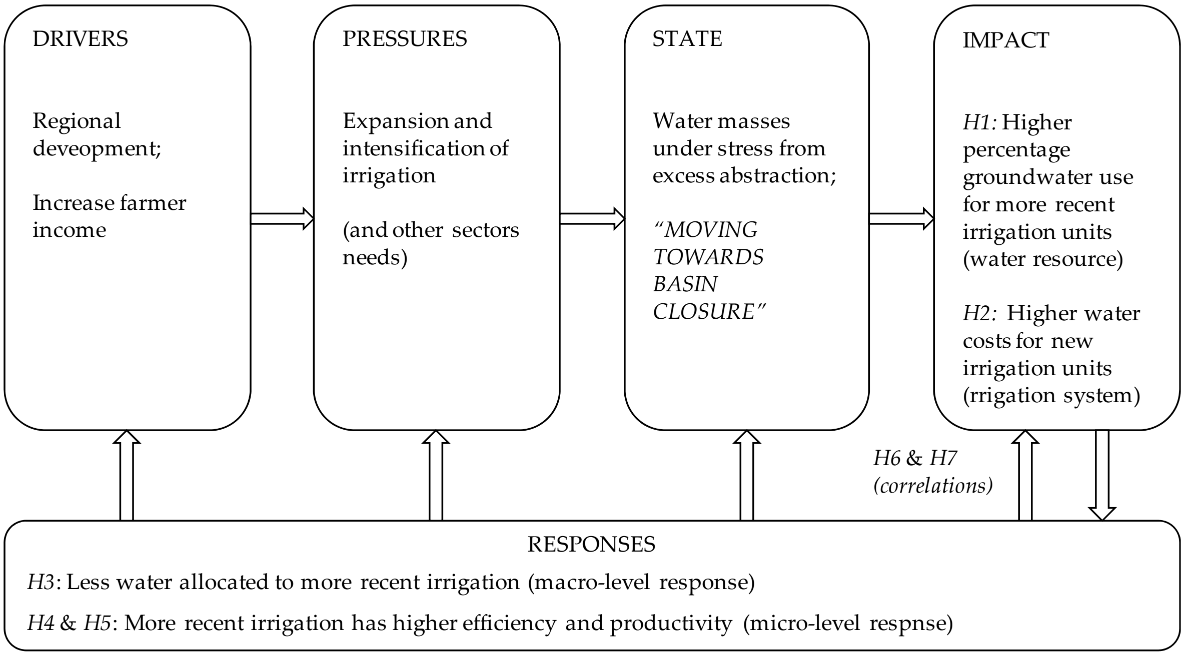
Table 15 Descriptive statistics of variables analyzed (year 2008)

Variable by irrigation unit (IU)	Unit	Min	Max	Mean	SD
Surface water (S)	%	0.0	100.0	61.1	46.4
Water costs (C)	€ m^{-3}	0.000	0.857	0.087	0.090
Gross water allocation (G)	m^3	1,750	12,235	3,936	2,749
Net water allocation (A)	m^3	1,500	10,400	2,911	2,005
Gross water productivity (P)	€ m^{-3}	0.032	10.216	1.294	0.959
Efficiency (E)	n.a.	0.550	0.857	0.777	0.107

Note: N=845,998 after weighting. Decimals are consistent horizontally by variable. Source: Author's calculations based on data from CHG (2010a).

The impacts and responses to access to water were analyzed with respect to *seniority in* water allocation, defined by what year water is first put to use for irrigation (year of appropriation). The *impacts* of basin closure were divided into the impact on the origin of water resources Hypothesis 1 (H1), and impact on irrigation unit's economy in terms of water costs, Hypothesis 2 (H2). The *responses* to basin closure were divided into a basin management response, Hypothesis 3 (H3), and an irrigation system response, Hypothesis 4 (H4) and Hypothesis 5 (H5). In addition to testing the hypotheses above, the aim was also to study the relationship between the impact and the response variables in the DPSIR framework using a correlation matrix to better understand the economic impacts and responses of a closed basin limited by the available data. The correlations studied are explained further on. There is an expectation of a correlation between water productivity (€ m^{-3}) and respectively i) and water costs (€ m^{-3}); and ii); and gross water allocation (m^3 ha^{-1}); Hypothesis 6 (H6). Also, there is an expectation of a correlation between efficiency (-) and gross water allocation (m^3 ha^{-1}), Hypothesis 7 (H7). See Figure 14.

Figure 14 Hypothesis in the context of a simplified DPSIR-framework.



Source: Author's elaboration

These hypotheses were analyzed with the help of T-tests, ANOVAs and fitted polynomial regression models (i.e. linear, quadratic and Tobit models). The use of parametric methods to functions with non-normal distributions is justified by the large sample size, applying the central limit theorem (Motulsky, 2010). The central limit theorem states that when n is large (n=845,998), the estimators are distributed approximately as normal (White, 1984). In the case of heteroscedasticity, log transformations are applied to the dependent variable. Relatively low R^2 adjusted values are expected due to few independent variables and a high number of observations. All the hypotheses are explained in further detail in the following sections. Finally, the relationship of the year of appropriation and the IUs response to water restriction was analyzed. Before presenting the models and the results, the next section analyses the formal and informal access to irrigation water in terms of year of appropriation. This is done to improve the understanding of the level of formal and informal water use in the basin.

6.2 FORMAL AND INFORMAL WATER ACCESS

Formal and informal water access were studied through the variable: reported water right status. This variable had three categories: 1) formal water right (with a license), 2) pending water right (pending license) and 3) no formal water right (no license). In year 2008, 77.2% of the irrigated area had license corresponding to more than 83.5% of the gross water allocation in the RB. Almost 15.9% of the irrigated area reported to have applied for a license (decision pending), corresponding to 12.1% of total water allocation. Finally, 6.9% of the land was reported to not have license and to use 4.4% of the water in the RB (Table 16).

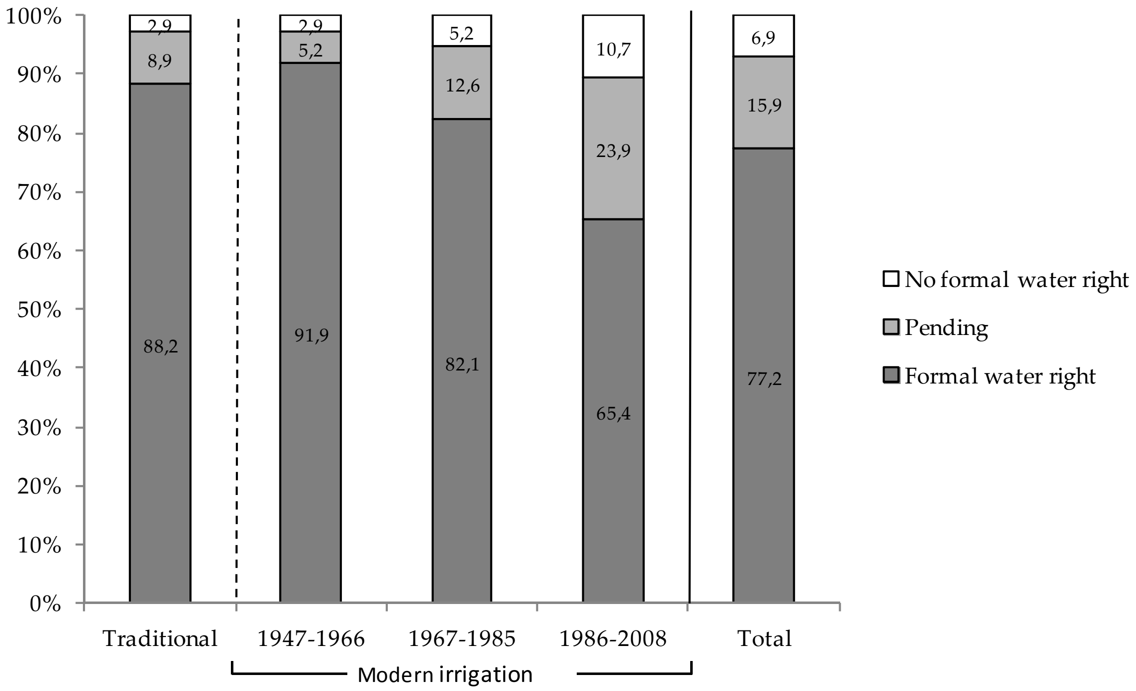
Table 16 Reported water right status by irrigated land (%) and gross water allocation (%) (2008)

Reported water right status	Irrigated area (%)	Gross water allocation (%)
Formal	77.2	83.5
Pending	15.9	12.1
None	6.9	4.4

Source: Author's calculations based on data from CHG (2010a). Note: 0.5 of the IUs had no information on water right status and were excluded from this analysis

Figure 15 shows the IUs reported water right status (%) by the four periods of appropriation justified in Section 4.1.3.3. The Pearson Chi-Square test indicated that water right status was significantly related to period of appropriation (no homogeneity), X^2 (9) = 58,459.6, p=0.000.

Figure 15 Percentage reported water right status for Irrigation Units by period of appropriation (2008).



Source: Author's calculations based on data from CHG (2010a).

Recent irrigation represents the bulk of the irrigated land without formal water right. Moreover, 56.6% of the IUs with pending reported water rights, was located in Jaen, 21.9% in Seville, and 13.2% in Granada, Huelva 4.0%, Cordoba 2.6% and Malaga 1.1%. Those without formal water right were located primarily in Jaen (55.3%) Cordoba (27.0%), Granada (11.8%), and Seville[16] (3.7%). Period of appropriation by province is given in Annex 5. In the hydrological planning for the basin, no distinction was made between the different categories of water right status, and there exists no complete register for public access (CHG-staff, personal communication, 2010). Hence, the empirical analysis in this thesis, as the draft GHBP, is based on all irrigation units in the irrigation inventory, independent upon reported formal water right status. In the next section the models and the results of the a priori hypothesis of this chapter are presented.

[16] *The remaining are less than 1%.*

6.3 IMPACT ON ORIGIN OF WATER RESOURCES

6.3.1 Model

For H1 it is assumed that surface water, in general, is most easily accessible, usually at a lower cost, and consequently the first source of origin to be exhausted. Therefore (H1):

> *If the year of appropriation of an irrigation unit is related to the percentage of surface water it uses, then the more junior the irrigation unit is, the lower percentage of surface water origin it will have.*

To test this hypothesis, variables for the 'origin of water' and 'the year the unit started to irrigate' were defined. There were three origins of water: surface water, groundwater and reutilized water, given in percentage. Almost all the water was either surface water or groundwater, while reutilized water constitutes only a minor percentage (0.5%) and was considered together with groundwater for the interpretation of results. Surface water (S), measured as the percentage of the surface water that an IU is allocated, was used as a quantitative variable to study the origin of water. The second variable, 'the year the unit started to irrigate' is referred to as 'seniority in use'. It has a dual treatment because of the nature of the data. First a categorical variable for seniority in use (q) is defined with two categories: Traditional irrigation, q_{trad}, (historical irrigation that is undated) and modern irrigation, q_{mod}, (year 1947 to 2008). Then, another scale variable called years (t) is defined, and it only refers to modern irrigation. It is measured as the number of years the units has within the period considered. The years, between 1947-2008, are given values between 1-62. First, the hypothesis that the mean of the variable S is different for qtrad and q_{mod} was tested. Then, a regression function S(t) was attempted fit to contrast the same hypothesis but only for modern irrigation units (scale variables). As, in this case, no polynomial regression model was found to explain any clear trend, an ANOVA analysis was conducted to check if there were differences between the periods of appropriation: 1947-1966, 1967-1985 and 1986-2008 (defined in Chapter 4).

6.3.2 Results

Surface water constitutes 74.5% of the water in the Guadalquivir RB, corresponding to 517,172 ha irrigated land. The remaining water is 25.0% groundwater and 0.5% reutilized water. There was a significant difference in the percentage of surface water for traditional *(M=80.7, SD=35.5)* and modern *(M=58.6, SD=47.0)* irrigation; *t(144,553.9)= 174.5, p=0.000* (M, mean; SD, standard deviation). These results suggest that period of allocation has an effect on origin of water. Specifically, these results suggest that the origin of water for traditional irrigation has a higher percentage of surface water compared to modern irrigation. This again implies that modern irrigation has a higher percentage groundwater use in its origin compared to traditional IUs. Table 17 shows the descriptive statistics for surface water (%) by period of appropriation (modern irrigation), that will be analyzed in the continuing section.

Table 17 Descriptive statistics for surface as origin of water by period of appropriation (modern irrigation) (2008)

Period of appropriation	Unit	N	Min	Max	Mean	SD
1947-1966	%	131,303	0.0	100.0	86.2	32.7
1967-1985	%	252,951	0.0	100.0	61.7	46.9
1986-2008	%	364,935	0.0	100.0	46.6	46.9

Source: Author's calculations based on data from CHG (2010a).

Considering only modern irrigation, an one-way ANOVA was used to test for the percentage of surface water for the three periods of appropriation defined above. Since the dependent variable is given in percentage, an arcsin-square root transformation was made to the variable referred to as surface water (%) to homogenize the variance. There was a significant effect of the period of appropriation on the proportion of surface water (%) allocated for the three groups, F(2, 749,186.0) = 38,866.0, p=0.000. Moreover, the Tukey HSD post-hoc comparisons between the three groups in terms of use of origin of surface water showed that the 1947-1966> 1967-1985 group > the 1986-2008 group, all comparisons at p=0.000 level. These results suggest that period when an IU started irrigation has an effect on the origin of the water it uses. Specifically, these results demonstrate that units of more recent seniority in use are allocated relatively less surface water, which implies that most of the origin of water for more recent irrigation is groundwater. It is important to note however, that when comparing traditional irrigation with the 1947-1966 group, the latter is significantly higher (p=0.000).

6.4 ECONOMIC IMPACT

'Water costs nothing for those with everything and everything for those with nothing'

Unknown

6.4.1 Model

Generally, groundwater tends to be more expensive than surface water because of increased costs of access (e.g. pumping). Nevertheless the cost of water increases both for surface water as the new consumers usually need to build larger and more distant infrastructure to get the surface resource as well as groundwater, where new IU usually need to pump water at deeper aquifers as the shallow and cheaper ones are already occupied. H1 indicates that traditional irrigation has more of its origin of water from surface water than modern irrigation. The economic impact of basin closure was studied in terms of water cost, therefore (H2):

> *If the year an irrigation unit initiating irrigation is related to water cost, then the more recent an irrigation unit is, the higher water costs it pays per water unit.*

The average water cost (C), as a quantitative variable, is measured in € m^{-3}. First it was contrasted that the mean of the variable C is different for the two categories of q. Then, the C(t) for modern irrigation was estimated.

6.4.2 Results

The average water cost in the basin is estimated to 0.087 (SD=0.090). There was a significant effect for year initiating irrigation t(144,992.0) = 203.107, p=0.000, with modern (M=0.930, SD=0.091), paying more for water than traditional (M=0.04, SD=0.07). These results suggest that modern irrigation has higher water costs compared to traditional irrigation. Considering only modern irrigation, descriptive statistics for water cost (€ m^{-3}) by period of appropriation is given in Table 18.

