Institutional Analysis of Water Management for Agriculture in the Chancay-Lambayeque Basin, Peru

by

Cathy Rubinos

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Approved July 2013 by the
Graduate Supervisory Committee:

Joshua Abbott, Co-Chair
Hallie Eakin, Co-Chair
Abigail York

ARIZONA STATE UNIVERSITY

August 2013

ABSTRACT

This research presents an analysis of the main institutions and economic incentives that drive farmers behaviors on water use in the Chancay-Lambayeque basin, located in Lambayeque (Peru), a semi arid area of great agricultural importance. I focus my research on identifying the underlying causes of non-collaborative behaviors in regard to water appropriation and infrastructure provisioning decision that generates violent conflicts between users. Since there is not an agreed and concrete criteria to assess "sustainability" I used economic efficiency as my evaluative criteria because, even though this is not a sufficient condition to achieve sustainability it is a necessary one, and thus achieving economic efficiency is moving towards sustainable outcomes. Water management in the basin is far from being economic efficient which means that there is some room for improving social welfare. Previous studies of the region have successfully described the symptoms of this problem; however, they did not focus their study on identifying the causes of the problem. In this study, I describe and analyze how different rules and norms (institutions) define farmers behaviors related to water use. For this, I use the Institutional Analysis and Development framework and a dynamic game theory model to analyze how biophysical attributes, community attributes and rules of the system combined with other factors, can affect farmers actions in regard to water use and affect the sustainability of water resources. Results show that water rights are the factor that is fundamental to the problem. Then, I present an outline for policy recommendation, which includes a revision of water rights and related rules and policies that could increase the social benefits with the use of compensation mechanisms to reach economic efficiency. Results also show that commonly proposed solutions, as switch to less water

intensive and more added value crops, improvement in the agronomic and entrepreneurial knowledge, or increases in water tariffs, can mitigate or exacerbate the loss of benefits that come from the poor incentives in the system; but they do not change the nature of the outcome.

To Sofia’s heart

ACKNOWLEDGMENTS

I would like to express the deepest appreciation to my two co-chairs Dr. Hallie Eakin and Dr. Joshua Abbot for offering wealth of knowledge to improve the quality of this work, and sharing with me their passion to find new things, while being rigorous and kind. I would like to thank my committee member, Dr. Abigail York, for helping me sharpen my focus, and for her guidance and support during the development of this work.

Many thanks to the stakeholders in Lambayeque who so generously shared their time, knowledge, experience, contacts, research, especially Engineer Luis Orbegoso whose enthusiasm was contagious and encouraging. Many thanks to my family: my parents for believing in me; my sisters for their constant support and encouragement, and my daughter for inspiring me to be a better being.

Many thanks to Bedregal, for his constant support since the start of this research, in fieldwork and through all the process of this work. Many thanks to my friends, specially to Carlos Gonzalez, Madeline Tyson, Nivedita Rengarajan, Tetiana Vaskivska, Patricia Perez, Diego Rosales, Marco Ortiz, and my dearest friend and professor Katherine Kyle who reminded me to be critical in my research; all of them contributed in many ways to the realization of this project.

Many thanks to the School of Sustainability community for giving me the opportunity to learn to be creative, ambitious and a team player, while enjoying of a friendly and collaborative environment. Finally, many thanks to anyone who is reading this research; I will always be open to receive comments, especially critics that collectively improve our findings.

TABLE OF CONTENTS

CHAPTER Page

APPENDIX Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Figure page

Chapter 1

INTRODUCTION

The Chancay – Lambayeque basin, located in Lambayeque and Cajamarca, is one of the most important basins in Peru because of its vast geographic extent (see figure 1). It is located in a semi-arid region with low precipitation, which makes agriculture, as a water-intensive activity, challenging. Nevertheless, agriculture is the main activity in the basin and uses 89% of available water to grow mostly water intensive crops: rice (39%), sugar cane (38%) and cotton (7%) (ANA 2008).

Water is scarce in the basin. Water scarcity manifests in two different ways. First, despite the availability of irrigation, instead of farming in two full seasons per year, farmers grow crops in only one full season, and then one short season. In drought years farmers are forced to reduce their production even more[1]. Second, water for irrigation use competes with domestic water use, and according to Alfaro (2008), the total demand in rural areas is not satisfied (in some districts of the region, like Manuel Mesones Disitrict, 75% of the population does not have access to potable water for domestic consumption).

Water scarcity not only implies unsustainable use of water resources, but also that the region is facing a limit to sustainable development. The effects of water scarcity are manifested in: (1) deaths due to malnourishment and water-related disease; (2) violent conflicts among users; (3) degradation of ecosystems, salinization, erosion; and (4)

---

[1] Information acquired from the scope analysis.

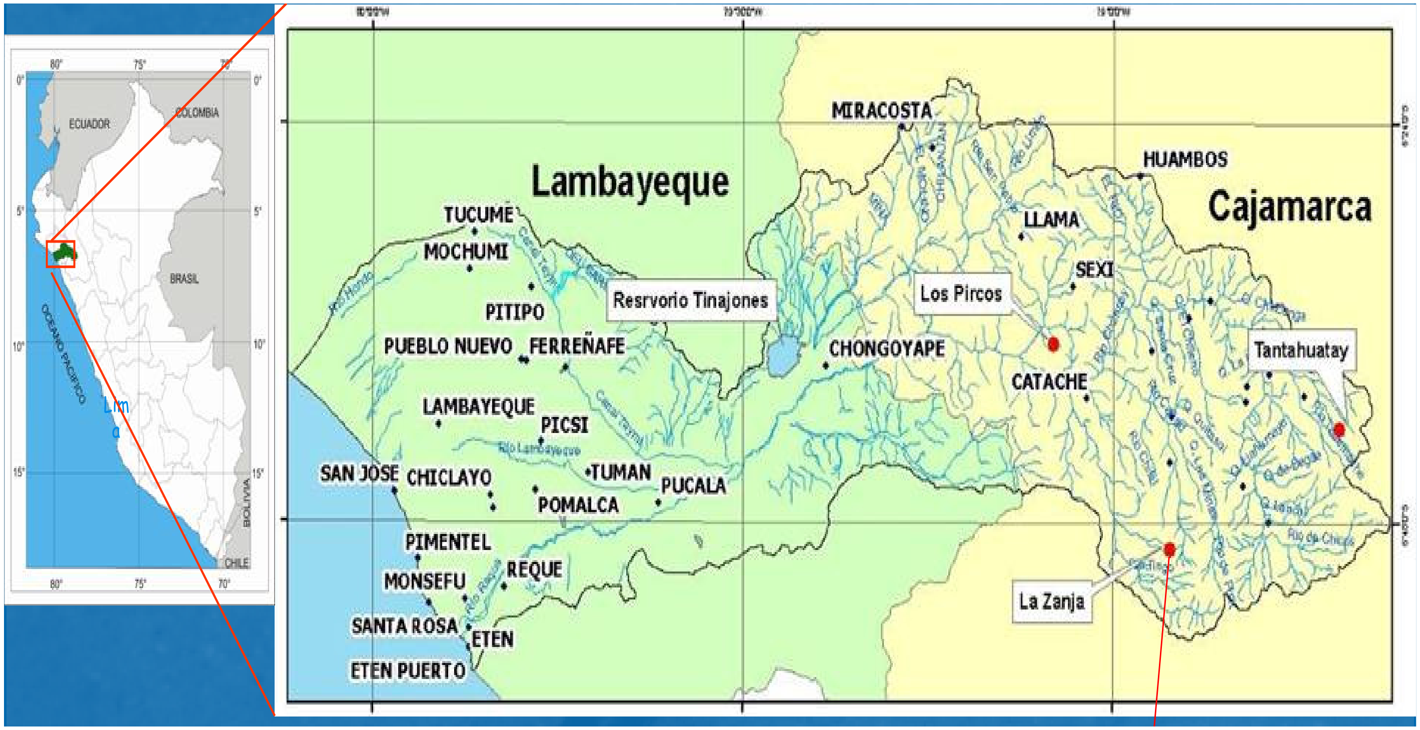


Figure 1. Map of the Chancay - Lambayeque Basin by ANA (2008)

limited economic growth because water is essential as an input to almost all productive activities (Alfaro, 2008; ANA, 2008). Poor water management, especially in regions of agricultural dependency, as the Chancay-Lambayeque basin, may cause poverty traps[2] (Hussain, 2007).

Additionaly, water problems in the basin are associated with inefficiencies in water use, which are strongly related to how water is managed in the basin. Managing water is a challenge and its success depends on its institutional design (Ostrom, 1990). By "institutions" I refer to rules, norms, and shared strategies that affect human behavior (Crawford & Ostrom, 1995).

Because farming activity is highly concentrated around the main canal of the basin, the Taymi Canal, my research focus on the use of water from the canal, which is almost entirely for irrigation purposes[3]. Moreover, non-collaborative behaviors in regard to water appropriation and payment of water tariffs are causing violent conflicts among users around the canal. Then I also focus this research on those non-collaborative behaviors.