Table 18 Descriptive statistics for water cost by period of appropriation (modern irrigation) (2008)

Period of appropriation	Unit	N	Min	Max	Mean	SD
1947-1966	€ m^{-3}	131,303	0.000	0.372	0.051	0.067
1967-1985	€ m^{-3}	252,951	0.003	0.392	0.065	0.068
1986-2008	€ m^{-3}	364,935	0.002	0.714	0.128	0.098

Source: Author's calculations based on data from CHG (2010a).

The prediction equation for water costs (C) in modern irrigation is corrected for heteroscedasticity through a logarithmic transformation of the dependent, and is given by:

$$\text{Ln } \hat{C}(t) = -3.829 + 0.028t, \quad R^2 .\text{adj} = 0.19$$

$$(-1{,}456.519)^{**} \quad (416.887)^{**}$$

The results indicate that t was a highly significant predictor of C (p=0.000). If one undoes the transformation it is found that: $\hat{C} = e^{(-3.829+0.028t)}$ and the derivate with respect to t, is given by $\frac{\partial \hat{c}}{\partial t} = 0.028\ e^{(-3.829+0.028t)}$. The elasticity varies for each IU and for an average of $\bar{t}$=36.737 a one unit increase (more recent IU) water cost is predicted to increase by 0.17 cents. The results indicate that how long time an irrigation unit has irrigated has an effect on the water cost within modern irrigation. Moreover, more recent irrigated areas tend to pay a higher water cost per water unit.

6.5 WATER ALLOCATION RESPONSE

6.5.1 Model

During basin closure, the availability of water is declining; hence it is likely that more recent IUs receive less water, therefore (H3):

> *If seniority in water use is related to allocation of water, then the more recent the unit is, the less water it is allocated.*

As in the previous section, it was contrasted whether the mean of the variable G, measured as $m^3\ ha^{-1}$, is different for the two categories of q. Then, the relationship between G and t is estimated as G(t).

6.5.2 Results

The total gross water allocation to the irrigation sector is estimated to 3.329.824.852 m^3 with an average of 3,936 m^3 ha^{-1} (SD=2,749). For allocation of irrigation water, the difference between traditional irrigation (M=5,202, SD=2,482) and modern irrigation (M=3,774, SD=2,739) was significant; *t (129,268)=-166, p = 0.000*. These results indicate that modern irrigation has lower gross water allocation compared to traditional irrigation. Table 19 shows the descriptive statistics for gross water allocation (m^3 ha^{-1}), for modern irrigation, by period of appropriation.

Table 19 Descriptive statistics of gross water allocation by period of appropriation (modern irrigation) (2008)

Group	Unit	N	Min	Max	Mean	SD
1947-1966	m^3 ha^{-1}	131,303	1,750	12,235	5,985	3,421
1967-1985	m^3 ha^{-1}	252,951	1,750	12,235	4,016	2,373
1986-2008	m^3 ha^{-1}	364,935	1,750	12,235	2,807	2,134

Source: Author's calculations based on data from CHG (2010a).

The prediction equation for gross water allocation, in modern irrigation, is given by:

$$\text{Ln}\, \widehat{G}(t) = 8.782 - 0.021t\text{ , } R^2 \text{ adj.} = 0.26$$
$$(5{,}423)^{**} \quad (-508)^{**}$$

This indicate that t is a highly significant predictor for G (p=0.000). Therefore, $\hat{G}=e^{(8.782-0.021t)}$ and the derivate with respect to t, is given by $\frac{\partial \hat{G}}{\partial t}$ =-0.021 $e^{(8.782-0.021t)}$. The elasticity varies for each IU and for an average of $\bar{t}$=36.737 a one unit increase (more recent IU) gross water allocation is predicted to decrease by -63.262 m^3. These results suggest that the number of years a unit has irrigated really does have an effect on water allocated to an IU. Specifically, these results suggest that more recent IUs are allocated less m^3 per hectare.

6.6 EFFICIENCY RESPONSE

6.6.1 Model

Considering the results of H2 and H3, then recent IUs pay higher water cost and receive less water, hence it is likely that these IUs use water more efficient, i.e. reducing losses in transport and distribution, therefore (H4):

> *If the seniority in use of a IU is related to efficiency in water allocation, then the more recent the unit is, the higher water distribution efficiency it has.*

Similar to previous sections, the variable E is contrasted for the two categories of q, and the relationship between E and t is estimated through E(t). A Tobit model is applied since the dependent variable is censored between [0, 1].

6.6.2 Results

Efficiency (E) is defined as the product of the application, the conduction, and the distribution-efficiency. The average efficiency in the Guadalquivir RB is estimated to be 0.777 (SD=0.107) on a scale from 0 to 1, indicating 77.7% of full efficiency. There was a significant difference in E for traditional irrigation (M=0.669, SD=0.115) and modern irrigation (M=0.791, SD=0.097); t (115,298.330)=317.731, p = 0.000. This indicates that modern IUs have higher E compared to traditional IUs.
Table 20 shows the mean efficiency for by period of appropriation for modern irrigation.

Table 20 Descriptive statistics for efficiency by period of appropriation (modern irrigation) (2008)

Period of appropriation	Unit	N	Min	Max	Mean	SD
1947-1966	n.a.	131,303	0.550	0.857	0.733	0.124
1967-1985	n.a.	252,951	0.550	0.857	0.779	0.091
1986-2008	n.a.	364,935	0.550	0.857	0.820	0.076

Source: Author’s calculations based on data from CHG (2010a).

Table 21 shows the results of the Tobit model for E(t) for modern irrigation.

Table 21 Tobit model for efficiency in water allocation by year of appropriation (modern irrigation) (2008)

Variable	Coefficient	Std.error.	p-value
Constant	0.678	0.004	0.000
Number of years (t)	0.003	0.000	0.000
N= 749,189		Log-Likelihood 2,720.986 D.f.: 3	

Source: Author's calculations based on data from CHG (2010a).

The model is highly significant and indicates that for every unit increase of year (more recent) the efficiency coefficient is predicted to increase with 0.003. These results suggest that number of years a unit has irrigated have an effect on efficiency of irrigation systems. Specifically, the results suggest that more recent irrigation units are more efficient in water allocation.

6.7 WATER PRODUCTIVITY RESPONSE

6.7.1 Model

Recent IUs pay more for water (H2) and are allocated less water (H3) and are therefore forced to be not only more technically efficient (to save water) (H4) but probably also more productive (economically efficient), therefore (H5):

> *If the seniority in water use and gross productivity is related, then the more recent a irrigation unit is, the higher its apparent gross water productivity.*

The *gross* (apparent) *water productivity (P)*, is measured as the gross income (I) divided on the gross water allocation (G): $P = \frac{I}{G}$ Similar to above sections, it was contrasted first if the mean of the variable P is different for the two categories of q, follow by estimating the relationship between P and t, as P(t).

6.7.2 Results

The mean P is estimated to 1.30 € m^{-3} (SD=0.99). For P there was a significant difference in the score of traditional (M=0.985, SD=0.938) and modern (M=1,334; SD=0,955) irrigation; t(124,197.301)=108.66, p=0.000, with higher scores for modern irrigation. These results suggest that modern irrigation has higher P compared to traditional irrigation. Table 22 shows P by period of appropriation period of appropriation for modern irrigation.

Table 22 Descriptive statistics of gross water allocation by period of appropriation (modern irrigation) (2008)

Period of appropriation	Unit	N	Min.	Max.	Mean	SD
1947-1966	€ m^{-3}	131,303	0.03	9.16	0.90	0.84
1967-1985	€ m^{-3}	252,951	0.04	10.22	1.23	1.13
1986-2008	€ m^{-3}	364,935	0.05	9.65	1.56	0.78

Source: Author's calculations based on data from CHG (2010a).

For modern irrigation, the prediction function P was given by:

$$\text{Ln } \hat{P} = \underset{(-325.080)^{**}}{-0.852} + \underset{(-334.216)^{**}}{0.022t}, \quad R^2 \text{ adj.} = 0.130$$

This indicate that t is a highly significant predictor for P (p=0.000). Therefore, $\hat{P}$=e $^{(-0.852-0.022t)}$ and the derivate with respect to t, is given by $\frac{\partial \hat{P}}{\partial t}$ = 0.022 e$^{(-0.852+0.022t)}$. The elasticity varies for each IU and for an average of $\bar{t}$=36.737 a one unit increase (more recent IU) gross water productivity is predicted to increase by 0.021. These results suggest that year of appropriation of the IU has an effect on gross water productivity. In particular, our results suggest that more recent irrigation has higher productivity than traditional irrigation. In the next section, the basin level relationships between the impacts and the responses are explored.

6.8 BASIN LEVEL RELATIONSHIP BETWEEN IMPACTS AND RESPONSES

6.8.1 Correlations

Since it could be difficult to decide the causal relationship between the variables in a DPSIR-framework (Maxim et al., 2009), the variables were analyzed through a correlation matrix. Correlation refers to a measure of how strongly two or more variables are related to each other. This is a weaker design than polynomial regressions, as it establishes associations rather than causation, i.e. it does not enable the researcher to meet the criterion of directionality of influence. However, one may strengthen the directionality argument on theoretical and logical grounds. In this case study, it is likely that IUs that receive a lower gross water allocation and pay higher water costs select crops with higher water productivity. Those IUs that receive low gross water allocation are expected to be more efficient than those with high gross water allocation. A positive correlation means that high values of one variable are associated with high values of the other. A negative correlation means that high values of one variable are associated with low values of the other. Hence, the relationship of water productivity and i) water costs and ii) water allocation is expected to be (H6):

> *There is a positive relationship between water productivity and water costs; and there is a negative relationship between water productivity and gross water allocation.*

And for gross water allocation and efficiency (H7):

> *There is a negative relationship between gross water allocation and efficiency.*

6.8.2 Results

The correlation matrix in Table 23 shows the correlation between the dependent variables studied in the above regression models. It was found that all variables were highly correlated (p=0.000).

Table 23 Correlation matrix of basin level impacts and responses (2008)

Variables	Unit	1.	2.	3.	4.
1. Water costs (C)	€ m^{-3}	1			
2. Gross water allocation (G)	m^3 ha^{-1}	-0.475**	1		
3. Efficiency (-)	n.a.	0.448**	-0.506**	1	
4. Water productivity (P)	€ m^{-3}	0.363**	-0.451**	0.463**	1

** Correlation is significant at the 0.01 level. Source: Author's calculations based on data from CHG (2010a).

The hypotheses stated were confirmed. P (€ m^{-3}) was positively correlated with C (€ m^{-3}) and negatively correlated with G (m^3 ha^{-1}). E was negatively correlated G (m^3 ha^{-1}). Next section will analyze the relationship between the period of appropriation and responses to water supply restrictions. No a priori hypothesis was made.

6.9 COPING STRATEGIES FOR RESTRICTIONS IN SUPPLY

The bi-variate relationships between period of appropriation, 1) traditional; 2) 1947-1966; 3) 1967-1985; and 4) 1986-2008, versus three types of *response to supply restriction*: i) water doses response; ii) irrigated area response; and iii) duration and interval response were studied through contingency tables. No homogeneity was found (Pearson chi-square test, p=0.001), indicating that there were a relationship between period of appropriation and water restriction strategies. Comparing Cramer´s V indicated that the water doses response was stronger related to period of appropriation than the irrigated area response, that again was stronger than the duration and interval response. A graphic of these responses are found in Annex 6. However, no clear pattern was found, probably an explanation is that responses are related to crops and farmer adaptation and this is a quite heterogeneous response related more to individual characteristics and decision making that to IU structure.

6.10 DISCUSSION

'Even the narrow notion of physical sustainability implies a concern for social equity between generations, a concern that must logically be extended to equity within each generation.'

Our common future, WCED (1987)

This chapter set out with the aim of assessing the impacts and responses of prior appropriation in access to water in a closed RB - the Guadalquivir RB (Objective 2). A set of a priori hypothesis was tested with t-tests, contingency tables and polynomial regression models focusing on the impacts and responses aspects of the DPSIR-framework. The analyses expanded on the use of the DPSIR-system view that normally does not go beyond the use of indicators. These aspects were studied with descriptive analyses and with statistical tools such as t-tests, ANOVA, contingency table, polynomial regression models and correlation matrix. The basin level data was taken from the Guadalquivir RB Irrigation Inventory database of 2008 (CHG, 2010a). The database did not have an appropriate unit of aggregation in terms of uniform scale and level; hence the analytic units had to be homogenized to minimize estimation errors (frequency weighting). There are several studies on basin closure, but most of these are descriptive, while others refer to empirical studies that do not systematically model the process of basin closure (see e.g. Molle, 2010a). This study contributes to empirical analysis of basin closure in an European context, as heretofore most of the studies on basin closure were conducted in an Asian context, even though several basins are closing in Europe, especially in Mediterranean countries. Moreover, the author did not find any comparative study of prior appropriation and basin closure.

Formal and informal water access was analysed in terms of reported water right status defined in three categories: i) formal water right, ii) pending water right, and iii) no-formal water right (section 6.2). It was found that 77.2% of the irrigated land and 83.5% of the water had formal water right the remaining water had either pending (15.9% and 12.1%) or no formal water right (6.9% and 4.4%). Water rights are granted for extremely long periods (an average of 50 years), which distorts in the resource's management (Velázquez, 2007). This could be part of the explanation why traditional irrigation and the IUs that started to irrigate between 1947-1966 report the same level of no formal water right, while the latter has slightly higher reported formal water right. Despite CHG screening the database, there are potential reliability issues related to the collection of the water right data. It has been possible, though it has not been much practiced, to trade water in situations of shortage since the 1985 Water Law (see Table 11, p. 78). However, water licenses are often only kept by the irrigators and there is no complete register over water rights in the basin (CHG-staff, personal communication, 2010). FAO (2003) claims that the imposition of transparent, stable and portable water use rights for both individual users and for user groups is a powerful instrument for encouraging efficiency and equity in distribution. The lack of a public register could hamper the transparency and possibility of peer monitoring to e.g. exclude possible free raiders. Access to water is linked to the land. Nevertheless, it is not always possible to assert that the right quantity has been applied exclusively to the area[17] with water right, as the same amount of water may be distributed in an extended area, by decreasing the average doses. Additionally, there could be some over and under reporting, depending upon subjective perceptions and objectives of irrigators. Moreover, there could be a fear that water not used could be lost ('use it or lose it'). The issue of not being in compliance with the law seem to be of relevance. For example, a study of 68 farms in Doñana National Park, downstream on the Guadalquivir RB, found that none of the

[17] *There is an example that an irrigator was allowed to irrigate land in Almeria due to the fact that he bought land in Sevilla with water right (J. Berbel, personal communication, 2011).*

exploitations which were analyzed were completely in compliance with the law (CHG, 2004). According to the WWF (2006), the RB Authority suppose that 10% of the existing 100,000 wells are illegal in the Guadalquivir RB, and states that illegal water use affects even areas of great ecological importance. The current study suggested that modern irrigation tends to have a higher percentage of non-formal water rights compared to traditional irrigation. The modern group of irrigated areas rely more on origin from groundwater, which could imply that a large proportion of the ground water is without formal water right. Jaen, representative of the recent expansion of intensive olive grove, has a high proportion of either pending or units without formal water rights (>55%). Illegal extraction is not only a problem in the studied basin. WWF (2006) claims that the Spanish Ministry of Environment believes that there are 510,000 illegal wells (urban and agriculture uses) in Spain which constitute at least 3,600 hm^3 per year of groundwater extracted illegally. Economic incentives also influence water use. One example is how EU subsidies, through the CAP[18] have led to the development of cereal cultivation in Spain, which again has contributed to the exhaustion of aquifers (Garrido, 2002).