---

[2] A poverty trap is a situation in which it is very difficult for people to leave poverty due to a lack of resources (capital, knowledge, etc.), and in which it may also be very difficult to acquire them, creating a self-reinforcing cycle of poverty (Carpenter and Brock 2008).

[3] However, it use competes with domestic water use that is delivered by other means.

Previous research on water management in the Chancay- Lambayeque basin (e.g., Alfaro, 2008; ANA, 2008; Regional Presidency, 2010) clearly describes water scarcity in the region, and the conflicts that currently revolve around water use. These studies outline the symptoms of the problems, but do not analyze the underlying causes. Without such an analysis, any solutions to the observed problems are unlikely to be successful. For this reason, I analyze how the institutional design affects management and farmers' behaviors in regard to water use, in an effort to better understand the causes current conflicts in the basin. Then, I discover how to improve these institutions to move towards a sustainable water management for agriculture in the basin.

Since there is not an agreed and concrete criterion to assess "sustainability" I use economic efficiency in this research as my evaluative criteria, because although this is not a sufficient condition to achieve sustainability it is a necessary condition[4]. Thus achieving economic efficiency is moving towards sustainable outcomes (Stavins, Wagner & Wagner, 2003).

To analyze how the institutional design affects farmers behaviors, I use the Institutional Analysis and Development (IAD) framework proposed by Ostrom (2009). The IAD framework is useful for understanding a wide variety of institutional arrangements (Imperial & Yandle, 2005), because it considers a variety of factors that help researchers generate the questions that need to be posed to analyze how water is

---

[4] Economic efficiency looks for non-wasteful outcomes in a sense that it seeks to achieve a resource allocation such us the social welfare is maximized and that no actor is worse off when changing the status quo.

managed. The IAD enable the study of different components that are normally unnoticed in previous studies such as the interconnection between rules as water rights and farmers' behavior. In this sense, the IAD is a framework for thinking about a complex socio-ecological system, that it is particularly well suited to understanding the impacts of institutional design on the system and feedbacks from the system to institutional design. Nevertheless, the IAD is not a model in itself, but rather provides a common structure for more focused modeling.

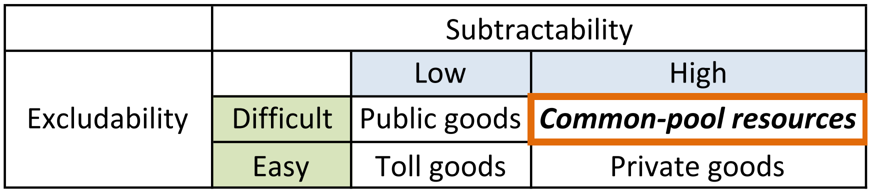
In many complex socio-ecological systems, such as the one that I present in this research, the number of variables that simultaneously affect individual behaviors is quite large, and these variables are related in a complex way. In order to achieve precise logical conclusions and sound quantitative and qualitative predictions of actors' choices, it is necessary to identify and analyze the exact configuration of key variables in a formal model. Otherwise, informal reasoning may lead to broad insights or conclusions that are not logically valid (Ostrom, Gardner & Walker, 1994). Thus, this study incorporates a dynamic game theory model that will be enriched by qualitative analysis.

Chapter 2 provides a literature review related to water management challenges and the importance of institutions as generators of conditions that provides different incentives, with a particular focus on the role of institutions of propery rights. In chapters 3 and 4 I explain the design of the research and how I collected the data. I used secondary data and 21 interviews of actors related water management or farming activity in the basin to inform the IAD framework. In chapter 5, I present how the IAD framework helps to organize the analysis of the case study. Here I present the results of how biophysical attributes, community attributes and rules of the system, combined with other factors can affect farmers' actions in regard to water use and affect the sustainability of water resources. In chapter 6 I present the model that I have built to be used to further analysis and I analyze it in chapter 7. In chapter 8, I discuss results and present an outline for policy recommendations, which include a revision of water rights and related rules. Finally in chapter 9, I share some concluding thoughts.

Chapter 2

THE WATER MANAGEMENT CHALLENGE AND THE IMPORTANCE OF INSTITUTIONS

Water systems are often characterized, as in this case, as common-pool resources (CPRs), a type of good defined by two characteristics (see figure 2): They can be used by more than one person or agent at the same time and/or over time, while excluding them from doing so is difficult or costly (non-excludability), and the use of the resource reduces the amount available for others (subtractability) (Ostrom et al., 1994).



		Subtractability	
Excludability		Low	High
	Difficult	Public goods	***Common-pool resources***
	Easy	Toll goods	Private goods

Figure 2. Types of Goods by Ostrom et al. (1994)*)*

Characteristics of non-excludability and subtractability present serious problems that are explained with rational choice theory. Rational choice theory states that individuals are driven by the goal of maximizing their well-being (Shughart, 2008ed.). This does not mean that they do not care about their families, friends, and community, because individual's well-being might depend on others' well-being, among other factors. Maximizing their well-being means that people do their best to satisfy their preference and needs under prevailing circumstances (Green, 2002).

In cases where cooperation is not fostered, rational users will maximize their own well-being by trying to get as much as possible from the resource (because if they do not others will consume it). However, because the good is also substractable, when users appropriate the good the availability of the good decreases (Ostrom, 2005). This effect is also known as the ***appropriation*** externality (Ostrom, et al., 1994).

Moreover, in many water systems, users build infrastructure to take a better advantage of water resources. In these cases, it is difficult to exclude users from benefits from infrastructure. However, maintaining those benefits has a cost that not everyone may be interested in paying because they may hope that others will pay for it (Olson 1965). This free-riding behavior will not always happen, but it is very likely to happen when users cannot easily be excluded for not contributing to the provisioning of the infrastructure maintenance (Ostrom, 2005). In this cases users will be facing a ***provision*** problem.

Then, in presence of appropriation externalities and provisioning problems, users may act in a non cooperative way that leads to inefficient outcomes – outcomes in which there is potential to make someone better off without making anyone else worse off. In such cases, cooperation will led to more desirable outcomes not only collectively but also individually (Ostrom, 2007). However, by definition it is difficult to control the resource use for CPRs, and since users will be acting independently, they may not achieve an efficient outcome.

Hardin (1968) in his classic article “The tragedy of the commons” explains that in a situation in which multiple individuals, acting independently and rationally in consideration of their own self-interest, a shared limited resource will ultimately be depleted, even when it is clear that it is not in anyone's long-term interest for this to happen. With this thought, many scholars proposed that successful CPRs management could be only achieved with policy interventions that impose government or private ownership (Poteete & Ostrom, 2002; Gibson, McKean & Ostrom, 2000).

Later, solid empirical evidence in regard to self-governance of CPRs (e.g. Lam (2005), Olson (1965), Dietz, Ostrom & Stern (2003) and specially Ostrom (1990)) stated that collective action is a valid option for communities to cope with CPRs problems and ensure its sustainability (Castillo & Saysel, 2005). They also showed that government intervention could sometimes frustrate the success of systems around CPRs, when users can organize themselves to create and enforce rules that protect natural resources (Milgrom, North & Weingast, 1990; Bromley et al., 1992). CPRs can be a government property (by a national, regional or local government); privately owned (by individuals or corporations) or owned by communal groups. The literature shows that no form of ownership is better than the other; but what is key for having a successful CPRs management are well-defined property rights (Schlager & Ostrom 1992).

Property rights are institutions that define the different privileges conceded to individuals to specific resources, such as water, land, fishes, etc. (Libecap, 1989). These privileges may involve a variety of rights, including the right to enter to a territory, to withdrawal or to appropriate the benefits from use or investment in the resource, the right to manage the resource, the right to decide who have rights to access the resource, and the rights to transfer other rights in a market (Ostrom, 2005, Libecap, 1989). The allocation of property rights, then, affects decision-making regarding resource use and, thus, affects actors' behavior and outcomes (Libecap, 1989). North (1978), De Alessi (1980), Libecap (1986), and Ostrom (1990) among others, studied how various property rights arrangements affect systems performance, which ranges from wasteful practices associated with open-access (when no one or everyone owns CPRs) or with property rights that do not suit local characteristics and values, to wealth – maximizing actions possible with well defined property rights.

Property rights as rules are one type of institution, but not the only institution that affects the success of CPR management. Consistent findings of many studies manifest that identifying well-defined property rights implies understanding local biophysical, social, and economic conditions (Ostrom, 1999; Meinzen-Dick, 2007) and it is because of this that there is no panacea – no one way - to organize irrigation activities (Chambers, 1988; Ostrom, 1990; Ostrom et al, 2007; Levine, 1980; Coward, 1979; Uphoff, 1986; Maass & Anderson, 1978). Thus in order to come up with a successful institutional design related to the supply and use of water systems it is necessary to understand how different variables build an incentive structure that affect system outcomes (Libecap, 1989). This is the aim of my research: to study how the Chancay- Lambayeque water system is affected by current water rights in combination of other factors as biophysical attributes, community attributes and other related rules.