The origin of water was studied in *Hypothesis 1* (6.3). Due to Hernandez-Mora et. al. (2001) few studies have looked at the role of that groundwater plays in irrigation. Those that do exist point to a higher productivity of irrigated agriculture using groundwater than using surface water. It is important that allocation management consider whether the water source is groundwater or surface water and the effects of how the water is used on the rate of groundwater recharge, which in turn affects aquifer levels and streams. The results indicates that traditional irrigation (undated, before 1947) has a significantly higher proportion of its origin from surface water than modern irrigation (1947-2008), and that for modern irrigation the percentage of surface water origin is lower for recent IUs (6.3). This, suggest that as the basin has moved towards closure, there has been a relatively higher pressure on groundwater resources than on surface resources, probably because the best places or water with easiest access have been extracted first. For examples, a shift to groundwater irrigation by irrigators has also been found in all provinces of Northern China and in the closing basins of the Zayandeh Rud basin in Iran (Molle et al., 2010a). It must be

[18] *Before the implementation of decoupeling of subsedies from production.*

noted, however, that the tendency found in the present study is not utterly clear. Traditional water appropriation includes groundwater sources, including shallow wells and springs that have been exploited since Arabic times (e.g. Vega de Granada) (J. Berbel, personal communication, 2012). IUs that started to irrigate between 1947-1966, have a significantly higher proportion of origin from surface water compared to traditional period IUs. A reason for this could be that the period 1947-1966 was defined by the introduction of the Franco regime's large irrigation schemes policy, where surface water was the main source. This may explain why traditional IU have a slightly higher percentage of groundwater use compared to the next period. In general, as basins close, water management becomes more complex as the water cycle, aquatic ecosystems and water users become more interconnected (SIWI, 2006)[19].

The results of *Hypothesis 2* (6.4), indicates that more recent IUs pays significantly higher water costs than more senior IUs (6.4). Despite of basin closure, society keeps water cost very low (M=0.09 € m^3). Generally, the abstraction costs of surface water tend to be cheaper than groundwater. It was not possible to determine if this difference was significantly higher, due to the nature of the aggregation of data. Another issue is that the quality of the water is higher at the upper part of the basin, than the lower part. As a follow up of the HBP a fair (without further specification) cost recovery plan should be developed and implemented. The factors mentioned here are among the reasons why it is difficult to put in place a fair water cost recovery system. The arguments over the cost of providing additional water resources in closing basins ends abruptly, since only marginal or distant resources remain available. Moreover, such mobilization also tend to have increasing environmental impacts, as the existing resource commitments are already high (Molle et al., 2007).

The results of *Hypothesis 3* (6.5), indicate a tendency of significant lower water allocation for more recent IUs. This reflects the scarcity of the resource and the non-formalized practice of a prior appropriation doctrine, 'first-in-first-served', initially a legal principle that evolved in the American West. One could say that the process of basin closure in the Guadalquivir RB has led to a gradual adaptation of a system of water allocation that is different from that

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[19] *E.g. extracting additional water for irrigation use within closing basins can cause irreversible losses of species and ecosystem services valuable to society.*

which exists in regions graced with more abundant rainfall where most demands can be met and with higher guarantee. Molle et al. (2010a) describes irrigators' adjustments to water scarcity and basin closure in six RBs in Asia and the Middle East. They claim that irrigators should be acknowledged for their efforts to respond to the challenge of decline in water allocation to the sector, where the responses includes higher irrigation efficiency and choice of more productive crops, i.e. crops with lower water requirements or higher economic profitability.

In this study it was found that the units started to irrigate later were both more efficient and productive. When the possibility to augmenting the access to water is reduced or more costly, the importance tends to shift to improved management and conservation (Molle et al., 2007). As societies develop, water resources at RB scale are gradually more controlled, diverted and consumed for agricultural, domestic and industrial purposes. As a result, the ability to meet the growing demands from various sectors and interests are being reduced (Falkenmark and Molden, 2008) and how water is allocated becomes increasingly controversial as competition increases. As basins close, however, the irrigation sector in particular has to adapt to the scarcity of the resource and to restrictions in the supply. Irrigation experiences the largest absolute cuts due to lack of priority, because it is the largest water user and because competition is increasing within the sector. Access to water in arid regions is a privilege, as it implies access to income. Irrigation is of special importance for rural livelihoods as it increases the value of production and is an important stimulator for rural development. It is estimated that the irrigated land in the Guadalquivir RB have 6.5 times higher per hectare GVA than rain-fed land, and 4.4 times higher net margin per hectare (Mesa-Jurado and Berbel, 2009**)**. As long as irrigation is profitable, there will probably be demand for and potential for conflicts over water.

In *Hypothesis 4* (6.6), *it was* shown that more recent IUs are significantly more efficient than older ones, which implies that older IUs have a higher saving potential than recent ones that are significantly more efficient. The findings reveal that there is a potential to increase efficiency for senior IUs in the basin through targeted policy objectives. Berbel et al., 2012 comment about the implementation of the Programme of Measures by year 2015 and the important role of water saving measures by improving efficiency.

The results of *Hypothesis 5* (6.7) demonstrate that the most recent irrigated areas have significantly higher water productivity (apparent) than older IUs (6.7). In Andalusia, irrigated agriculture accounts for more than 55% of total agricultural production and represents one of the most productive and competitive agricultural areas in Europe, despite a wide range of water productivity values (0.2 – 12 € m^{-3}) reflecting a highly diversified irrigated agriculture in this region (Corominas, 2004, cited in García-Vila, 2010). The average water productivity in this study was estimated to 1.29 € m^{-3} (SD=0.96) with a large range i.e. 0.03 to 10.22 € m^{-3}. The water productivity is higher than in many other Spanish basins. The reasons for this include a favourable climate and competitive farming. The productivity of agriculture in the Guadalquivir RB depends not only upon irrigation, it also depend upon land slope, the use of annual or perennial crops such as olive tree. Moreover, the intensity of farming, as well as the skills and performance of the farmers are important factors. It could be confirmed that current water planning follows a prior appropriation doctrine, 'first-in-first-served'. Those that arrive later compensate for this by higher efficiency and productivity. Policies relating to water allocation in agriculture should provide incentives to enhance efficiency and social equity. The question that arises is whether it is fair that those that arrived first enjoy the privilege of higher water doses per hectare and cheaper water, despite being the least efficient and productive. This debate enters into perceptions of what is fair, and that is beyond the scope of this thesis.

Various authors have claimed that the DPSIR-framework is unsatisfying for analytic purposes because of its simple causal relations assumed cannot capture the complexity of interdependencies in the real world (see e.g. Maxim et al., 2009). Therefore, *Hypothesis 6 and 7* on the relationships between the impacts and the responses in the framework, were studied through a correlation matrix that does not assume causal relationships (6.8). All correlations were significant and indicated that water productivity (€ m^{-3}) was positively correlated with water costs (€ m^{-3}) and negatively correlated with gross water allocation (m^3 ha^{-1}) (Hypothesis 6). Efficiency was negatively correlated with Gross water allocation (m^3 ha^{-1}) (Hypothesis 7).

Preliminary analysis of coping strategies for restriction in supply found that water doses response, irrigated area response, duration and interval response were significantly linked to the period of appropriation. However, no distinct tendency was found and further studies need to be done to go beyond these results. These empirical results indicate that access to water does not purely follow a prior appropriation doctrine when it comes to sharing resources in situations of drought and restrictions in supply. The drought plan refers to the importance of setting up a reserve to ensure priority use of interconnect systems for the equitable sharing of the effects of droughts, with special attention to perennial crops. More specifically tree crops and high value crops that could affect territorial economy (social risk) are prioritised (CHG and MIMAM, 2006). Using the lion's share of the water in the basin and not being a societal priority, irrigation the experiences the largest reductions in volume delivered and the greatest negative effects of drought. Based on the historical experience of recurrent droughts, irrigation in the Guadalquivir RB has a adopted a great flexibility to cope with drought conditions by adapting, and changing the distribution of crops, and reducing irrigation areas. However, this adaptation is constrained by inadequate availability of water and has logically significant socioeconomic costs (CHG and MIMAN, 2006). For example, the severe drought of 1992-1995 reduced the total irrigated production by 66% and the marginal production by 75% (CHG, 1995).

As long as irrigation water generates added value and profit there will probably be a pressure on the water resource, pushing for expansion of land and additional water allocation until and beyond basin closure. As water becomes scarce the challenge is how do we share the water, and ensure that the water allocation leads to outcomes that are visible fair and efficient. The measures should simultaneously reduce conflict and improve sustainability, requiring constant improvement of monitoring and adaptation. Therefore, in the next chapter, the objective is to go beyond the results of this chapter to study water allocation and its outcomes to propose tools to measure and monitor the performance of water allocation inequality at basin level.

6.11 SUMMARY

The aim of the chapter was to achieve a better understanding of how the irrigation sector is adapting to basin closure. Accordingly, this chapter has presented empirical results of some selected hypothesis of impacts and responses to basin closure for the irrigation sector in the Guadalquivir RB. An adapted DPSIR framework served to put a set of hypothesis and the results in context. Access to water in arid regions is a privilege as it implies access to income. The study indicates that irrigated land with formal water right corresponded to 77.2% of the area and 83.5% of the gross water allocation, while the remaining was either pending or no formal water rights. Water right status is significantly related to seniority. The most recent irrigation seniority group (1985-2008) had the lowest proportion of formal water rights (65.4%). More than 55% of the IUs without formal water right were located in Jaen, which recently began irrigating. T-tests, ANOVA, polynomial regressions and contingency tables were applied to reveal tendencies and consequences of irrigation water allocation in a closed basin. Frequency weighting was applied to deal with data of different scale and level. There were significant difference between traditional (undated) and modern irrigation (1947-2008). Considering only modern irrigation, all models were significant and indicated that the more recent an IU is a) the lower proportion of its origin is surface water; b) the higher water costs it pays; c) the less water it is allocated; d) more efficient; e) the more productive. Generally, these results show how new irrigation units adapt to drop in supply during basin closure and their effectiveness in counter balance drop in supply and higher water costs by increasing efficiency and productivity, but at the same time, modern irrigation tend to strain stressed ground water more than traditional irrigation.

Water productivity (€ m^{-3}) was positively correlated with water costs (€ m^{-3}) and negatively correlated with gross water allocation (m^3 ha^{-1}). Efficiency was negatively correlated with gross water allocation (m^3 ha^{-1}). All correlations were significant. It was found that water allocation follows a prior appropriation doctrine in situations of a normal year, and that a prior appropriation is a significant determinant of the inputs and outcomes of water allocation. However, in a situation of restrictions in supply due to extreme events, no clear tendency was found between prior appropriation and coping strategies. How water shortage is shared is an important topic that should be investigated further. In the next chapter, inequality in water allocation in the Guadalquivir RB is studied.

CHAPTER 7

INEQUALITY IN WATER ALLOCATION

'Just as states have fought over oil, water has played a role in international conflicts. Water resources have been military and political goals. Water resources have been used as weapons of war. Water systems and infrastructure, such as dams and supply canals, have been targets of war. And inequities in the distribution, use and consequences of water management and use have been a source of tension and dispute.'

Gleick (2005)

This chapter reports the first empirical results of irrigation water allocation related inequality in the Guadalquivir RB[20]. Methodological tools predominantly used to measure economic inequality in development economics were employed to examine irrigation related inequality in the context of basin closure. The chapter is divided in four sections. First inequality in water related variables for, respectively, year 2008 (7.1) and the BHP planning scenario for year 2015 (7.2) are charted, measured and decomposed. Finally, a discussion (7.3) and a chapter summary (7.4) are given.

7.1 INEQUALITY IN WATER RELATED VARIABLES (2008)

The two first sections presents the descriptive analyses of the variables and provide Lorenz curves and histograms for key variables of 2008.

7.1.1 Statistical measures of dispersion

As in the previous chapter, the unit of analysis is irrigation unit (IU), where 1 IU=1 ha (See Section 4.1.3.2). The key variables selected for the analysis in this chapter included water allocation (m^3); water cost (€) (due to location and infrastructure: cost of energy (mainly), transport and pumping costs); and finally gross income (€) that is a result of, especially, location (climate, soil) and farm decisions. Annex 2 summarizes the descriptive statistics of

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[20]*Preliminary results of this chapter were presented on a scientific seminar: Kolberg, S., Dios-Palomares, R., Berbel J., 2010. Measuring irrigation water use inequality in a river basin. Oral presentation at Ecoriego at University of Cordoba, November 12, 2010.*

the key variables for year 2008. The distributions of all variables are positively skewed, as the IUs tend to cluster toward the lower end of the scale with increasingly fewer scores at the upper end, indicating that the bulk of the values lies to the left of the mean, especially for the income variable (see the histograms in the next section). There is a large range in the income and water cost variables. The minimum per hectare value of gross income is just 0.5% of the maximum, and the minimum water cost per hectare is 0.1% of the maximum. The next section presents the Lorenz curves and the histograms for gross water allocation, gross income and water costs for all IUs.

7.1.2 Lorenz curves and histograms

For Lorenz curve, the horizontal axis depicts the cumulative population of IUs and the vertical axis the cumulative percentage of the variable distributed. Figure 16 shows the Lorenz curve for gross water allocation and it indicates that the 20% of the IUs that receives less water allocation less than 10% of the total allocated water, whilst the highest 20% IUs are allocated more than 40% of the water. The corresponding histogram shows that the majority of the IUs in this basin receive a gross water allocation of up to 2,000 m^3. Nevertheless, the most frequent cluster is around 1,750 m^3 (olive production) and rice production is observed around 12,000 m^3. Figure 17 shows the Lorenz curve for gross income. It indicates that the 20% of the IUs that generate less income has less than 10% of the total income, while the high 20% generate around 50% of total income. The corresponding histogram shows that most IUs generate a gross income less than 4,000 €. Figure 18 illustrates the Lorenz curve for water costs and indicates that the IUs with the 20% lowest water costs pay around 10% of the total water costs; whilst the 20% highest cost UIs pay 40% of all water costs. The corresponding histogram shows that the majority of the IUs have a water cost of 100 to 200 €.

Figure 16 Lorenz curve and histogram for gross water allocation per irrigation unit (2008).