For this end, I apply the IAD framework to a case of conflict between upstream and downstream farmers over irrigation water from the Taymi Canal, the main canal of the system. I focus my analysis on two aspects of the conflict: (1) water appropriation, because upstream farmers water use is unregulated, and (2) the common irrigation infrastructure provisioning, because upstream farmers are not contributing to this end. I use the IAD framework because it provides a guideline on how to combine the analysis of factors (e.g. crops produced, rules, norms, agricultural knowledge, equity issues, etc.) that affect farmers' behaviors on these two aspects of the conflict. I hypothesize that improved property rights – which implies assigning regulated irrigation water access and water infrastructure maintenance responsibilities to upstream farmers – could lead to a more sustainable allocation of water among users, and thus reduce disputes among them. I explore this hypothesis and other proposed solutions using a game theoretic model on chapters 6, 7 and 8.

Chapter 3

RESEARCH DESIGN

Institutional Analysis and Development Framework (IAD)

Frameworks operate at the broadest possible specificity level for theoretical analysis. Frameworks identify the elements and their relationships needed to consider for, in this case, institutional analysis; and they also organize diagnostics and prescriptive inquiry. Frameworks are useful to compare theories and to identify the “universal elements that any theory relevant to the same kind of phenomena needs to include” (Ostrom, 2011). The Institutional Analysis and Development (IAD) framework proposed by E. Ostrom (2009) identifies a common set of variables that affect incentives on different behaviors in regard to water use (or CPRs in general), and helps to identify the important variables and their impacts on the patterns of interaction among water users. For this research I use the IAD framework because it helps to understand and test how rational choice theory and property rights theory explain current outcomes considering local conditions in the Chancay-Lambayeque basin.

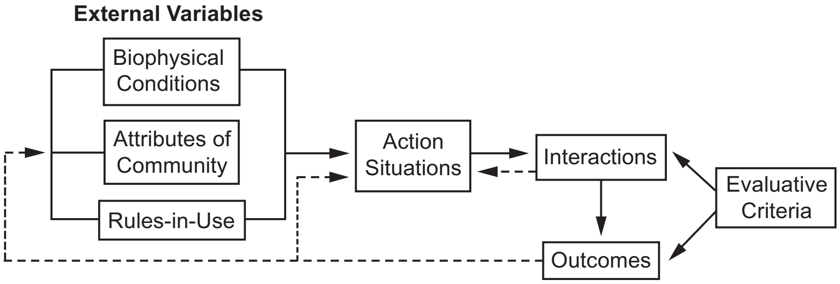


Figure 3. A Framework for Institutional Analysis by Ostrom (2011)

The starting point of the IAD framework, and the core of analysis is the *action arena* that considers actors interacting in an *action situation***,** which is a social space (see figure 3). Ostrom defines a common set of variables used to describe the structure of an action situation: (1) the set of actors, (2) the actors' positions or roles (e.g. irrigation association members vs. those who are not), (3) actors decisions and their outcomes, (4) outcomes as a result of actions, (5) actors' level of control over choice (e.g. some actors may take decisions on water withdrawal by their own, others can act collaboratively), (6) cost and benefits related to outcomes and, (7) available information (see figure 4).

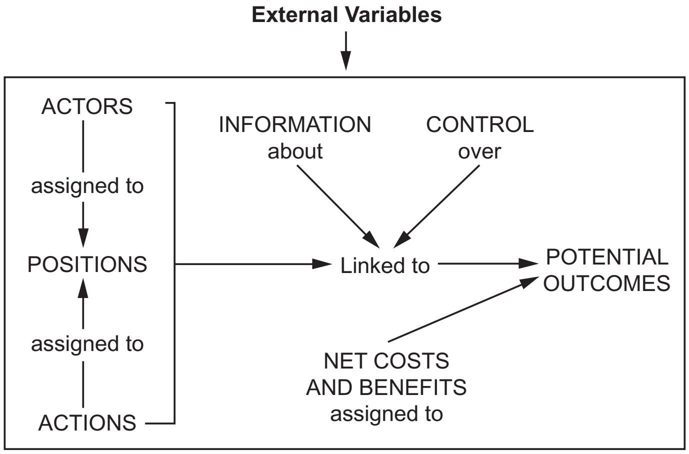


Figure 4. The Internal Structure of an Action Situation by Ostrom (2011)

Moreover, Ostrom presents three types of *external factors* that affect the action situations and the outcomes: (1) the conditions of physical world (e.g. how much water is available, type of crops that are grown, etc.), (2) the rules that govern the action arena, which include formal (written) or informal (norms) and; (3) the structure (or characteristics) of the community (e.g. shared values, homogeneity of their members).

The IAD framework only outlines the categories of variables that are relevant to the problem and the relationship among variables. In order to explore how variables relate in a specific geographic context and in relation to simulated changes in institutional arrangements, further analysis is required. One method of analysis that fits well with the IAD framework is game theory modeling (Ostrom, 2011). In general, models complement qualitative research by enabling the researcher to arrive at precise logical conclusions through analyzing the variables of the IAD framework (Ostrom, 2005); specifically, game theory helps to examine individuals' incentives to collaborate or not in the two type of dilemmas that I am analyzing in this research: Appropriation and Provision problems. Thus, in this research I use a dynamic game theory model in order to analyze how the variables of the IAD framework determine a certain incentive structure for the Chancay- Lambayeque community and determine why and when farmers will be aiming to collaborate.

Dynamic Game Theory Model

Game theoretic models are used for predictions about agents' behaviors and to compare different possible outcomes. To arrive at such predictions, the models incorporate theories and assumptions for a set of variables and parameters (e.g. the strategy sets available to all players, their state of knowledge, the positions of the players, the rules of the game (institutions), among others) (Ostrom, 2011). Game theory models fit well with the IAD framework because the basic elements of games are the seven components of the action situation (Selten 1975; Shubik 1982; Ostrom, Gardner and Walker 1994). Also, game theoretic models help to understand how changes in external variables (biophysical characteristics, rules, norms and community's attributes) may affect the performance of a system (Ostrom, et al. 1994). Thus, game theory models enable the analysis of strategic actions for decision makers, helping them develop more broadly acceptable solutions (Madani, 2010).

Game theory builds on rational choice theory because it claims that everyone will pursue their own well-being and that can lead to a cooperative or non-cooperative behavior (Shughart, 2008ed.). Thus, it is helpful for explaining why sometimes actors' decisions and behaviors might appear to be irrational, because actors do not attain the maximum outcome that they could have attained (individually and collectively) if they had only made different decisions (Messick & Brewer 1983). Game theory helps explain how decision makers' rational behavior, aimed at maximizing their own goals, might result in overall Pareto-inferior[5] outcomes. Likewise, game theory explains cooperative behaviors by understanding how incentive structures can allow agents to maximize their individual benefit when collaborating (Madani, 2010).

With a game theoretic model, we mathematically describe a social situation in which two or more actors interact. In cases where there are more than two actors there may be collusion among subsets of the players. Still, there are many other characteristics that define different kinds of models. There may involve several sequential periods or one period for each player, situations may be repeated or be faced only once, it could be static or dynamic, etc. In this study I use a dynamic, two-periods discrete game because it helps us understand how the incentive structure (action situation) experienced in each time

---

[5] Pareto Efficiency: A situation in which no one can be made better off without making someone else worse off. Pareto inferior means that it is not Pareto efficient (Perman et al. 2003).

period is affected by actors' actions, outcomes and shocks in the external factors. It will specifically help us understand how payoffs of one actor can be affected by other actors' actions over time.

In this two-step model, players will face the decision of how much to invest in the common irrigation infrastructure in the first period, and in the second period the will have to decide how much water they will individually withdraw from the canal. This is a stylized representation of the reality, where we can observe two types of externalities connected to the decisions that players will make: appropriation and provision externalities. Addressing appropriation problems implies focusing on the allocation of the flow of water, and addressing provision problems implies focusing on the creation or maintenance of irrigation infrastructure. Normally provision problems are left out of analysis or studied separately from appropriation problems (Lee, 1994), but they are highly interdependent and linked to successful self-governed irrigation water systems (Gardner, Ostrom, & Walker 1990; Ostrom, 1990).

Although the ability of game theory to represent the Chancay-Lambayeque Basin is real, it is not exempt of criticism. One major critique is the assumption of agents' rationality. Some critics argue that individuals are not entirely rational all the time and that research should include a bounded rationality analysis (Mccubbins, 1996). However, there are situations in which even if we used weak rationality assumptions, such as bounded rationality, we could obtain the same outcome we would if we used full rationality assumptions, due to the effects of learning, actors' heterogeneity, natural selection and statistical averaging (Tsebellis, 1990). Moreover, while the critiques are valid, the goal of using a game theoretic model, and models in general, is not to describe the reality in all its complexity, but to gain insights of the implications of the essential structure of a situation, and thus simplification is required. Beyond this balance, there is a tradeoff between the complexity added to a model, and the insights we can get from it.