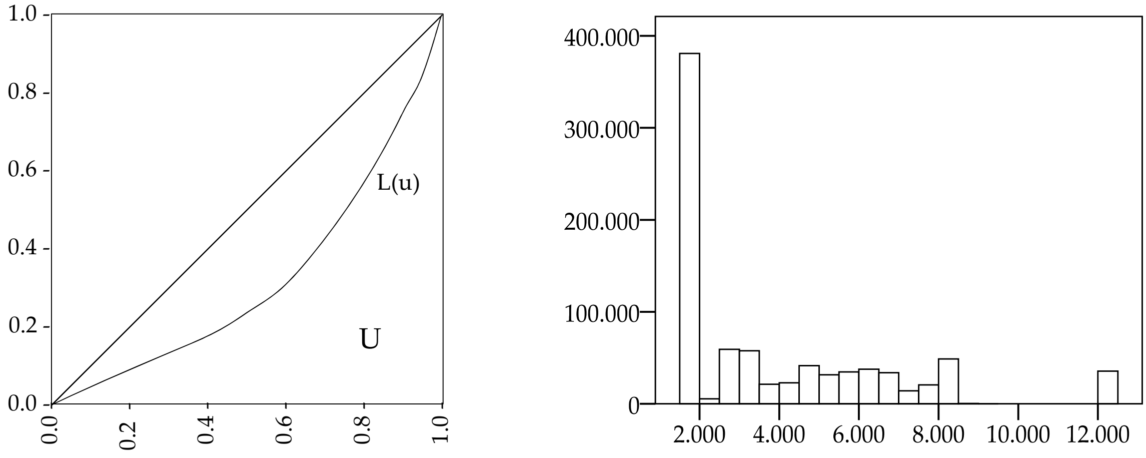


Figure 17 Lorenz curve and histogram for gross income by irrigation unit (2008).

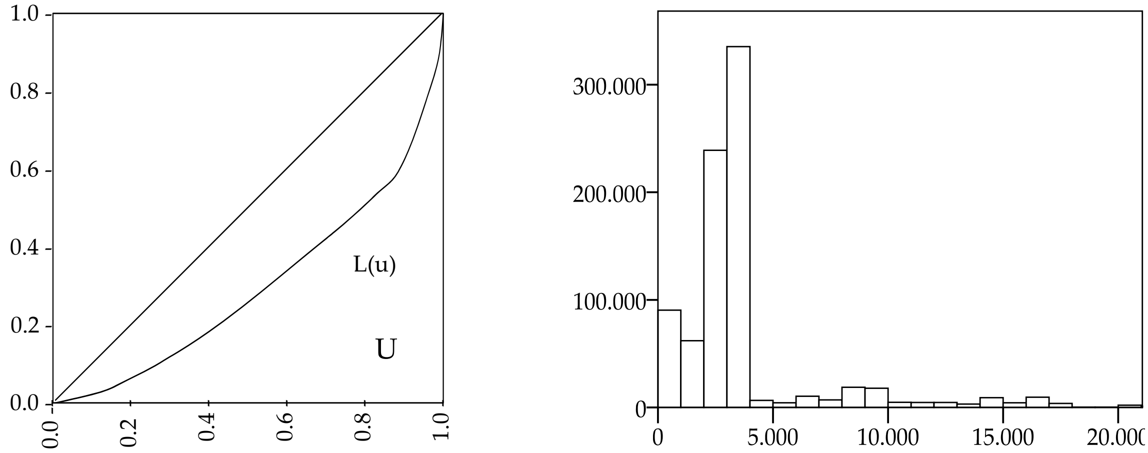
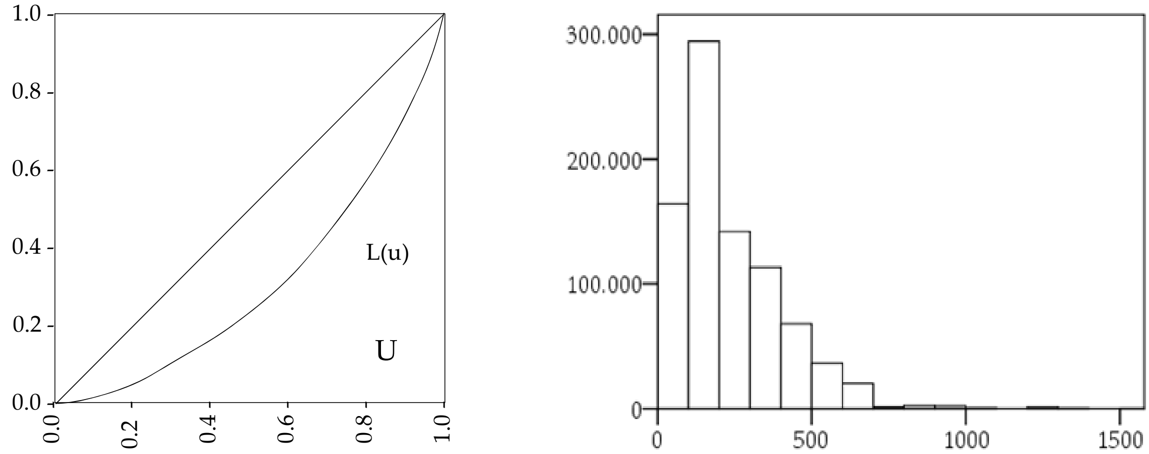


Figure 18 Lorenz curve and histogram for water costs by irrigation unit (2008).



Source: Author's calculations based on data from CHG (2010a).

7.1.3 Complex inequality measures

Research question:

Are there differences in inequality between gross water allocation, water costs and gross income?

Table 24 shows the selected complex inequality measures for gross water allocation, gross income and water costs. The closer a measure is to zero, the more equally distributed is the variable.

Table 24 Inequality measures for gross water allocation, income and water cost (2008)

Index	Gross water allocation (m^3)		Water cost (€)		Gross income (€)
Coefficient of variation	0.698	<	0.715	<	1.060
Gini coefficient	0.357	<	0.371	<	0.397
Theil index	0.213	<	0.227	<	0.341
Atkinson index					
(ε=0.20)	0.042	<	0.045	<	0.064
(ε=0.80)	0.156	<	0.181	<	0.216

Source: Author's calculations based on data from CHG (2010a).

Regardless of the use of inequality measure applied above, all indicators express that gross water allocation per IU is more equally distributed than water costs and gross income. It is necessary to remark that IUs within the highest and lowest part of the distribution are not necessarily the same for the three Lorenz curves, since the rankings should be done independently for each variable. To obtain more information on what is beyond gross water allocation, the next sections compares high and low water allocations.

7.1.4 Beyond high and low water allocation

'Gone is the era when humanity can pretend that water defies the principles of economics'

Longo and Spears (2003)

Research question:

Are there significant differences in water allocation income, water costs and efficiency between IUs with high and low water use?

With a starting point in the Lorenz curve for gross water allocation (Figure 16), the IUs that receive the most water (highest 20%) are compared to those IUs that receive the least water (lowest 20%). Table 25 shows that the IUs with the highest gross water allocation has significantly higher gross and net water allocation; also, they have lower water cost (per hectare and per volume) than the IUs with lowest 20% water allocation; however, they are less efficient, have higher income by hectare but less by volume.

Table 25 Comparison of Irrigation Units receiving 20% low versus 20% high water allocation (2008)

Variable (mean)	Unit	Low (20%)		High (20%)	High/Low	Sig. (2-tailed)
Gross water allocation	m^3	1,750	L<H	8,444	4.8	0.000
Net water allocation	m^3	1,500	L<H	5,743	3.8	0.000
Gross income:						
per hectare	€ ha^{-1}	3,122	L<H	4,347	1.4	0.000
per volume	€ m^{-3}	1.79	L>H	0.5	0.3	0.000
Water cost:						
per hectare	€ ha^{-1}	275	L>H	184	0.7	0.000
per volume	€ m^{-3}	0.16	L>H	0.02	0.1	0.000
Efficiency	n.a.	0.85	L>H	0.66	0.8	0.000

Source: Author's calculations based on data from CHG (2010a).

The 20% lowest water allocation IUs, compared to the 20% highest allocation IUs, had a ratio of net to gross water allocation of 68.0% and 86.0%, and the ratio of water costs to income was 8.8% versus 4.2%. The lowest water allocations IUs grow almost exclusively olive orchards. The highest water allocation IUs produce a crop mix of 63.3% cotton; 21.0% rice; 5.5% horticulture; 3.7% sugar beet; 2.3% maize, the remaining 3.2% are sunflowers, citrus and fruit trees, greenhouse production and others.

7.1.5 Decomposition of inequality by period of appropriation

Research question:

What is the structure of inequality in water allocation by period of appropriation?

In order to understand the structure of inequality in gross water allocation, the Theil index was decomposed with respect to seniority, with the same grouping as in Chapter 6. The analysis gave a between-group, Theil (BET)=0.043, and the within-group component, Theil(WIT)=0.170 (Table 26).

Table 26 The results of decomposing the Theil index by seniority of irrigation water allocation

	Period of appropriation	Theil contribution	Contribution rate (%)
Theil (WIT) elements	(Traditional)	(0.018)	(8.6)
	(1947-1966)	(0.038)	(17.9)
	(1967-1985)	(0.049)	(23.0)
	(1985-2008)	(0.064)	(30.2)
Σ Theil (WIT)		0.170	79.7
Theil (BET):		0.043	20.3
Theil index		0.213	100.0

Source: Author's calculations based on data from CHG (2010a).

The 'within inequality' element captures the inequality due to the variability of gross water allocation within each group, while the 'between inequality' captures the inequality due to the variability of water allocation across the different groups and is measured. The largest contribution to the inequality in the Theil index was the Theil (WIT) counting for almost 79.7% of the inequality. The contribution rate of Theil(WIT) is higher for the more recent period of appropriation group than the older groups, from 8.6% for traditional irrigation to 30.2% for the most recent seniority group. Summing Theil (BET) and Theil (WIT) gives the Theil of the original water allocation distribution = 0.213. The result of Table 26 shows that the structure of inequality in water allocation is related to period of appropriation, and that inequality increases with the inclusion of the most recent group.

7.2 WATER ALLOCATION INEQUALITY 2008 VERSUS 2015

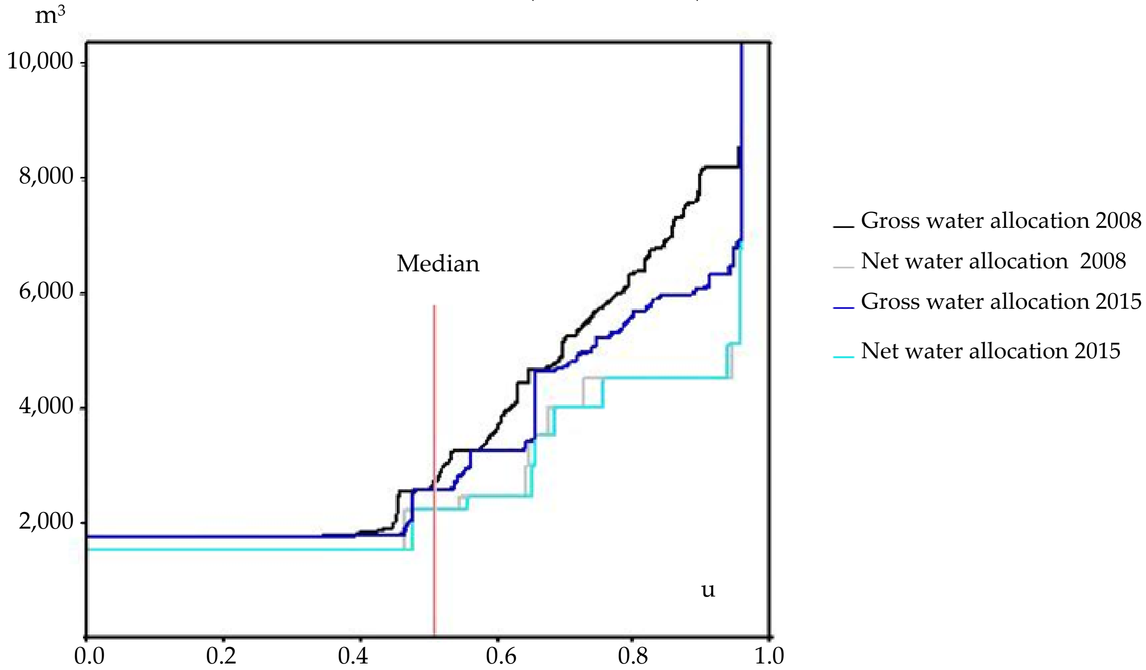
7.2.1 Statistical measures of dispersion

Annex 2 shows the net and gross water allocation for the 2015 planning scenario presented in the HBP. By 2015, the total irrigated area will increase 4.0%. The total net water allocation will increase with 2.6%, while the total gross water allocation decrease with –6.7%. The net water allocation will increase by 63 hm^3, and gross water allocation is reduced -222 hm^3. The net water allocation per hectare is expected to decrease -1.5% and the gross water allocation per hectare to decrease -10.4%. The net to gross water allocation ratio will increase from 74.0% in 2008 to 81.0% in 2015. The modes and medians of gross and of net water allocation for 2008 and 2015 did hardly, while the maximum gross water allocation and variance in 2015 were lower than in 2008, suggesting less gross water allocation inequality in 2015. Annex 3 shows the change in crop pattern scenario for 2015. It can be noted that the largest crop mix change is due to an 8.6% decrease in irrigated cotton. Cotton subsidies have been reduced drastically and the profitability has become lower, hence the irrigated area is expected to reduce. In the long term cotton may disappear. The largest increases are due to horticulture (2%) and an unspecified group of other crops (2.6%). The remaining constitute <1%.

7.2.2 Pen's Parade

In Pen´s Parade (Figure 19), the horizontal-axis represents the relative position in the Pen´s Parade, scaled 0 to 1, and the vertical axis is the water allocation (m^3). For every $0 \le u \le 1$, each point shows how much net and gross water allocation an IU is expected to receive, such that a fraction u is allocated G or less. The point on the horizontal axis corresponding to 0.5 shows the water allocation such that exactly 50% of the hectares receive between 2,200 and 2,569 m^3 per IU (median water allocation, M) or less water.

Figure 19 Pen´s Parade of estimated net and gross irrigation water allocation in the Guadalquivir river basin (2008 and 2015).



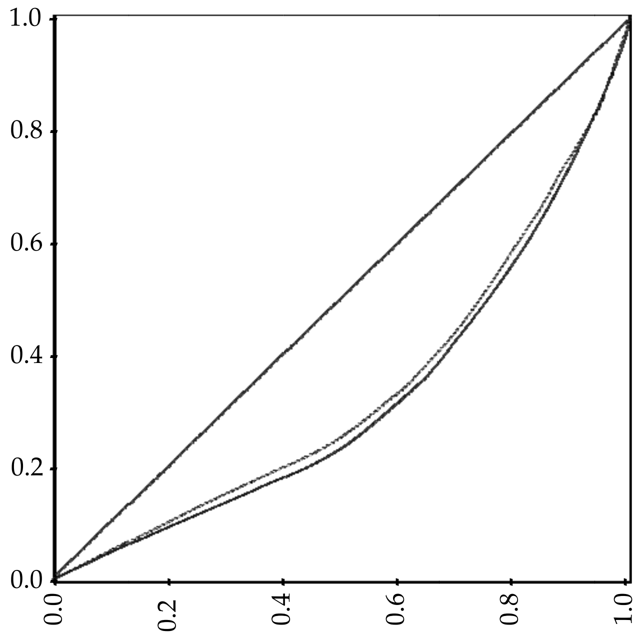
Source: Author's calculations and elaboration based on data from CHG (2010a).