Similarly, we should answer in the same way to critiques regarding the definition of payoffs. All those may not be perfectly captured by the game model because it is difficult to solve game theoretic models featuring the extremely difficult mathematical expressions that would be necessary to capture all individual benefits derived from cultural traditions or specifics values (Ostrom, 2005). Also, complicated attitudes toward risk or discount rates are difficult to calculate and be incorporated into game theoretic models (Ostrom, 1990; Martin, 1978).

Game theoretic models' conclusions and predictions are a sound first step in understanding the implications for agent behavior and system outcomes of institutional design features – even if additional refinements are necessary (Ostrom et al., 1994). The fact that game theoretic models are not intended to capture reality in all its integrity does not invalidate nor deny their ability to offer us a plausible method for understanding the effects of how agents behave and the actual effects of institutions as designed and enforced in real situations.

Chapter 4

DATA COLLECTION PROCESS

My data collection process entailed a review of existing published literature, interviews with key actors and experts in the region, and the identification of relevant secondary data necessary for my analysis and model development. First, I undertook a comprehensive review of published studies that illustrated the water problems of the region, specifically that narrated conflicts in the area (Alfaro 2008), and that attempted to diagnose problems associated with water management (ANA, 2008; Bustamante, 2010). Then I conducted field research in the Chancay- Lambayeque Basin in December 2012. I interviewed ten downstream farmers (tailenders), one upstream farmer (headenders)[6], one agricultural engineer, two water managers, one representative of the irrigation users association, two representatives from the national water authority, three agro-exporters representatives, two representatives from the agricultural ministry and one mayor (for the complete interview protocol, see appendix A). The main objective of the field research was to confirm, correct and complement the review of existing studies of the basin, and to contact different actors for further interaction. In March 2013 I contacted some of the actors I had previously interviewed to confirm the results of data I had processed and to fill knowledge gaps.

The information I gathered in the field was used to complement the literature review and to redefine the problem. To this end, I used the Institutional Analysis and Development (IAD) framework. Then I constructed a modified game theory model for

---

[6] Since they are not in the formal sector I experienced some difficulties in contacting more upstream farmers.

Common Pool Resources (CPR) applied to water management, capturing the main characteristics of the region. With this model I was able to understand the current dynamics of the system as well as perform some prospective analyses of changes in water management policies.

Chapter 5

THE CHANCAY–LAMBAYEQUE BASIN'S INSTITUTIONAL DESIGN

The biophysical and social context of the Chancy-Lambayeque Basin, and the institutional arrangements governing water use, are complex. In this chapter, I describe this context and governing institutions in detail, organizing my description according to the key variables featured in the IAD framework. In my description below, I use capital letters to signal how attributes of the Chancy-Lambayque Basin case study correspond to variables of IAD framework summarized in figures 9 and 10 shown at the end of this section.

Case Study findings

Location and main biophysical attributes (H). The Chancay-Lambayeque Basin is situated in a semi arid area with very little precipitation in northwest Peru, and it has three defined areas: A valley in the lower region (coast) of Lambayeque region; the middle-elevation area shared by Lambayeque and Cajamarca regions, and the high-elevation area (highlands located in Cajamarca. The valley is the most important irrigated area of the basin with 118,523 ha. of irrigated land. For this reason, I will focus this study in the valley of the Lambayeque region (H3). Also, my main focus is on agriculture activity because it is the main consumer of water, using a share of 89% of total water use (ANA, 2010; see table 1).

The main river of the basin is the Chancay River (H2) and it has an extension of 5,309 Km^2 (see figure 5) and the main components of the hydrological infrastructure

(H4) are Tinajones Project Hydrological System[7], the Taymi Canal (see figure 6) and the Tinajones Reservoir (see figure 7).

Table 1
Water Demand in the Chancay - Lambayeque Basin[8]

Sector	Demand in 2001 (MCM)	% Share
Agriculture	1550.13	89%
Domestic Use	86.76	5%
Industry	25.2	1%
Mining	0.5	0%
Min Ecological Requirement	78.4	5%
Total Demand	1740.99	100%

Note. From National Authority of Water (ANA)

In 1964 the Peruvian Government built the Tinajones reservoir, recognizing the importance of agriculture in the basin and the need to build an irrigation system for its development. Later, in 1975 the government, with farmers' participation, built the Taymi canal to bring water from the Chancay River to farmlands that were located near the coast (Regional Government, 2012). Farmers who were actively farming at that time were located downstream and to right side of the canal (A).

Most of these farmers previously used to be workers of bigger farms that were expropriated during the land reform, and the land was redistributed to workers. In 1992, acknowledging the need for organized water management the farmers formed the

---

[7] See Appendix B for a full description of the infrastructure

[8] Million cubic meters (MCM)

Irrigation Association of Chancay- Lambayeque (JUCHL). In compliance with the Legislative Decree[9] 653, an Act that promoted private investment in the agricultural sector, the JUCHL was placed in charge of infrastructure maintenance, tariff charge, water allocation, among other duties. The JUCHL now represents around 3,500 farmers (B).

Later, through the Law Decree[10] Nº 25986 ("Budget of the Public Sector Law of 1993") the government created the Olmos -Tinajones Special Project as an agency that depends on the Presidential Ministry and the National Development Institute (INADE). The main goal of this project is the design and implementation of hydropower and irrigation systems to improve the economic development of irrigated land. They are also the supervising entity of the JUCHL in regard to the infrastructure maintenance. The entity that supervises and co-manages water allocation and appropriation with the JUCHL is the National Water Authority (ANA) through the local agency Local Water Authority (ALA – Chancay Lambayeque).

---

[9] In Peru, a Legislative Decree is an executive order of national application, issued by the President and the cabinet when granted powers by Congress to directly pass legislation

[10] In Peru, a Law Decree is an executive order issued by the President and the cabinet but not previously authorized by Congress. In 1992, pressured by political inaction and radical opposition in both chambers of Congress, President Fujimori closed the Peruvian Congress and called for elections for a Constitutional Assembly which later in 1993 passed the new and current Peruvian Constitution, under which a new Congress -comprised of only one chamber of congressmen- was elected shortly after. During the time of Constitutional Assembly and new Congress election, the executive branch under Fujimori directly passed Law Decrees, when rules of the hierarchy of a Law of Congress were needed. Law decrees passed during that time -covering many fields- remain in force, except where amended by subsequent Congress legislation.

Recent demographic (B) and hydrological change (H). The Valley Surface is 3,037 km2, and it holds a population of 735,840 citizens (Regional Presidency, 2010). Even though there is no information about migration into the basin, there are signs of significant migrations from rural to urban areas of the valley. As we can see in table 3, population is expected to grow at high rates (Regional Presidency, 2010). Population growth in a context of diminishing water availability increases stress on the water resource, especially when the allocation of water for domestic use already does not satisfy the total demand in rural areas (in some districts of the region, like Manuel Mesones Disitrict, 75% of the population doesn't have access to potable water for domestic consumption (Alfaro, 2008)

Table 2

Chancay - Lambayeque Basin: Projected Population 2000 – 2020

Years	TOTAL	% Change in 5 years	Lower Valley	% Change in 5 years
1993 Census*	837,512	--	735,840	--
2000	962,102	14.9%	852,819	15.9%
2005	1,035,633	7.6%	917,998	7.6%
2010	1,106,434	6.8%	980,757	6.8%
2015	1,172,928	6.0%	1,039,698	6.0%
2020	1,237,024	5.5%	1,096,514	5.5%

* Actual population

Note. From Regional Presidency (2010)

Moreover, the region is highly vulnerable to extreme events as droughts and floods, and these are linked to the El Niño Southern Oscillation phenonmenon. The last El Niño event that took place in the basin was in 1998, and it affected agriculture in many