Gross water allocation (black line) lies over net water allocation (grey line) for both years. Gross water allocation for 2008 lies over gross water for 2015 for the majority of the distribution. The curves of the two years for net water allocation, are practically overlapping for most of the distribution. The Pen´s Parade curves show that both net water allocation (grey line) and gross water allocation (black line) are basically equally distributed for both years until around fraction 0.45. The reason is that IUs with low gross and net water allocation already use the water highly efficient and further reduction in water allocation would not be economically viable in order to recuperate investments in irrigation infrastructure. Moreover, the investment in modernization is considerable high, therefore, improvements in infrastructure are prioritized first by higher water allocation IUs up to a fraction around 0.95. The remaining IUs are due to rice production that is already highly efficient.

7.2.3 Lorenz curves and inequality measures

On a larger version of Figure 20, it is possible to see that the Lorenz curves for 2015 gross water allocation (grey line) lies entirely above the one of 2008 (black) (Lorenz dominance). The closer a line lies to the line of equality; the greater is the equality of the corresponding distribution. Accordingly, distribution of gross water in 2015 is slightly less unequal than the one for 2008.

Figure 20 Lorenz curve for gross water allocation (2008 and 2015).



Source: Author's calculations based on data from CHG (2010a).

Table 27 shows a small, but consistent inequality changes between years in the estimated indicators.

Table 27 Complex inequality measures for gross water allocation by irrigation unit (2008 versus 2015)

Inequality measure	2008		2015	Change (%)
Gini coefficient	0.357	>	0.330	-7.6
Coefficient of variation	0.698	>	0.670	-4.0
Atkinson index				
ε= 0.20	0.042	>	0.037	-11.5
ε=0.80	0.157	>	0.137	-12.6
Theil index	0.213	>	0.190	-11.0

Source: Author's calculations based on data from CHG (2010a).

7.3 DISCUSSION

'…statements such as 'social justice' and 'equity' should not just be phrases in the introductory sections of a law or policy documents for those in charge to feel good about or at best perceiving justice as a subjective variable, rather such statements carry with them underpinning philosophies and principles which can be used to effectively evaluate the law or policy.'

Tisdell (2003)

Historically, water resources have been allocated on the basis of social criteria to maintain the community in terms of water for human consumption, sanitation, and food production (Le Moigne et al., 1997), and societies have invested capital in infrastructure to ensure this allocation. When all water is allocated and committed and a basin is closed, the question on how to use and how to share scarcer and scarcer resources becomes increasingly pertinent. This is especially true for the irrigation sector, which uses the lion share of fresh water worldwide. According to MIMAM (1998), irrigated agriculture in Spain is a fundamental factor structuring the landscape and territorial variables. Moreover, in a great number of Spanish rural areas the only significant option for development is irrigation-based agriculture. However, irrigation sector is typically the first sector affected by policy responses to water scarcity by a focus on water efficiency and productivity, and on approaches that maximize the economic and social return of limited water resources (UN, 2006). It could be said that effective, integrated RB management moves from a pure resource exploitation ethic to incorporate social equity and environmental management in the management plans (Hooper, 2010). All water policies will always be ineffective without being in quest of their social anchorage (Íñiguez, 1994 cited in García-Vila, 2010). Mainstream policy and management principles state that the benefits and burden of access to water has to be shared in a fair, efficient and sustainable manner. Accordingly, equity and equality in water allocation have, during the last decades, become key policy objectives of an integrated approach to SWM. However, the equity criteria are often unclear, and there are no standard procedures to monitor the sharing of irrigation water within the sector (see Chapter 3). Obviously, it is not possible to manage or monitor the level of equity/equality if it is not measured. Failure to control and be transparent about water allocation could potentially raise the conflict level between stakeholders. One of the main objectives of Spanish water law is to achieve an 'equilibrium and harmonization of regional development' (Article 40), and this could be related to a fair water allocation. This objective has not been clearly measured and implemented, and standard methods and indicators for the achievement are missing in the literature. This thesis tries to help contributing to filling this methodological gap.

Accordingly, the aim of this chapter is to address Objective 3 of the thesis by exploring the potential of inequality measures and concentration curves to empirically measure and chart how water is shared and the level of inequality in irrigation water allocation related variables at basin-level scale in the Guadalquivir RB. This chapter explores inequality in irrigation at basin level empirically, by homogenising aggregated data with different levels and scale. A principal motivation for inequality measurement is normative, to guide policy (Kaplow, 2002). This thesis argues that empirical analysis could help to examine the claims made for water between and within sectors and geographical areas, help identify areas of concern, see how inequality has changed over time, and be utilized to track the progress of policy initiatives. More explicitly, the tools proposed could help make the water planning process and the public debate more transparent, as one can answer whether water, and other relevant indicators, is more or less equally distributed within the basin or even between basins and sectors, given the availability of appropriate data. Decomposition of inequality measures could help to determine the structure of that inequality. The distribution of inputs according to the principles of equity or equality can neither take for granted nor ignore its effect on the distribution of output (Sivramkrishna and Jyotishi, 2006). Therefore, the analysis of inequality should be based on some idea of distributional justice (Bojer, 2003). Moreover, perceptions of basic liberties and procedural and distributive justice are repeatedly central in water disputes (Tisdell, 2003; and Syme et al., 1999). Therefore, it is important to understand that the concepts of equity and equality are applicable to, on one hand, input, resources or opportunities (e.g. water) and, on the other hand, output (e.g. gross income). In irrigation, equity does not necessarily mean that every farmer gets the same amount of water. It rather implies that each farmer gets an amount that is fair (Laycock, 2007). The question that arises is, 'What is fair distribution?'. Some irrigators may get a larger share of water than other irrigators. This could be due to prior appropriation (Chapter 6) or in compensation for more input in system construction or maintenance. As a result, it is much more difficult to define entitlement to water based on value systems (equity) than entitlement based on a principle of equal sharing (equality) (Murray-Rust et al., 2000), which can be measured with the tools proposed. Inequality measures do not measure inequity, but has the potential to do so. Inequality in the selected variables was charted with histograms, Lorenz curves and Pen's Parade. The simple measures of statistical dispersion and the histograms revealed that gross income (€), water costs (€), and gross and net water allocation (m^3) of the IUs were positively skewed. This indicated that the bulk of the observations were clustered at the lower end of the variable. For the statistical measures of dispersion, the range is easy to understand, but does not weight the observations. The median water allocation, where there is an equal number of IUs with the water allocation below and above that value, is, when compared with the mean, less affected by extreme water allocation observations and therefore, seemed to be a better measure of the centre of the distribution.

Inequality in water allocation, gross income, and water cost were studied. Lorenz curves were drawn for all distributions. The Lorenz curves and the complex inequality measures revealed that, for year 2008, gross water allocation (m^3) was less unequally distributed than water costs (€), which again were less unequally distributed than gross income (€) (Lorenz dominance). The policy consequences of more unequal gross income distribution than water costs or water allocation distribution are not clear. This is probably an adaptation to the circumstances, where higher cost implies a need for higher value and productivity to pay for the input. It may show that there is room for improvement in the management of water by farmers that have better locations.

The Lorenz curve for gross water allocation (2008) indicated that the 20% of the units that receive less water allocation use almost 10% of the total water, while the upper 20% use more than 40%. T-test and descriptive statistics were applied to know what was beyond these extremes. The highest 20% IUs have a significantly higher water allocation (gross and net) and water cost (per hectare and per volume); however, they are less efficient, have higher income per hectare but less by volume of water used. The 20% highest water allocation IUs, compared with 20% lowest, had a significant higher water allocation (m^3) and income (€), while the IUs that were allocated less water were more efficient and paid higher water costs (€).

The decomposition analysis of the Theil index for four groups of water allocation (periods of appropriation) (2008) suggests that the within group inequality is more important than between group inequality. Accordingly, the greatest part of total inequality is explained by the variation of gross water allocation within groups (79.7%), while the remaining inequality is due to variation between period of appropriation groups (20.3%). The contribution rate to Theil (WIT) increased with more recent period of appropriation, contributing most to the inequality in the basin. Pen's Parade and Lorenz curves are used to visualize the change in inequality in the irrigation sector for the current (2008) versus a future scenario (2015) as of the GHBP. The shapes of the net and gross water allocation distributions were asymmetric, and strongly skewed to the left. The median is smaller than the mean for both variables and both years, indicating that most IUs receive less water than the average. The mean net water allocation in 2008 is higher than in 2015. This indicates that more IUs had less net water than the average in 2008 than in 2015. Comparing inequality measures for water allocation for 2008 versus 2015 reveal only small changes in inequality observed. indicating that gross water is expected to decrease by 2015 with the implementation of the draft GHBP. Again, because of Lorenz dominance, all inequality measures give the same ranking.

The Pen´s Parade, not found applied in literature on water management, turns out to be a persuasive and easily interpretable visual aid to understand water allocation distribution over time. Gross water allocation changes for 2008 and 2015 were apparent. Lorenz curves, though hard to distinguish by eye between years in our case, are useful for comparing different distributions and ranking and ordering distributions according to degree of inequality when they do not cross. The inequality measures fulfilling the axioms of anonymity and Pigou-Dalton transfer principle rank the same way as the Lorenz dominance (Atkinson, 1970), as seen for gross water allocation of 2008 versus 2015. Most inequality measures are ordinal (Cowell, 2009), hence they can be used to compare inequalities in water distributions, but they cannot measure differences in inequalities. Nevertheless, if inequality measures are calculated in a well-explained and consistent way, they can still offer a good tool for quantitative comparisons of inequalities (Bojer, 2003). In cases where rankings are ambiguous, the analysis must be aimed towards different parts of the distribution and several measures should be computed for each distribution (Ibid).

These tools could potentially to be adopted to different levels, scales and dimensions (see Chapter 2). A limitation in examining the nature of inequality over space and time is the availability and quality of data. According to Hale (2003), measures like the coefficient of variation and the Gini coefficient would usually be sufficient for describing inequality if the researcher had complete, individual level data for the population of relevance. These types of data are seldom available, and the researcher has to make due with aggregated data. Hale (Ibid.) suggests it is still possible to calculate e.g. the Coefficient of variation and the Gini coefficient for aggregated data under the assumption that each individual in the aggregation unit receives exactly the average value in cases where only the average values of an aggregated unit is available. However, the result would only give upper and lower bound for each inequality measures, because the variance within each aggregation unit would contribute to total inequality. In this thesis, the data in the Irrigation Inventory were aggregated into different levels and scale, posing an analytic challenge. There were no reliable numbers of farms or individuals in the database neither for year 2008 and the HBP scenario for 2015. The data were aggregated, collected and structured in a different way than in previous inventories of the basin, and no GIS maps were available. At a RB scale, one will often need to work with new groupings (losing information) or approximations. To address these problems of aggregation, this study has advocated the use of individual hectares as the unit of analysis (Irrigation Unit, IU), unlike most inequality studies on water that use an irrigator or an irrigation entity as the unit of analysis. The introduced method of homogenization of unstandardised aggregation units (disaggregation) could be useful when analyzing census and irrigation inventories that have different levels and scale of data aggregation. This is the case as long as one can assume that all hectares in the least aggregated unit have a homogenous distribution, so that one hectare is one unit of analysis. Moreover, the advantage of such a disaggregation is that it eases the possibility to do comparisons where aggregated units have different levels and risks of double counting such as for irrigation inventories.

The concept of inequality is a complex one that often cannot be expressed in a single measure. In addition, equality often refers to a division of a common resource in equal shares that can be related to a directly measurable parameter. In irrigation systems, the most frequent form of division is by irrigated area, implying that each unit area of land is given the same water allocation (Murray-Rust et al., 2000). However, the policy objective is not necessarily that each area of land should get the same water allocations (net or gross). Other factors, such as crop water requirements, location, soil type, seniority in water allocation, water right status etc., also are given priority as different stakeholders determine what distribution is considered fair. Moreover, equity is relevant at different levels and scales and has many dimensions (as seen in Chapter 4) that have to be contextually specified.

The empirical literature on the measurement of inequalities is vast and rapidly expanding. Hitherto, these tools have mainly been used for income and land distribution analysis. In reviewing literature (Chapter 3), few examples were found applying these tools to irrigation sector at basin level. Cullin and van Koppen (2007) studied inequality in water allocation across sectors in the Olifants Water Management Area in South Africa. They suggest that there is a potential to adapt the Gini coefficient to measure inequality in water allocation as well as the benefits of water allocation, and to use this as a tool to help achieving equity, efficiency and sustainable use of water. The Gini coefficient, they argue, is useful to better understand the link between inequality of water allocation and the benefits of water allocation. Sampath (1988) argues that the Theil index is a better measure for equity [inequality] in irrigation than the range, coefficient of variation and the Gini coefficient, because it fulfils all important axiomatic properties, is decomposable, and has attractive cardinal properties. Interpretations of the inequality measures are not straight forward. Although the level of inequality is reflected in the value of the measures, it is difficult to judge with the available data whether the inequality is tolerable to the stakeholders. Thus, the most common practice is to compare the values with other results. Unfortunately, finding a proper comparative group is not always easy, especially when empirical studies use different units and levels of analysis and the institutional and contextual situation differs, and few studies explore the use of inequality measures to water allocation.

These indicators do just what the name says *indicate*. They simplify and model reality with explanations, predictions and decisions. Unfortunately, to do rigorous analyses with grouped data is more difficult, and often one has to work with approximations. However, ordinal comparisons can be made to a certain extent. Cullin and van Koppen (Ibid) found that benefits of water were more equally distributed than the water itself, while in the Guadalquivir RB, though the studies are only partly comparable, water was more equally distributed than gross income.

Water allocation needs to be perceived fair in order to work towards hydro-political stability. By asking if it is fair that those that, per hectare, are allocated less water pay more but earn less money, one is entering into a discussion of perceptions, moral and questions of equity beyond this paper. Since there are multiple perceptions of what is fair water allocation, there will be always conflicting short term and long term objectives and goals between different stakeholders within and at different levels. This is another argument favouring measuring a sharing system that is based on equal sharing instead of value based sharing. In order to use these tools, the policy makers should have clear criteria of what should be equal or unequal. Participatory approaches to law and hydrological planning could ensure that the allocation could be considered more fair than a top down approach, such of the proposed definition of formal equity in Chapter 3. Identifying what variables are relevant to formal equity is critically important. Depending on the objective of equity in each country, basin and irrigation scheme, this list of variables will be a mix of input and output variables. In order to use these tools, the policy makers should have clear criteria of what should be equal or unequal. The proposed tools could be used to compare a settled sharing criteria with different allocation scenarios. These tools could be effective for monitoring in e.g. a situation of supply limitations, defining if inequality is increasing or decreasing, or learn how far reality is from achieving formal equity (benchmark) of water allocation in a RB. Especially for basins that experience both issues of water supply restrictions and lack of water rights registers. Financial costs and feasibility challenges make it impossible to do an in-depth assessment and to monitor every single aspect of irrigation performance. It is, however, not viable for policymakers and managers to monitor and respond to trends and tendencies of a large number of variables or indicators.

Concerns to take into consideration include accessible, appropriate, equitable, flexibility, guarantee and affordable. The inequality tools help to indicate in which direction we go without considering all other factors. The measurement of irrigation water allocation input and output inequalities could serve as an accountability tool for government and water agencies to start addressing and holding officials responsible for performance in their localities and at basin level. Beyond these fundamental considerations, researchers, policymakers and water managers have to choose which dimensions and aspects of inequalities they ought to consider. Countries and managers cannot afford to track every potentially relevant inequality indicator; consequently the choice of measure is important as it indirectly shapes the program and policy options informed by monitoring inequalities in irrigation water allocation at basin level, and at other system or individual levels. The decisions do not end after indicator selection or even once data are collected through various monitoring systems; in fact, in some ways, they only begin when the quantification and analytical approach for evaluating irrigation inequalities must be determined. For instance, how should researchers and policymakers develop comparative metrics for indicators over space (e.g. countries, counties, municipals, basins) and time or frequency? As data are collected with different methods and operational definitions over time and space, how should they be analysed? Applying these tools could especially be, in the author´s opinion, relevant to address the difficulties of putting into practice the principle of equitable cost recovery of the WFD that is the next step in implementing the GHBP.

In conclusion, these inequality measures, in particular the Theil index, and the concentration curves, both Pen’s Parade and Lorenz curves, could potentially be part of a monitoring approach. These tools could be applied to empower policymakers, and researchers with meaningful and representative information about water allocation related inequalities for farms, populations, geographic or spatial areas, or socially-defined group and trends.

7.4 SUMMARY

The chapter presents the empirical results of inequality measurement in the input and output of irrigation water allocation for 2008 and the hydrological planning scenario of 2015 of the latest BHP of the Guadalquivir RB. The tools applied include standard measures of dispersion, the Gini-coefficient, the Theil´s indexes and the Atkinson index. Pen's Parade and Lorenz curves are used to visualize inequality in the irrigation sector for the current and a future scenario. First, descriptive inequality measures and concentration curves were applied to selected variables for 2008 (gross water use, gross income and water costs) and 2015 (gross and net water use). Conflicting ranking within and between distributions were checked. The empirical results indicate that the inequality in water allocation-related variables is high. For example, 20% of the units that received less water allocation use almost 10% of the total water, whilst the upper 20% use more than 40% (year 2008), with inequality in gross income>water costs>gross water allocation per IU. The decomposition analysis reveals that the within-group inequality of groups that started to irrigate later is contributing more to the inequality than those that started earlier, while inequality is expected to be reduced by 2015. The discussion posits that the proposed inequality measures and concentration curves, fulfilling certain requirement, are useful to analyze and monitor aspects related to inequality in irrigation water allocation and could potentially be useful to attain transparency and expose tendencies toward inequality in water allocation. It is proposed to use one hectare unit as the unit of analysis in cases where the data is aggregated in different scales and levels. It is expected that this new approach could aid policy makers and the implementing-agency to better monitor water allocation and have straightforward tools to state, clearly, if inequality has increased or decreased. Inequality measures and concentration curves can be part of monitoring systems to empower policymakers, researchers and managers with meaningful and representative information about water allocation- related inequalities for a population, geographic area or socially-defined group and over time. Empirical studies on irrigation sector inequalities could be useful to build water policy scenarios, simulate the impact of alternative policies on water and income distribution, and rank policy options. Empirical studies could provide opportunities to examine the claims made for water between and within sectors and geographical areas, help identify areas of concern, see how inequality has changed over time, and be used to track the progress of policy. In addition, these could help to make the water planning process and public-debate more transparent, since one can answer whether water is more or less equally distributed within the basin, and decomposition analysis could help to determine what the structure of that inequality is.

CHAPTER 8

CONCLUSIONS AND TENTATIVE RECOMMENDATIONS

'As competition for water intensifies, commitment and political will are needed to ensure fair access to water'

HRH the Prince of Orange (b. 1967)

The objectives of this research are threefold. Firstly, the concepts of equity and equality in irrigation water management are analyzed in the context of water scarcity (Chapter 2 and 3). Secondly, with the methods applied (Chapter 4) the outcomes of water allocation in the context of basin closure are described (Chapter 5) and empirically studied (Chapter 6), and thirdly, inequality in water related variables are graphically and empirically examined (Chapter 7). Based on the results and discussions presented in the previous chapters, this chapter draws the conclusions and the recommendations. The five sections of this chapter summarize the main findings (8.1); presents the research contribution and implications (8.2); present tentative recommendations for policy and management (8.3); the recommendations for future research are given (8.4) and finally the concluding remarks of this thesis (8.6).

8.1 MAIN FINDINGS

The purpose of this thesis was to study concepts and measurement of equity and equality in irrigation water allocation under basin closure at basin level. Returning to the main objectives posed in Chapter 1, the main findings are presented in the next three sub-sections.

8.1.1 Objective 1: Define equity and equality in irrigation

All science depends on its concepts. These are ideas which receive names.
They determine the questions one asks, and the answers one gets.
They are more fundamental than the theories which are stated in terms of them.
Sir G. Thompson (1892 – 1975).

The thesis first addresses conceptual ambiguity to increase the understanding of equity and equality related concepts in the context of basin closure. The argument put forward in this research is that equity and equality, despite being ambiguous and ill-defined concepts, are highly relevant to rational use of irrigation water and the management of scarce water at all levels, especially when water becomes a constraint to productive activity. Equity or equality is referred to in most water management-related guiding principles, and the terms are prerequisites of hydro-political stability and hydro-solidarity. The nature of the water allocating criteria is at the heart of territorial development, especially where irrigated agriculture gives high added value to crop production. The thesis shows that these are broad and multifaceted terms that need to be defined depending upon the specific context, the relevant dimensions, levels and scales. That is why it is almost impossible to make a 'one-fits-all' definition for irrigation water management. Moreover, a clear distinction in the use of the terms equity and equality should be made, as they do not necessarily imply the same. Equity tends to refer to the state of being fair, impartial or right judgment and is lacking a mathematical definition (subjective), while equality is concerned with the state of being equal and can be measured (objective). Most literature reviewed considered the terms as management targets in terms of either benefits or/and burdens, however there are no standard methodologies to measure and monitor their performance, leaving unanswered questions like: ¨What should be equal or equitable? How should we measure and monitor these targets? A confusion of the two terms results in frequent random usage and interchangeability, even though the terms have different connotations and consequences. Still, there seems to be some general conformity in science and public debate that greater equity and equality in irrigation is desirable. Conceivably it could be that the lack of clear definitions contributes to a general consensus that these objectives are worth striving for (suggesting everyone having their own idea of what the terms mean). It is not likely people would reach a clear consensus of their meanings, and it can be concluded that equity and equality in irrigation water management, though important, still is not well theorized for inputs or outcomes.

In the case of the Guadalquivir RB equity or equality are referred to as part of the management strategy of the basin. However, a clear approach how this could be monitored was not found, neither for benefits nor burdens of access to water. In the search for reaching so-called SWM, water managers seem willing to work with a poorly defined goal. However, having a poorly defined target means one is only sure to move towards it when being very far from reaching it. The challenge of integrating the principles into policy and legislation design, lays in well-specified principles for sharing water (See section 8.3 for relevant questions to ask when defining specific targets for equity and equality in irrigation water management).

8.1.2 Objective 2: Access to water during basin closure

The legislation and policy of management of irrigation water resources in the arid Guadalquivir RB are historically grounded. The drivers of change from plenty of water to basin closure can be explained by the articulated needs of the growing population´s economic activity, development and growth. There is a need to buffer for natural hazards and to balance natural injustice in order to meet territorial development objectives. Equity and equality are highly relevant components of the RUW concept. Their importance increases as the pressure and competition for water increases within irrigation sector, the basin, and beyond its borders. Moreover, several studies show that efficiency of water use in some agricultural sectors is low. To use water rationally, planners of water saving measures must be aware of resources and constraints at micro (household, farm and community), meso (infrastructure, institutions, RBs) and macro level (legal, national and institutional) to determine which changes are needed at each level. The past development of the basin and its gradual anthropogenisation are affecting the present situation and the future prospects and alternatives of water allocation within sectors and between sectors. Basin closure in the Guadalquivir RB seems to be a natural consequence of these drivers. In fact, it is likely that all basins in arid areas will, sooner or later, undergo similar evolutions and close. This validates the importance of a deeper understanding of the basin trajectories of closing basins beyond descriptive analysis that is the most common approach found in the literature reviewed.

The case study of the Guadalquivir RB support the idea that those IUs that first irrigated benefit from 'first-in, first-served' advantages in terms of significantly higher net and gross water allocations and lower water costs. On the contrary, more modern IUs counterbalance lower water allocations and higher water costs by making use of significantly more efficient irrigation systems, more productive crops, resulting in significantly higher water productivity. This can partly be explained by the fact that surface water is more easily available and cheaper to extract than ground water and that older IUs have a significantly higher percentage of its origin from surface water. These results indicate that newer irrigation has a higher percentage of it origin from groundwater as the basin closes.

8.1.3 Objective 3: Measure inequality in irrigation sector

'You can't manage what you don't measure'

Old management adage

A set of inequality measures was explored to develop practical measures of equality for irrigation sector performance at basin level in the Guadalquivir RB. The application of descriptive inequality measures and concentration curves revealed high inequality in water management related variables in the basin. Regardless of what measure was applied, all indicators expressed that gross water allocation was more equally distributed than water costs and gross income per IU for year 2008. Inequality in gross water allocation is expected to be reduced from 2008 to 2015 as of the water allocation scenario described in the draft hydrological plan. Lorenz curves and t-tests reveal that the 20% of the IUs that are allocated less water compared to those 20% of the IUs that receive more water have significantly lower gross and net water allocation (m^3), gross and net crop income (€); and they have significantly higher total costs (€), higher total water costs (€) and higher efficiency in absolute terms. At the same time the average gross crop income per volume (€ m^{-3}) is 3.5 times higher for low water allocation IUs than high water allocation IUs; similarly, the water costs per volume (€ m^{-3}) are 8.6 times higher. The correlation between gross water allocation (m^3) and, respectively, gross crop income (€) and water costs (€) were both low and insignificant that could be explained by the heterogeneity of the basin. Decomposition analysis can provide help in explaining how economic trends and government policies affect the distribution of water in irrigation sector. The results show that most of the inequality in water allocation (2008) stem from the presence of recent irrigation and that the within group inequality is largely higher than the between group inequality. The Pen´s Parade curves shows that both net and gross water allocations are practically equally distributed for the years 2008 and 2015 until around fraction 0.45. The reason is that IUs with low gross and net water use already use the water highly efficient and further reduction in water use would not be economically viable in order to recuperate investments in irrigation infrastructure. Moreover, the investments in modernization are considerable. Improvements in infrastructure are prioritized over higher consumption by IUs within fraction 0.45 to 0.95 of the Pen´s Parade. The remaining units produce rice, which is the largest per hectare water user and already highly efficient. The results demonstrate that the planned modernization and allocation of irrigation water towards 2015 as of the draft GHBP will increase the efficiency of older irrigation units in the basin and lead to a more equally distributed water allocation. There are considerable fluctuations in annual water allowance, therefore water saved by older units could help to ensure a more stable supply and increase and secure the annual water allowance of the irrigation sector. Descriptive inequality measures and concentration curves are useful to measure and compare inequality in selected irrigation related variables and between time periods. Nevertheless, given that equity is a value-laden concept and requires human judgment, there are few examples to compare the results of what equity might imply empirically. The measurements are given meaning as they are put to use in policies. But, they must be concrete, well defined, taking into consideration scale and level so that it is possible to monitor progress. Measures and their analysis need to be adapted to the setting, as the strategies of one basin could be highly different from another basin setting.

8.2 RESEARCH CONTRIBUTION AND IMPLICATIONS

8.2.1 The significance of the findings

'Gone is the era when humanity can pretend that water defies the principles of economics'

Longo and Spears (2003)

The suggestions made in this thesis are exploratory and conceptual. They are meant to stimulate critical thinking about the problem of sharing and allocating scarce water within the irrigation sector of a RB. The findings of this study make several contributions to the current literature. First, the findings enhance our understanding of the conceptual dimensions of irrigation equity and expand our knowledge of equity-related concerns in situations of water shortage and increasing demands in a closing basin. The study adds to a growing body of literature applying a DPSIR-approach by adapting the framework to the context of basin closure. Whilst most DPSIR studies use descriptive methods or indicators, this research go beyond these standard approaches by using test statistics and polynomial regression models. Studying how access to water is related to how long a unit has been irrigating assists in our understanding of the role of temporal dimensions of equity raising questions of fairness. Moreover, standard measures of inequality has been adapted from a context of development economics, poverty and economic inequality analysis to the context of 'poverty of water' and allocation issues. Various methodological adoptions have been made to cope with issues of scale and level of aggregation. The new proposed approach can make it possible to compare results to a larger extent with other basins and between years, given that the least aggregated unit available is homogeneous across the variables studied. Even though decomposition analysis is commonly used in income analysis, to the author's knowledge, this study is one of the first that has made use of this technique for understanding the relative contribution of spatial and temporal factors to water allocation. The empirical study of the Guadalquivir RB provides new site specific knowledge in a sector and a basin with high potential for water conflicts. It adds to our understanding of basin level evolution and trajectories of Mediterranean basins located in a region that suffers water resource exhaustion and drought spells that are likely to aggravate because of climate change resulting in a drier, warmer climate. Simultaneously, these findings are also relevant to a larger context in two ways. First, they could serve as a one of the pioneer studies on basin closure in an European setting and a developed country context. Thus potentially they could serve as basis for future studies of other RBs in Spain and other developed countries. Second, the methods used to analyze the equity and equality dimensions in irrigation in this basin may be applied to other basins elsewhere in the world where basin level data, census and irrigation inventories (with aggregation issues) are available.