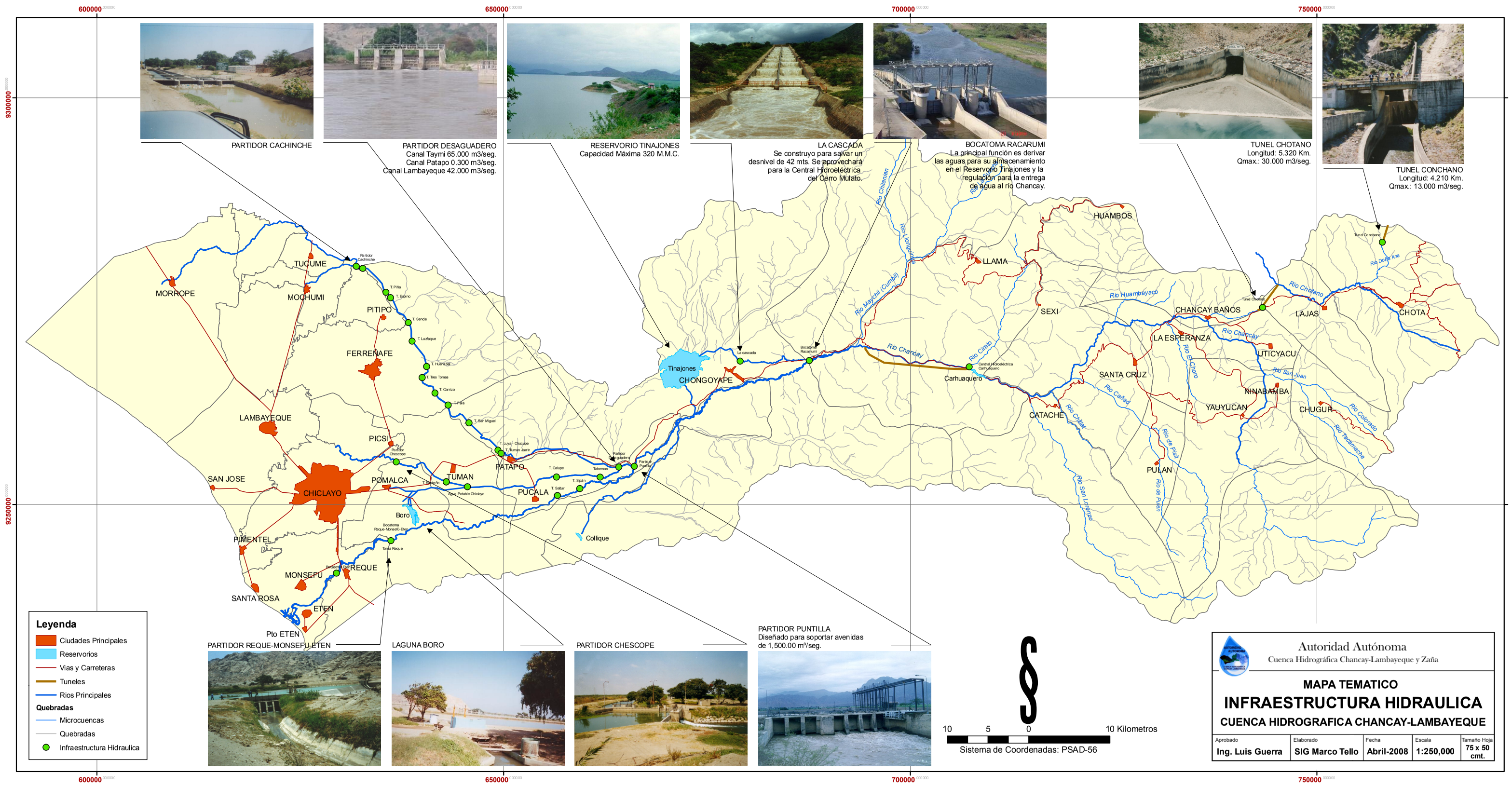


Figure 5. Chancay - Lambayeque Infrastructure

Figure 6. The Taymi Canal

Figure 7. Tinajones Reservoir

ways: reducing GDP by 13%, damaging many types of infrastructure and taking 150,000 lives (ANA, 2010). Also, as stated by Bustamante (2010), this region is highly vulnerable to climate change. Changes in precipitation are expected to increase water shortages in the Basin. Moreover, because of deforestation, the system has reduced its capacity to capture rainwater and at the same time, deforestation has made it is more vulnerable to floods (Bustamante, 2010).

On the other hand, there is a project to expand the Tinajones reservoir's capacity and also to build a smaller reservoir (H4). These projects would not only be useful for collecting and storing water in a normal year, but also for preventing catastrophes as floods when experiencing El Niño events. However, that project has not been approved yet.

Agriculture characteristics and production conditions. Farmers (A) and Crop Production *(H1).* Besides the group of farmers that are part of the irrigation association located downstream the canal, referred to here as "tailenders", there is another group of farmers. These farmers do not participate in formal water governance systems and are located upstream along the canal, close to the first 30 km of the canal (J1). These farmers, referred to here as "headenders" because of their location upstream along the canal (A), arrived from the adjacent Andean region of Cajamarca (especially from Chota and Santa Cruz towns) to the basin, beginning in 1984 to work in agro-industrial companies, mostly related to the sugar industry.

Later on, they saw the opportunity of using water from the canal and decided to build their houses and farms upstream along the canal. Most of them are still working for sugar companies, but are also farming and trying different crops in these areas. Since the settlement of this community was actually spontaneous, improvised and not planned nor overseen by the government at its national or regional levels, it has experienced limited development and still faces serious problems associated with nutrition, education (I1) and access to basic services, such as potable water and electric power (Alfaro, 2008).

At the beginning, these settlers were not able to register their farms or houses within the legal system. However, given that the Peruvian Civil Code[11] grants "squatters rights" for anyone that possesses land for more than 10 years, they are *de facto* owners of that land[12] (J3). However, none of these *de facto* landowners have registered themselves in the irrigation water association (B) and thus any water they appropriate is ultimately outside the formal structure of rules that governs the activities of members of the association.

---

[11] Articles 950 to 953 of the Peruvian Civil Code set the rules for acquisitive prescription in Peru. Acquisitive prescription, also named *usucapion* (Latin), is a concept found in civil law systems -those used in continental Europe, Central and South America, and even the State of Louisiana-, which originated in Roman Property Law. Usucapion is a method by which property can be gained by possession of it beyond the lapse of a certain period of time, providing that possession is public, continuous and pacific -meaning not formally nor physically disputed-. The real effect of *usucapion* is to remedy defects in a title, and therefore make it certain in order to transit to its most valued use. Peruvian Law establishes that acquisitive prescription of land is obtained after 5 years of possession if a sufficient title to property and good faith are proven. If no title exists, Peruvian Law requires a continued, pacific and public possession of the land for 10 years for courts to apply the remedy.

[12] This is called adverse possession.

Headenders frequently claim that the rules are organized in such a way that favors rich farmers and does not allow for equal opportunities (I) (Alfaro 2008). I did not have the opportunity to talk to them about this perception but it may be because governmental policies have traditionally been focused on the development of the capital city and its surroundings, marginalizing people from the highlands and the jungle. Since upstream farmers are originally form the highlands, they may have already the feelings of abandonment from the government. Moreover, downstream farmers do not want them to use water from the canal, to take away form them their mean for subsistence, knowing this background, is probably seen as unfair.

These headender farmers grow mainly maize, which is a relatively low water consumptive crop, but because of their small-scale parcels, their crops are produced at a high cost and low profits. Tailenders on the other hand tend to grow high water-intensive (but also higher-value) crops such as rice (39%), sugar cane (38%), and cotton (7%) (H1).

Farms sizes (A). Downstream, there are 28,431 farms of a total irrigated extension of 118,523 ha[2] that belong to 24,335 users. Most of the farms (89.30%) are smaller than 10 ha and represents the 53.99% of total irrigated land. Only 0.18% of farms are greater than 100 ha but these represent 17.59% of the total irrigated area.

Legal framework for water use and allocation. The first law (J) and the base of the legal framework of water use was issued in 1969 - Law 17752 - “Ley general de Aguas” (LGA). It was issued in the context in which the national government centralized the management of all natural resources and at the same time focused its policies in the agricultural sector. Thus, the law ascribed the Ministry of Agriculture as the national authority of water management, which were supported by local authorities: Irrigation District Technical Managers (ATDR).

Later, in 2010 the law was changed into a new one: Ley de Recursos Hídricos, Ley N 29338. This law establishes the following priorities for water allocation (J3):

1. Primary use (direct withdraws from rivers or canals for consumption or hygiene)
2. Domestic use
3. Agricultural use
4. Fishery Industry use
5. Other productive sectors[13]

The law also states that water users association (Irrigation Districts) have the right to access, withdraw and to manage water resources in the basin (J1). This last right includes the right to construction and maintenance of infrastructure related to water (and duties), to distribute water and to designate tariffs (J2). However, the State maintains its rights of exclusion and alienation.

Farmers have to register their farm in the water local authority (ALA) so they can obtain a license that allows them to use water for agricultural purposes. This license allows the farmer to use a maximum amount of water related to their land size (10,423m3 for 1 ha). The license is valid indefinitely and it is not transferable. However, the law also

---

[13] I am combining different sectors into "Other productive sectors" for simplicity, but the law states a detailed list of priorities.

states that when water is scarce they may have access to less water than indicated in the license.

The law also states that if a farmer has been using water for irrigation purposes for more than 5 years, even if it was through informal arrangements, they automatically gain the right to water[14] (J3). Accordingly, some of the current informal farmers have the legal right to use water from the basin, but still have to respect others sectors higher priority rights and the allocation rules stipulated by water managers, and pay water tariffs. Also, they must register their land and pay tariffs, which must be used to improve irrigation infrastructure (This is the rule related to the provisioning of public infrastructure). Moreover, there are no limits to agriculture land expansion, and any new farmer can claim his right to water use.