8.2.2 Theoretical and methodological implications

A focus on irrigation sector is important, as irrigation uses the lion's share of water in the world´s RBs. Its evolution undoubtedly has big implications on both the quantity and quality of water in most RBs. The thesis shows that the inclusion of simple regressions and statistics in a DPSIR-framework is helpful to examine the relationship between one dependent and one independent variable in the DPSIR-framework, as the regression statistics can be used to predict the dependent variable when the independent variable is known. Regression goes beyond correlation by adding prediction capabilities. These new approaches to the DPSIR-framework could be used to better the understanding of basin level processes and their interactions and to identify potential trade-offs between equity (social and spatial) and efficiency in economic rationality in other basins as well. The descriptive inequality measures and the concentration curves investigated potentially could be used to help examine water claims within the sector and geographical areas, quantify the allocation to identify areas of concern, track progress of policy initiatives, and see how inequality changes over time. It is clear that the different measures tell different stories of inequality, and in many cases the meaning of the indicators will be disputed, for example in the case of time series data or in the case of crossing Lorenz curves. Nevertheless, indicators with decreasing or increasing values will trigger the scientist's curiosity to understand change and the impact of change. Since the question of interest very often is a comparison of distributions over time, between regions, etc., one cannot trust only one single inequality measure to tell the whole truth. Moreover, inequality measures are most often ordinal measures in nature. Because of this, the chosen measures should cover different parts of the distribution, especially in the case where Lorenz curves are crossing. The thesis has argued that, in particular, the Theil index is useful due to its axiomatic properties and decomposition quality. The thesis deals with data of different level and scale. To address this problem a frequency weighting approach to homogenize the unit of analysis is adopted. This approach to measure irrigation inequalities has an advantage in that it can be used for comparing RBs or temporal data under the condition that the weighting is made at the least aggregated level (homogeneous) and with inequality measures that are not scale sensitive. Finally, this thesis draws attention to the importance of context, level and scale when specifying definitions of equity and equality and proposes a set of new approaches and tools for investigating equity and equality related issues in irrigation water management.

8.2.3 Limitations of the research

This thesis did not ask whether or not a particular equity and equality policy in the Guadalquivir RB has been successful in achieving the government's intended goal. This is because the governments intended equity and equality goals were not clear. For example, its welfare function was not known, nor how it is influenced by the demand of special interests. A government´s stated goal can hardly be taken at face value, since strategic behaviour often requires the government to make statements which are at odds with its true objectives. Yet it is a good strategy to measure progress toward them to encourage future transparency and hold institutions to what they say they intend. Instead, a number of criteria and measures to aid and monitor policy impact are proposed, leaving it to the policy maker to subsequently use this information to make policy choices which can also force transparency. To that end, a number of important limitations need to be considered.

The thesis relies entirely on secondary data as no funding was available for additional fieldwork or travel. It was crucial for the analysis to get access to basin level data, the thesis would have benefited of collecting additional data to try to understand additional aspects or explanations to the results. This research was not specifically designed to evaluate all dimensions of equity and equality related to basin closure at basin closure. Moreover, only hypotheses related to available data could be tested. Moreover, the data were not utterly adapted to the research needs either in terms of specification of variables or in terms of unit of aggregation. However, to date, these are the best data available at basin level and have been collected and quality screened through an expensive, time consuming process that in any case would have been outside the scope of data collection for a PhD thesis. It must be stressed that efforts were made to assure a precise interpretation of the variables to ensure the quality of the results. This was done by consulting the staffs of the fieldwork and the database of the irrigation inventory, as well as by presenting the thesis to the CHG so that they could give their suggestions, corrections and points of view before submission.

A major weakness of this research was the paucity of robust and real water use and water allocation data. Reported water use data suffered severe problems of validity and reliability. After a careful consideration and consultancy with CHG, other key informants and experts, this variable was discarded from the analysis. Instead, estimated net and gross water use were applied. These variables were cautiously estimated by hydrologists and agronomists and were, in the end, considered more reliable than the reported water use as they were site-specific estimations taking into consideration crop type and a range of factors reflected in the efficiency of the system. Another advantage of using these variables was that they were the same data that the CHG use in the planning of management of the Guadalquivir RB basin involving the water allocation scenarios for 2008 and 2015. Moreover, the gross water allocation variable was given more importance than net water allocation. The difference was the estimated global losses. The argument for using gross water allocation is that it tends to be more accurate because it represents what is actually extracted from the basin, and it is related to farmer water rights. Water authority controls the gross volume abstracted but the exact water consumption (evapotranspiration) is also dependent upon factors such as precipitation, location, soil conditions etc that are not available information at basin level. The water cost variable was given as a ratio implying the gross water variable.

The allocation of a water right to a farm land is directly related to potential income generation. However how well the water is applied is not only related to technical efficiency but also to the physical condition of the area and the capability of the person that receives it. These are data that were not available for this analysis. The study lacked information about the quality of the water. Water does not go back to the system clean – it contains salt and minerals, and its quality may deteriorate as it proceeds toward the sea, leading to higher water quality up stream than at the end of the basin. Returning to aggregation unit, the approach in the inventory posed a challenge to the analysis, as the units had a mix of levels and scales that could not be divided into comparable units of analysis, such as standard

units of analysis of farmer or irrigation scheme. To aggregate the units into municipalities or counties was a possibility considered, but it was discarded, as it would have implied a large loss of information and challenges in terms of constructing categorical data. Nevertheless, spatial division of the units would not have been a strait forward process as the location coding was not utterly clear and the GIS-maps made for the database were not permitted used for this thesis due to political sensitivity and protection of data. Therefore, this issue was resolved by proposing the use of one unit of analysis corresponding to one hectare.
The crop patterns of 2008 and 2015 gives a snap shot of the crop pattern situation and its change towards the future. It is important to take into reflection that the future scenarios always will be constrained by the unpredictable. Though the future scenario could be quite uncertain, it is reasonable to assume that even with a drastic CAP reform that change the profitability of current crops, the role of irrigation sector in water use in Mediterranean RBs such as the Guadalquivir RB always will play a key role in saving water. Furthermore, the underlying hypothesis for the sustainability of the Guadalquivir RB is that water saving through technical and economic measures should imply no increase in irrigation area in order to make sustainable use of the water saved.

8.3 TENTATIVE RECOMMENDATIONS FOR POLICY AND MANAGEMENT

'Well done is better than well said.'
Benjamin Franklin (1706-1790)

The conclusions of this thesis call for the need for a more clearly articulated policy agenda around the issues of equity and equality in irrigation sector. The findings of this research suggest several courses of action for a better management and monitoring of allocation of irrigation water resources in the Guadalquivir RB. These can be summarized in three main points:

- Better definitions
- More transparency
- Monitoring

8.3.1 Better definitions

Law and water institutions should take serious the important role of improving water allocation practices by finding equilibriums that simultaneously are sustainable and are considered fair by the majority of the stakeholders, preferably through public participation (formal equity). However, if equity and equality are not well defined, what difference do these words make? And how can they lead to any meaningful change in the policies pursued by mainstream irrigation water management? When allocating water in the irrigation sector at basin level, a reasonable approach to tackle this issue is to identify answers to questions like:

- What form should the allocation take?
- What are the eligibility criteria? Who is entitled to receive a share?
- What factors should count in the allocation? What is the normative versus actual distribution?
- What are the relevant allocation principles? (parity, priority, proportionality)
- Should the most productive lands receive more water?
- How to share costs of investments and to recover costs?
- What are the relevant precedents? Will the majority of the claimants perceive the allocation as fair?
- How should competing principles and criteria be reconciled? No single distributive criterion: Compromise or trade-offs
- What incentives does a rule create?

Although the current research reveals that to give priority to land that first started to irrigate is one of the allocation criteria in the Guadalquivir RB, there are many more dimensions and factors relevant to clarify and tackle in irrigation water management. Especially, there is an explicit need for a more elaborated and specific definition of the equity criteria on how water should be shared in situation of drought and water restrictions. Allocation criteria also have to take into account the fact that water availability varies within and between areas and years. They need to clearly spell out how to 'share scarcity' in times of shortages. For example, mechanisms to compensate farmers should be planned in advance so that during severe droughts they can release water for other uses. In the long run, arrangements may also be affected by changes in land use, runoff patterns, or societal values. So, they need to be adaptable and flexible. This would not only help the farmer to plan better, it would probably also reduce the potential for conflicts. Moreover, what should be equal or unequal is important beyond water allocation as it is related to benefits and burdens and territorial development.

8.3.2 Transparency

Water managers have to strive to address the lack of transparency and criteria for how water is shared in irrigation sector. Increasing transparency could help peer monitoring the use of the water, once water allocation criteria at different levels scales are established, representing formal equity. Formal equity is a term the author of this thesis proposes to be defined as the distributional criteria that what the law and legislation has established as fair, through a involving public participation process.

In the Guadalquivir RB there is an urgent need to register all legal water rights entitlements, chiefly in terms of the site, quantity and duration of the right. The GHBP estimates and plans for the irrigated area currently in use, including those that report to not hold formal water rights. The lack of a complete central register can be source of confusion, foment conflicts and lead to lack of monitoring of illegitimate claims and use. Lack of a register can limit the volume of trading in a water market quite apart from the transition problems involved in creating a new rights structure over existing water allocation arrangements.

8.3.3 Monitoring

The thesis may serve as tool for managers to start to address and monitor equity and equality related concerns more systematically. Proper management of irrigation water is important for the sustainable management of most basins in the world, and as long as water use is profitable in the irrigation sector, there will be claimants and pressures on the resource continues. The methodological tools proposed in this research can be used to develop policy targets aimed at more transparency and to monitor the level of inequality in inputs and output variables. This is especially relevant for water strategies in situations of water shortage. Sustainable development encompasses the three core dimensions of environment, economy and equity. Impacts on one of these dimensions have implications for the other two. These concerns need to be taken into account when considering the state and water agency's capacity to meet equity in the context of basin closure.

Access to water in RBs cannot be realized unless one considers the implications of water resource balance and sustainable development. This also points to the importance of a holistic approach of RUW at a micro, meso and macro level. Models should play an important role in supporting decision making processes, just us other technological tools do. The methods applied in this study can be used to simplify and model reality in order to return to reality with explanations, predictions and decisions. Another issue is that the WFD require management to establish adequate water pricing with full cost recovery, including environmental and resource cost. This is an issue that has proved difficult. This approach has expected to act as an incentive for sustainable use of water resources and help to achieve the WFD's environmental objectives. In this regard, conceptually valid and empirically sound estimates of water variables are essential for rational allocation of water among uses and users over time.

8.4 RECOMMENDATIONS FOR FUTURE RESEARCH

'When I had all the answers, the questions changed...'

Paulo Coelho (b. 1947)

The findings of this research must be viewed in the light of its limitations which again provide avenues for future research. This thesis has raised many questions in need of further investigation. Foremost, there have been few evaluations of Spanish water decision-making systems, or outcomes, in terms of procedural or distributional justice. The basic underlying themes in most planning arguments relate to what is 'just', 'fair' and equitable in terms of who should benefit from water allocations. However, equity and equality is not only relevant to how water is allocated, but also who should bear the costs; and how should such decisions be made. There are many questions that could guide future research: Is it fair to pay old users for their rights in a water market? Given the criteria of equal opportunities for past and future generations, is it fair to exclude new claimants that might have higher willingness to pay for water and might be more efficient? Moreover, what would be the effect on extraction of irrigation water if there was an easily available public register on water rights? Considerably more effort will be needed to help improving legislation and management guidelines to clarify what should be the criteria for water allocation.

Water conflicts are becoming inevitable as there are mismatch between supply and demand, and water is not used intelligently and perceived fair. It would be important to know more about how we can link the level of individual to that of social preferences. Therefore it seems important to evaluate existing valuation methods for water management regarding their capacity to express social preferences and act as inputs to social choice. It is suggested that future research, based on the above findings, propose an improved methods that is better at capturing the social dimension involved when making decisions over the use of water as a basic resource. These methods should capture the micro, meso and macro level of rational water use to fill gaps in basin trajectory knowledge and contribute to the area of choice theory to obtain a better understanding of what is the basis for social choices when compromised solutions are required.

Up to now, most research and economic modelling under the WFD have been focused on estimation of water price and financial cost recovery, and current economic research on WFD is directed to environmental cost estimation and cost-effectiveness analysis of the programme of measures, all based on traditional environmental valuation methods. It would be interesting to also include studies of the distributional effects of these initiatives.

8.5 CONCLUDING REMARKS: MAKING EVERY DROP COUNT WHILE FAIR

Water use demand management under scarcity is challenging. Improved performance in water use and water saving is key to meeting the general objectives of economic efficiency, environmental conservation, and community and consumer satisfaction. Socially, efficiency looks after the interests of future generations; environmentally, sustainable use of water ensures good ecological status and minimum flows. Economically, water efficiency reduces business costs and defers costly investment in water supply development and sewage treatment capacity expansions. The terms we use are never neutral; they tend to be given meaning as they are put to use in policies. However, in the end, equity or equality will not have any practical implications unless the terms are well defined in terms of scale, level and dimension and they are measureable.

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APPENDICES

ANNEX 1 TOTAL AND PER SECTOR WATER DEMAND IN THE MEDITERRANEAN (2000-2005)

Countries	km³/year					%			
	Total demand	Drinking water	Irrigation	Industry	Energy	Drinking water	Irrigation	Industry	Energy
Spain	37.070	5.300	24.160	1.440	6.170	14.3	65.2	3.9	16.6
France	34.960	6.200	4.100	3.380	21.280	17.7	11.7	9.7	60.9
Italy	41.982	7.940	20.136	7.986	5.919	18.9	48.0	19.0	14.1
Greece	7.800	1.250	6.300	0.130	0.120	16.0	80.8	1.7	1.5
Malta	0.058	0.031	0.024	0.003		53.4	41.4	5.2	
Cyprus	0.253	0.067	0.182	0.004		26.5	71.9	1.4	
Slovenia	0.894	0.187	0.007	0.080	0.620	20.9	0.8	8.9	69.4
Croatia	0.375	0.314	0.001	0.050	0.010	83.7	0.3	13.3	2.7
Bosnia-Herzegovina	0.930	0.230	0.600	0.100		24.7	64.5	10.8	
Montenegro	0.050	0.050				100.0			
Albania	1.700	0.460	1.050	0.190		27.1	61.8	11.2	
Turkey	40.100	6.000	30.100	4.000		15.0	75.1	10.0	
Syria	16.690	1.426	14.669	0.595		8.5	87.9	3.6	
Lebanon	1.400	0.450	0.940	0.010		32.1	67.1	0.7	
Israel	1.950	0.712	1.129	0.113		36.5	57.9	5.8	
Palestinian Territories	0.280	0.125	0.155			44.6	55.4		
Egypt	70.430	4.760	58.800	2.200	4.670	6.8	83.5	3.1	6.6
Libya	4.260	0.600	3.540	0.120		14.1	83.1	2.8	
Tunisia	2.457	0.406	1.918	0.133		16.5	78.1	5.4	
Algeria	6.270	1.330	3.940	0.800	0.200	21.2	62.8	12.8	3.2
Morocco	9.488	0.855	8.475	0.158		9.0	89.3	1.7	
Total/Average									
North Shore	126.072	22.029	56.560	13.363	34.119	17.5	44.9	10.6	27.1
South and East Shore	153.325	16.664	123.666	8.129	4.870	10.9	80.7	5.3	3.2
Mediterranean	279.397	38.693	180.226	21.492	38.989	13.8	64.5	7.7	14.0

Ratio					
North Shore / Mediterranean	45%	57%	31%	62%	88%
South and East Shore / Mediterranean	55%	43%	69%	38%	12%

Source: State of the Environment and Development in the Mediterranean 2009 (UNEP/MAP-Plan Bleu, 2009).