Although the law establishes the rights and obligations referred to water appropriation and public infrastructure provisioning (infrastructure construction and maintenance), it does not clarify the administration of how to proceed in the case of non-compliance of a rule by any agent (J6). Moreover, government agencies do not have the power or the resources to effectively enforce water rules and strengthen governance (J6). In 1993 the Peruvian Constitution was changed and created regional governments that therefore needed to be coordinated with local governments, also called Municipalities. Before this period national governance was centralized in the capital and thus economic opportunities of growth were created more intensively in Lima and surrounding regions.

---

[14] This is called adverse possession.

The need to foster regional governance was eminent. However, there was poor transfer of knowledge and economic resources for management, especially relating to water. With limited economic growth and governmental assistance, the population of the Lambayeque region had insufficient capacities for self-management. As a result, water users remained in a chaotic situation in which neither the national nor the regional authorities had real power to manage water resources. What we see in the region now is powerless local government and thus very low incentives to comply with the law.

Tailenders' rules (J2*).* There is no evidence of major conflicts among Tailenders[15]. Water appropriation and public infrastructure provisioning rules enables coordination among tailenders and they are bound by the following collective action rules.

Tailenders' water appropriation rules. Water appropriation for tailender farmers depends on the crop they grow and of the size of their landholding. At a national level there is a consensus of irrigation coefficients for each crop and the Irrigation District will deliver water considering those coefficients (see table 3) and for the determined month too (e.g. rice will receive water only from December to May, each month has its coefficient and in the total period the maximum amount per ha is 14,000 m^3). However, when water is scarce, if the size of the landholding of the farmer is big, he will only receive a percentage of what he asked (e.g. if he is declaring that he intends to grow in 20 ha then the irrigation district will deliver water to his farm considering the needs for 12

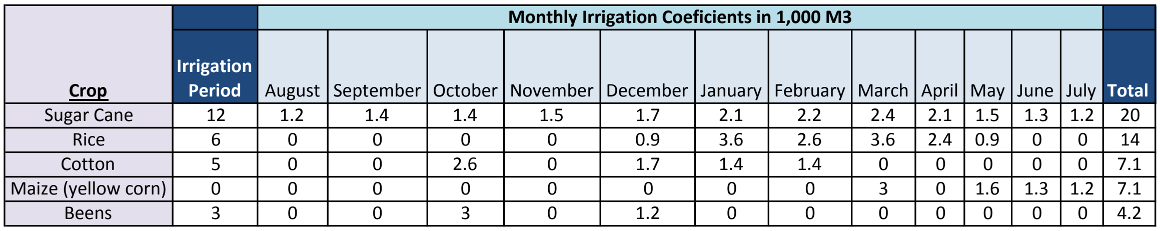
---

[15] No conflict is mentioned in any report or research in the basin, nor mentioned in interviews performed in fieldwork, even when I asked about it.

ha only). Because cotton is very sensitive to drought, cotton growers have a priority of water when the resource is scarce. Farmers cannot declare an intention to use more land of what he really has because he must previously declare his farm size to the water national authority and the irrigation district has this information.

Table 3

Crops and Irrigations Coefficients – 1000m^3/Ha (example)



		Monthly Irrigation Coeficients in 1,000 M3												
Crop	**Irrigation Period**	August	September	October	November	December	January	February	March	April	May	June	July	**Total**
Sugar Cane	12	1.2	1.4	1.4	1.5	1.7	2.1	2.2	2.4	2.1	1.5	1.3	1.2	20
Rice	6	0	0	0	0	0.9	3.6	2.6	3.6	2.4	0.9	0	0	14
Cotton	5	0	0	2.6	0	1.7	1.4	1.4	0	0	0	0	0	7.1
Maize (yellow corn)	0	0	0	0	0	0	0	0	3	0	1.6	1.3	1.2	7.1
Beens	3	0	0	3	0	1.2	0	0	0	0	0	0	0	4.2

Note. From Junta de Regantes Chancay Lambayeque (Irrigation District)

Tailenders public infrastructure provisioning rules. The infrastructure maintenance expenses are financed from water tariffs, and when there are particular projects requiring investment, from additional voluntary contributions from users or subsidized by the government. The required amount of investment depends on annual budgets. However, there are no studies that determine real maintenance needs, so this budget does not reflect real conditions and thus, annual investment budgets are underestimated[16] (Regional Presidency, 2010).

Moreover, water tariffs are determined by the irrigation association, which represents users. This is based on these annual investment budgets divided by the

---

[16] This information was corroborated during fieldwork.

estimated volume of water to be delivered. The water volume estimation is based on the average used water during the preceding 10 years (according to the tariff of and quota for water for irrigation regulation). However, users often lobby so managers estimate this water volume considering only the smallest annual value of water use in those 10 years, instead of considering the average. Their argument is that the agricultural economic conditions are not good and that thus they can't afford to pay the full water tariff as stipulated by regulation. Then, water tariffs are very low (0.0243[17] S/. per thousands m^3) and the irrigation association finds itself short on resources to invest in infrastructure.

As a result, because of both 1) they do not know how much they need to invest in the infrastructure maintenance to maintain or improve its efficiency, and 2) because they do not collect enough money, the irrigation infrastructure is underprovided. As a consequence, around 20% of the total water is lost through the canal and reservoir, mainly because of infiltration and leakages (Regional Presidency, 2010).

Barriers faced by farmers. From interviews I conducted in the region, tailenders farmers identified that the main barriers that the agricultural activity face (E) are (from most important to less)[18]:

- *Access to credit* (F). Most farmers face credit constraints because their credit risk is very high and banks are willing to lend money only to a very small group of farmers and at a very high interest rate. Some farmers invest less

---

[17] 0.009 USD per thousands m^3

[18] Tailenders answered individually to the open question: "Which are the main barriers that you identify for you economic activity?"

than they know they should, decreasing their land productivity and thus their total production and profits. This is a vicious cycle: The next season they face the same constraints as before. Some other farmers get credit from rice or sugar cane mills, but then they are required to grow either rice or sugar, depending on who lent them the money. This creates a vicious cycle because those crops are high water intensive crops and are not very profitable, especially because they have to sell it to the mill at artificially low prices (E). It also affects their willingness to pay higher tariffs, and thus the water manager capacity to invest in the infrastructure maintenance.

- *Technical assistance*. Farmers have very limited technical assistance for agriculture practices (e.g. knowledge of how much fertilizer to use, which type of seeds, how to drain the fields, crop rotation), irrigation (they don't know the precise amount of water that the crop needs) and for participating in the market (some of them have grown more value added crops but then they don't know how to sell it) (I1). Then, their knowledge limitations affect their profit levels, and at the same time another vicious cycle is created: with low profits, farmers find it difficult to "self finance" investments in their human capital. The presence of water intensive crops intensified by inefficient irrigation practices, are also contributing to soil salinization, which is also a significant problem in the basin. For example, farmers that are growing rice are currently using 20% more water than what rice needs, and rice is one of the most important crops in the regions (ANA 2008). Moreover, the use of excessive fertilizers, insecticides and herbicides are contaminating groundwater of the basin (Regional Presidency 2010).

- *Water deficit* (G). Farmers argue that they do not get as much water as they need to farm what they plan. This is what they call water shortage and this is how I will use from now on this term[19]. Instead of growing over two full seasons farmers grow one full season and one short season because of water deficit. Also, when the reservoir holds less water than what it normally does, farmers do not get their full water allocation. This also affects their productivity and thus their profits (E). In this case there is also a vicious cycle in which low profits combined with other factors (including institutions) affect water deficit and vice versa.

Water Deficit (G). Table 4 shows biannual water supply[20] (H2), demand[21], deficit and surplus from 2003 to 2011. The water deficit and surplus are calculated on a monthly basis and the table shows their biannual amount. We can see that water demand is greater than water supply (G). Moreover, because of an inadequate irrigation

---

[19] Systems rarely provide a resource to its entire demand. Then, it is not my intention to eradicate the phenomenon explained as water deficit. However, this upsets farmers and given that there is a great space for improving efficiency in the system and to reduce the gap of water demand and supply, I share farmers view and acknowledge it as a problem. The term Water Deficit will be therefore used throughout this text to refer to this specific phenomenon, as indicated by the farmers working in the system.

[20] Water supply is the calculated amount (with a 75% of probability or persistence) of water available in the Chancay River and in the Tinajones Reservoir together.

[21] Non-agricultural demand is estimated as a fixed demand since there is not annual information about its accurate value. Agricultural demand is calculated base upon farmers' statement on their intention to plant each year, plus a roughly estimation of upstream farmers water demand.

infrastructure that does not fully capture water from the river, the total annual deficit is higher than it otherwise would be. Current infrastructure has storage limitations, but it also loses water when it is brought through the canal due to evaporation too but mostly because of inadequate infrastructure. Moreover, as I will explain later, there are farmers that are not registered in the formal system upstream the Taymi canal that are withdrawing water without permission and regulation.