Notes:

- Total water demand corresponds to the sum of water directly abstracted, including losses in transport and use, and the production of non-conventional water
- Drinking water demand refers to water directly abstracted and water issued from desalination of sea water and brackish water for supplying the households, public services, commercial establishments and deserved industries.
- Water demand for irrigation refers to water directly abstracted and non-conventional production (desalination, clean wastewater reuse, drainage, etc.) for irrigated agriculture production.
- Water demand for industry refers to water directly abstracted for the industries not deserved by the public drinking water network.
- Water demand for energy refers only to the thermal power plant cooling.

ANNEX 2 DESCRIPTIVE STATISTICS OF WATER ALLOCATION RELATED VARIABLES BY IU (2008 AND 2015)

	2008				2015	
	Gross income (€)	Water costs (€)	Net water allocation (m^3)	Gross water allocation (m^3)	Net water allocation (m^3)	Gross water allocation (m^3)
N	845,998	845,998	845,998	845,998	881,568	881,568
Range	50,416	1,660.21	8,900	10.486	8,900	9,811
Min	259	1.78	1,500	1.750	1,500	1,744
Max	50,675	1,661.99	10,400	12.235	10,400	11,556
Sum	3,302,109,258	191,997,855	2,463,070,100	3.329.824.852	2,526,359,870	3,107,650,173
Mean	3,903	226.95	2,911	3.936	2,866	3,525
Median	3,059	175.83	2,200	2.569	2,200	2,558
Mode	3,413	300.00	1,500	1.750	1,500	1,744
Std.dev.	4,136	162.97	2,005	2.749	1,981	2,363
Variance	17,103,369	26,559.89	4,019,983	7.555.155	3,925,455	5,583,270
Skewness	42	1.85	2.2	1.3	2.2	1.6
Kurtosis	25	6.76	5.4	1.2	5.7	2.8

Source: Author’s calculations based on data from CHG (2010a).

ANNEX 3 IRRIGATED LAND BY CROP TYPE (%) AND CROP MIX CHANGE IN THE GUADALQUIVIR RB (2008 AND 2015)

Crop type (%)	2008 Irrigated area	2015 Irrigated area	Crop mix change
Olive	46.5	47.8	1.3
Olive (intensive)	8.2	7.9	-0.3
Extensive winter crops	9.4	9.5	0.1
Strawberry	0.5	0.4	-0.1
Sunflowers	3.0	3.0	0.0
Citrus	3.3	4.3	1.0
Fruit trees	2.1	2.8	0.7
Cotton	15.0	6.4	-8.6
Horticulture	4.1	6.1	2.0
Green house	0.1	0.1	0.0
Others	1.6	4.2	2.6
Sugar beet	1.0	1.4	0.4
Maize	1.1	2.1	1.0
Rice	4.2	4.0	-0.2

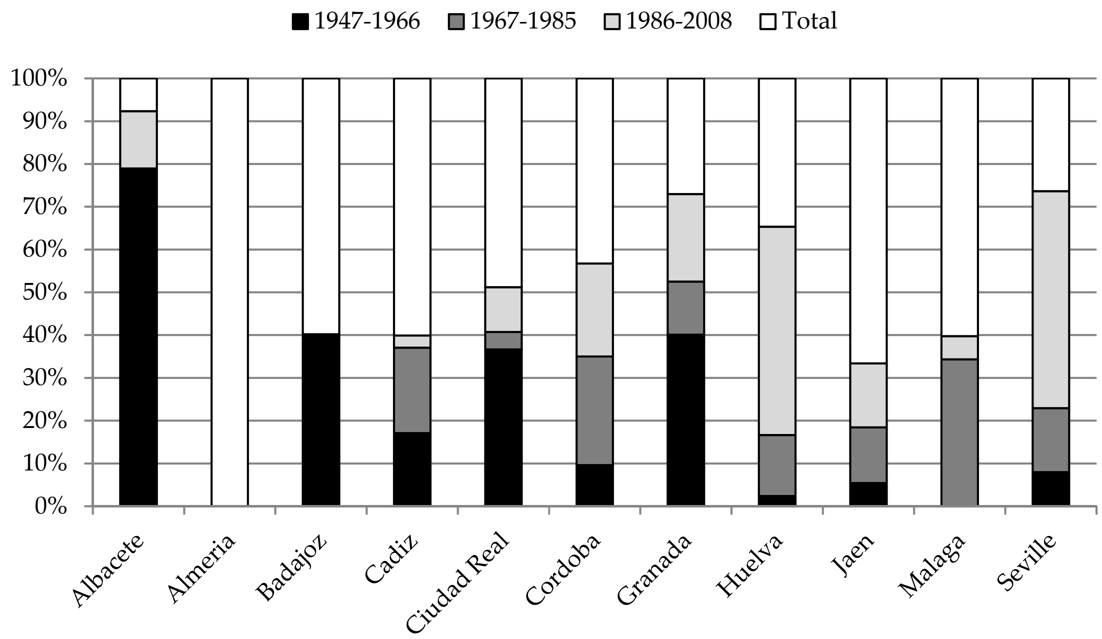
Source: Author’s calculations.

ANNEX 4 GROSS WATER PRODUCTIVITY (P) AND WATER COSTS (C) (2008)

Crop type		P (€ m^{-3})	C (€ m^{3})	% C of P	P/C
Cotton	Mean	0.570	0.026	4.5	22.1
	SD	0.560	0.023		
Rice	Mean	0.203	0.026	12.7	7.9
	SD	0.002	0.006		
Citrus	Mean	1.797	0.046	2.6	38.9
	SD	0.332	0.040		
Extensive winter crops	Mean	0.271	0.042	15.7	6.4
	SD	0.058	0.031		
Strawberry	Mean	8.830	0.152	1.7	58.2
	SD	0.408	0.062		
Fruit trees	Mean	2.485	0.044	1.8	56.1
	SD	0.921	0.039		
Sunflower	Mean	0.177	0.032	18.0	5.5
	SD	0.038	0.023		
Horticulture	Mean	2.260	0.057	2.5	39.8
	SD	0.902	0.051		
Green house	Mean	8.364	0.037	0.4	228.6
	SD	0.610	0.026		
Maíze	Mean	0.400	0.044	10.9	9.2
	SD	0.045	0.038		
Olive	Mean	1.757	0.140	8.0	12.5
	SD	0.300	0.102		
Intensive olive	Mean	1.123	0.063	5.6	17.9
	SD	0.262	0.051		
Others	Mean	0.213	0.051	23.9	4.2
	SD	0.148	0.042		
Sugar beet	Mean	0.358	0.041	11.4	8.8
	SD	0.069	0.022		

Source: Author’s calculations

ANNEX 5 PROVINCE BY PERIOD OF APPROPRIATION (2008)

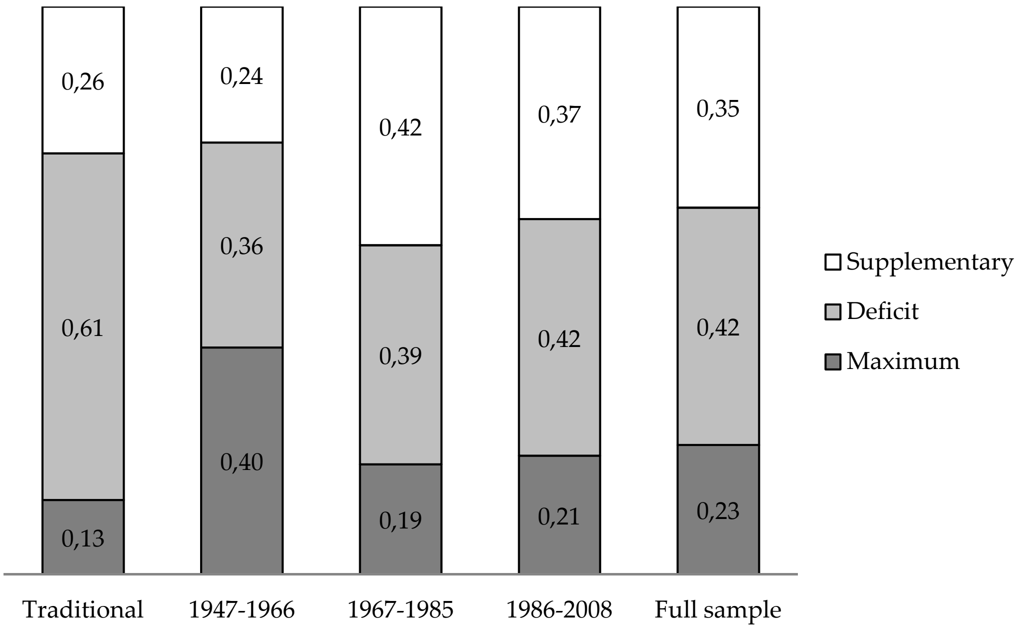


Source: Author's calculations

ANNEX 6 SUPPLY RESTRICTION RESPONSES BY PERIOD OF APPROPRIATION

(a) Water doses response

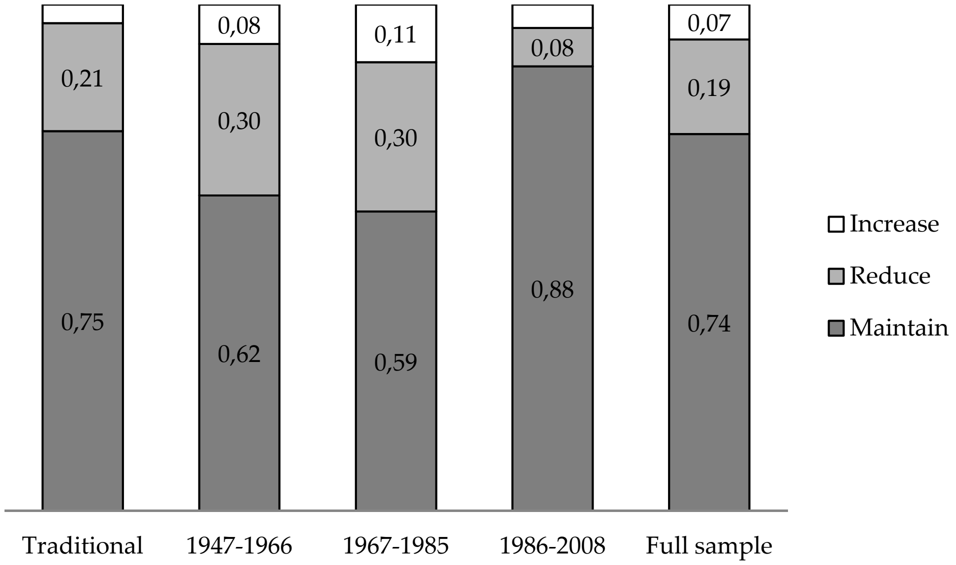
Pearson Chi-Square test indicated that water doses response was significantly related to the period of appropriation (no homogeneity), X^2 (6)=35,092.936, p=0.000 , see next figure.



Source: Author's calculations

(b) Irrigated area response

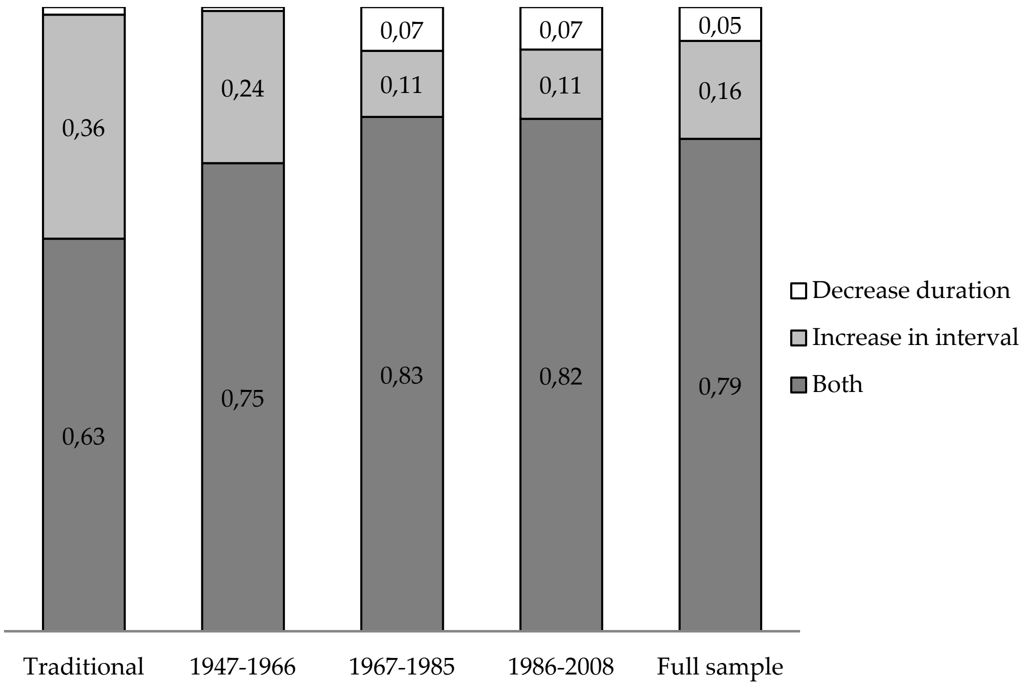
Pearson Chi-Square test that indicates that irrigate area response was significantly related to period of appropriation (no homogeneity), X^2 (6)= 67,142.492, p=.000, see next figure.



Source: Author's calculations

(c) Duration and interval response

Pearson Chi-Square test that indicates that duration and interval response was significantly related to seniority (no homogeneity), X^2 (6)= 26676.824, p=0.00, see next figure.



Source: Author's calculations

ANNEX 7 INFORME DE DIRECTORES

TÍTULO DE LA TESIS:

Equity and equality in irrigation water allocation under basin closure: Concepts and measurement.

DOCTORANDA:

Solveig Kolberg

INFORME RAZONADO DEL/DE LOS DIRECTOR/ES DE LA TESIS
(se hará mención a la evolución y desarrollo de la tesis, así como a trabajos y publicaciones derivados de la misma).

La tesis que presenta Solveig Kolberg se inició formalmente con los cursos de doctorado el año 2006, presentando posteriormente un trabajo para la Suficiencia Investigadora a fines de 2007 donde ya se adelantaban los temas de investigación sobre el análisis económico del agua de riego. Desde esa fecha se ha trabajado en el desarrollo metodológico y en la obtención de material, que finalmente se ha basado en la explotación, análisis y depuración del base de datos suministrada por C.H. Guadalquivir. La metodología elaborada es original de la doctoranda, siendo una innovación al aplicar herramientas para la medición de la equidad en la asignación de agua, considerando tanto inputs como outputs del reparto del recurso. La aplicación de esta metodología a escala cuenca y considerando la variable temporal ha permitido obtener resultados que son relevantes para lo formulación de políticas hidráulicas y la gestión ordinaria del regadío.

Parte de los resultados previos se han ido publicando en distintos medios de divulgación científica aunque los principales resultados se van publicar con posterioridad a la defensa de la tesis. Este trabajo se ha simultaneado con la ejecución de proyectos europeos donde ha participado mediante contratos con cargo al proyecto Melia y Ministerio de Medioambiente.

Por todo ello, se autoriza la presentación de la tesis doctoral.

Córdoba, 21 de mayo de 2012

Firma del/de los director/es

Fdo.: Julio Berbel Vecino   Fdo.: Rafaela Dios Palomares