Table 4

Water Demand and Supply at 75% of persistence in the Basin (MCM)

	20003-20004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011
Chancay River	511.63	508.91	701.77	702.20	706.80	708.53	708.53	623.59
Recovered Water	50.00	25.00	50.00	50.00	50.00	50.00	50.00	50.00
Groundwater	80.00	150.00	70.00	70.00	70.00	70.00	70.00	70.00
Total Supply	641.60	683.91	821.77	822.20	826.80	828.53	828.53	743.59
Agricultural Demand	874.57	1086.87	751.80	901.16	1006.29	980.88	945.45	803.72
Non-agricultural Demand	68.56	68.56	68.56	68.56	68.56	68.56	68.56	68.56
Total Demand	942.92	1155.42	820.36	969.72	1074.85	1049.44	1014.01	872.28
Deficit	-306.50	-471.52	-124.21	-225.44	-277.19	-326.34	-251.63	-199.41
Surplus	5.21	0.00	125.62	77.92	29.14	105.44	66.15	70.72

Note. From Regional Government (2010)

Conflicts among users (G). Alfaro (2008) reported that there have been violent conflicts among headenders (upstream farmers that are illegally pumping water), and tailenders (farmers that are part of the formal sector) (G). This was corroborated in field research. There are around 1,500 headenders located along the canal and the amount that they are withdrawing, while difficult to quantify, is (anecdotally and based upon the implicit water needs of the acreage under headender tillage) considerable. However, they have not been paying tariffs. During fieldwork, I talked to a headender that mentioned that some of them have started paying but there is not record of such payments, and when they show receipts they are not from the Irrigation Association. The local water authority confirmed this fact, but they cannot ensure what is happening: Are headenders falsifying those receipts? Is the irrigation association giving different receipts? Is someone else illegally charging a water tariff anonymously? etc. These questions remain unanswered, but for farmers and for the national authorities, this is one of the main concerns in regard to water management.

Figure 8. Headednders' Pumps in the Taymi Canal

Given the insufficiency of government’s capacity to enforce water appropriation and public infrastructure provisioning rules, one would hope to see collective action among users but this is not happening. Headenders and tailenders have different approaches of fairness in regard to current water management and rules (I2). Headenders claim that the rules are organized in such a way that favors rich farmers and forbids equal opportunities (Alfaro, 2008) (I2). Thus they do not pay water tariffs and are pumping without any restriction and legal authorization from the canal (see figure 8). Tailenders believe that what is unfair is that they are the only group that pays for water and that gets constraints in their water use. Some of them would even prefer to avoid extending membership to the headenders since that would imply to recognize their right to appropriate water, and they fear that it could be translated in higher appropriation levels from headenders (I2).

Water use and delivery inefficiency (G). Water has not been used efficiently, the total efficiency of water use in the basin is 36.55% while a minimum of 50% of efficiency is required for an acceptable performance (ANA, 2008), and this is affecting water availability and short-term and long-term production. The types of efficiency loss explored in this section are the following. First, farmers are growing water intensive crops at minimum profits. In the region there are many sugar and rice mills that give credit to farmers so they can grow rice and sugar. Without personal savings for investment or access to other type of credit, farmers choose to grow sugar or rice.

Second, farmers' irrigation techniques are very inefficient (they use gravity irrigation and irrigate with more water than what the crop needs (ANA, 2008)). Third, farmers' agricultural practices are also inefficient which affects the water demand of crops. This poor management capacity leads to soil degradation, salinization, low quality crops and low productivity. Obviously, this decreases their revenues, increases their costs and makes it difficult to increase water tariffs to better fund infrastructure development and maintenance. All these factors lead to inadequate maintenance of water infrastructure, which is the fourth cause of inefficiency. The fifth cause is the failure to formalize upstream farmers that are using water without legal authorization or regulation. All these efficiencies affect the sustainability of the water resource and the sustainable development of the region.

The Institutional Analysis and Development Framework

Figures 9 and 10 show identified variables of the of the Chancay-Lambayeque system when using the IAD framework. Figure 9 shows the Action Situation as it explains the internal variables that affect farmers' actions; and Figure 10, shows the identified external variables that affect the incentive structure of the system.

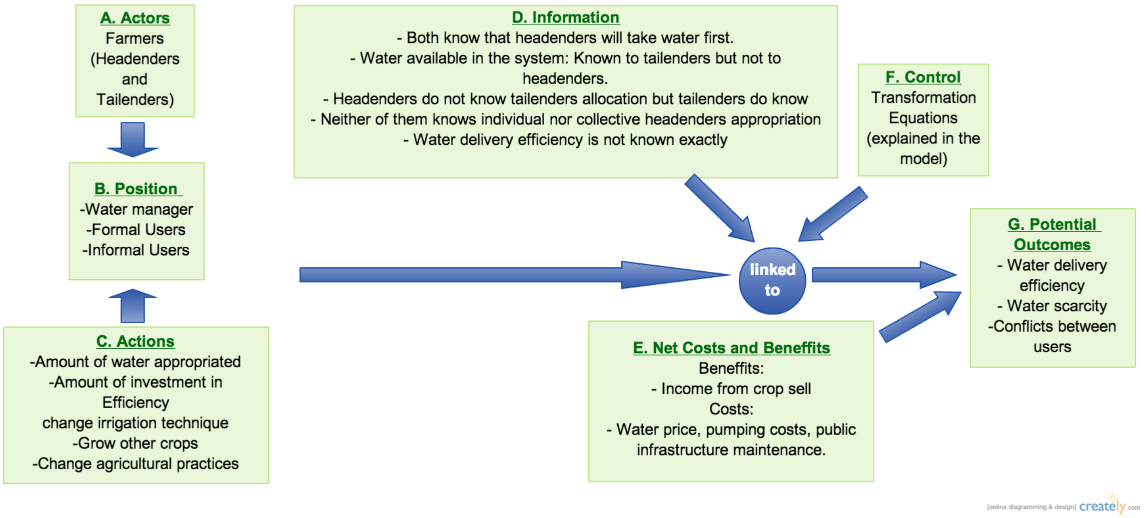


Figure 9. The Chancay - Lambayeque Action Situation

H. Biophysical Conditions	I. Attributes of Community	J. Rules in Use
H1. Crops Grown: Headenders grow mainly maize and tailenders grow mainly rice, sugar cane and cotton (in that order) **H2. Water Supply and Capacity of the Canal:** Water Supply of the basin is around 186 MMC The Capacity of the canal is: 65 m3/s in the initial part (Until Partidor Desaguadero) and of 25 m3/s from Partidor Cachinche. **H3. Topography:** Semi-arid region located on the north west of Peru **H4. Engineering works:** Tinajones Reservoir, Taymi Canal (Main ones)	**I1. Level of education:** The Land reform was performed with out any capacity building or any type of training, thus tailenders' knowledge of agricultural practices is limited. Headenders' knowledge is limited too because they come from the highlands, which is a different region where levels of education are even lower. **I2. Notions of equity:** Tailenders feel that it is unfair that they have to pay for all the system and headenders do not pay for it, and also that they have constrained water demands and headenders do not. On the other hand, there is huge sense of resentment from headenders. They believe that rules are unfair, that they are done for rich people.	**J1. Position Rules:** Two types of farmers. 1) Headenders: Informal users, located upstream the canal, mainly maize growers. 2) Tailenders: Formal users, located downstream the canal, mainly growers of high water intensive crops as rice, sugar and cotton. There are by far more tailenders than headenders (aprox. 2800 vs. 1500) **J2. Boundary Rules**: Water use is subject to ownership or leasing of land for farming and subject to a tariff (headenders do not comply with this rule) **J3. Choice Rules:** Headenders have the legal right of appropriation because they have being using that water for more than 20 years (adverse possession: the law states that if they have been using water from a system for more than 5 years, then they acquire water rights of that system); however, they have to pay a tariff and comply with regulations. Tailenders may take water that is allocated and must not take more water than that. Each year, the government allocates a certain amount of water to farmers. The law stipulates that water should go first for (in this order): A. Primary use (direct withdraws from rivers or canals for consumption or hygiene), B. Domestic use, C. Agricultural use, D: Fishery Industry use, E: Other productive sectors. **J4. Scope Rules:** for tailenders who are managers, there is a maximum amount of water that they can bring to the gate. Every season, tailenders are assigned a maximum amount of water. Headenders are not monitored, the law says that they must register, pay for water and comply with their allocation; but in reality no one controls them. J**5. Information Rules:** Tailenders have to specify at the beginning of a farming season, the type of crops and size of the land that they intend to farm. Managers will later tell them how much water is available to bring to the gate and how much water they can allocate to them. Headenders should have the same practice, but in reality they do not participate in this information process. **J6. Payoff Rules:** There is no sanction for headenders. For tailenders, if they do not pay water tariff managers will not deliver water to their gates. Managers hire people to control water delivery for each tailender. There is not a clear punishment for farmers (tailenders) that appropriate more water than their allotment. **J7. Aggregation Rules:** tailenders elect managers

Figure 10. The External Variables the Affect the Action Situation

Options to Explore with the Theoretic Game Model

Although I identify many other problems over the sustainability of water management in the basin, I focus the rest of this study in the main causes of conflict between headenders and tailenders related to the water appropriation and common irrigation infrastructure provision in the basin, and on how this may affect them individually and collectively. In this sense, it is clear that the key concerns are the efficiency of water resource allocation and use. Thus, I explore the possibilities of addressing efficiency concerns via modeling.

One important finding is that the presence of the government has not been effective because of the limited resources assigned to water management in the basin and because of a loss of authority. Full public governance may require higher rates of investment from the government; then one solution may be to provide users the conditions that may facilitate collaboration among them and thus to increase the efficiency of water resource allocation and use. Providing these conditions may imply:

1. **Property rights**. An important part of the law reform should be focused in the proper definition of property rights. Property Rights Theory says that a condition to ensure the preservation of a common pool resource (CPR) is to have well-defined territories. CPRs can be a governmental property (by a national, regional or local government); privately owned (by individuals or corporations) or owned by communal groups. If no one (or everyone) owns CPRs, they are called open access resources and will probably be depleted or cause conflicts. To ensure the

sustainability of a CPR, it is necessary to have well-defined property rights, which are not limited to one solution or arrangement.

A more careful design is needed for the Chancay – Lambayeque basin. Given strong evidences from literature of CPRs management that recommends focusing on property rights (Schlager and Ostrom 1992, Libecap 1989, North 1978, De Alessi 1980, Libecap 1986, and Ostrom 1990), in the next section I will analyze how changing property rights may change outcomes. In the Basin, because water is owned by the state, farmers have the right to manage it and exclude collectively, but not of alienation. However, no one has the real power to enforce rules, thus the system is acting almost as an open access resource or as if there are not defined property rights. The consequences are that farmers that are upstream fulfill their water needs while farmers downstream the canal do not, and at the same time upstream farmers avoid paying tariffs. This leads to water farmers downstream the canal to face water scarcity and to a underinvestment in the infrastructure maintenance of the canal (this will be carefully analyzed in chapter 8 through the model)

2. **Economic performance and pricing**. The performance of the agricultural activity relies on water availability, and water availability relies in the economic performance. Because the tariff that farmers pay, when they do not default, is very low it affects not only the willingness to conserve water, but also the total money collected to invest in water quality improvement, infrastructure maintenance, law

enforcement (e.g. to control water withdrawals of informal farmers), and other complementary activities. However, at the same time, farmers in the region argue that they are not making enough profits to pay a higher rate for water and to force them to pay higher prices could be politically unviable. If this is true, an integrated plan of management that progressively increases water tariffs according to a certain schedule could be ideal for this case. In that schedule, the government could invest in infrastructure maintenance, capacity building, targeting that farmers have notions of better agricultural practices as noted before. Also, because this is a policy recommended by previous reports (Regional Presidency 2010), In chapter 8, using the game theoretic model, I analyze how increases in water tariffs affect the incentive structure for the water appropriation and infrastructure provision dilemma, and how this may affect farmers' actions and outcomes.

3. **Agricultural and entrepreneurial knowledge:** There are different crops that have higher value in the market than rice, corn or sugar, and that farmers could make better profits selling them, as has been proposed by many experts (MINCETUR 2004, Herrera and Caferata 2009). The region have good weather conditions to grow fruits and vegetables that are less water intensive, more profitable and that would help to prevent more soil salinization. For this, the government could use external resources (which are currently available from different sources, as the World Bank, The European Union Cooperation with Andean countries to help to improve agricultural yields and exports, etc.). Some

farmers are already switching to fruit and vegetables, however, because they do not know how to grow these crops or they have insufficient capacities to sell them, they end up losing money and going back to the traditional crops.

Also, farmers or the government could invest in the acquisition of knowledge to improve farmers' agricultural practices. Their use of agrochemicals, water, and other inputs is not based on technical advice but more on practical knowledge and many times merely on intuition. This investment in knowledge could also be in regard to entrepreneurial knowledge. Farmers ultimately are small firm holders and they need to improve their knowledge about finance, productivity and resource saving practices. This is very important in order to ensure that in the long run, farmers are able to manage their farms efficiently and are capable of making profits and thus paying higher rates for the infrastructure maintenance and also to stop facing financial constraints that leave them with no option but to grow only one crop.

While these suggestions, could clearly improve farmers' income or farming performance it may result in the long run in even more water demand. Then, in chapter 8, I explore with the model the potential consequences of policies of actions in the direction of these suggestions, in terms of the water appropriation problem and infrastructure provision.

In the next chapter, I set up the game theoretic model to then use it in chapters 7 and 8. In chapter 8, I use the model to analyze how variables of the IAD framework determine the incentive structure that affect farmers behaviors in terms of water appropriation and infrastructure provision decisions, and in chapter 8 to explore these three solution options mentioned above.

Chapter 6

THE APPROPRIATION – PROVISION MODEL

Introduction to the model

To be able to model the system's dynamics and incentive structure, I focus on only a few aspects of the system. These aspects are key factors for explaining the appropriation (water use) and provision dilemma (related to the irrigation infrastructure maintenance). My aim is to simplify the system to be able to represent it in a model that is useful to understand what the main factors that affect farmers' behavior are, and how these factors influence their decisions with regards to the appropriation and provision dilemmas. With this purpose, I make necessary assumptions meant first to understand the system as a set of parts, and then to understand its dynamics.

The model I use in this research is an adaptation of one suggested by Lee (1994) for irrigation systems. Many analyses of upstream – downstream farmers sharing a basin have been done (e.g. Burness & Quirk (1979); (1980); Madani (2009)). However the application of this model is distinct because I consider the appropriation and the provision problem as linked together, with the latter conditioning behavior in the former, in a dynamic game context, rather than taking the more common approach of considering each of these games separately (Lee, 1994). The resolution of the provision dilemma affects water availability for everyone, and thus it also affects water appropriation. At the same time, the parameters and anticipated outcomes of behaviors in the appropriation game will affect users' decisions with regard to infrastructure maintenance.

Understanding the model and its assumptions

A formal game is one method of analyzing an action situation and its interactions with the three external variables: Physical Attributes, Rules, and Community Attributes (Ostrom, et al. 1994). I conceptualize the incentive structure as an action situation that is represented by parameters and variables. The two main variables of the model will be representing possible actions, or farmers' behavior: (1) amount of water appropriated (u_{it}, where i indicates the number of the player =1,2; and t is the time period = 1,2); and (2) amount of investment in the infrastructure maintenance ($m_{i,}$).

I represent the two groups of farmers (headenders and tailenders) as 2 players. Player 1 (P_1) is the headender and Player 2 (P_2) is the tailender. By combining both types of farmers in just two players I am assuming, for simplicity, that there is no asymmetry within each group, but the characteristics of headenders and tailenders are different in terms of their location with respect to the canal, the crops that they grow, the type of technology that they use to appropriate and irrigate water and in general their agricultural practices.

In this model I represent tailenders as the most vulnerable group to water scarcity because they have a *de facto* junior right. However, this is not the case in the Chancay-Lambayeque basin since tailenders are the main users and have a privileged position: they are the water managers and they have control over how much water is brought to the system (canal). Nevertheless they are subject to unregulated use and appropriation by headenders, and for simplicity and to better understand only the appropriation and provision decisions and analyze them in isolation, I will neglect the control that tailenders have over the amount of water that is brought in to the system.

For this model I assume that players have complete and perfect information. Complete information implies that they know each other's payoffs, possible outcomes, strategies, etc., and perfect information implies that they also know other players' actions (Gibbons, 1997). I am also defining the game as a finite game of only 2 periods, which allow us to understand the linkage between provision and appropriation without the additional complexity of viewing these decisions in a repeated interactions framework.

Until now I have described action situation parameters and variables. In the next section, I will show how with game theory models we can see the relationship between these action situation parameters and variables, and the parameters that represent the key external variables of the IAD framework: physical attributes, rule configurations, and attributes of the community.

Payoff Structure. I explain first benefit and cost characteristics and then I explain how these internal and external components of the IAD framework interact.

- ***Benefits.*** Water use (u_i) is translated into crop production through a production function. I assume that other production decisions (such as amount of fertilizer) are optimized according to the choice of water use, and crop choice remains constant over the horizon of the game. This production function describes the relationship between different units of water used for irrigation purposes and crop production. Lets assume the following production function:

$$X_i = d_i u_i - 0.5 g_i u^2{}_i$$

Where X_i is the units of crops produced (output) by player i and d_i and g_i are defined as:

$$d_i = \frac{q_i}{p_i}, g_i = \frac{r_i}{p_i};$$

q_i is the monetary value of the additional output generated by the first unit of irrigation water; r_i determines how the marginal value changes in monetary values as the amount of appropriated water changes, and p_i is crop price[22].

With the production function X_i we can find the marginal product[23] of u_i (MP_{u_i}):

$$MP_{u_i} = d_i - g_i u_i$$

If we multiply MP_{u_i} by p_i, then we get the Marginal Benefit of water (MB_i). The MB_i is also farmers' water demand (see *Figure 11.* Water Marginal Benefit1) because it indicates farmers' value of water at any additional unit.

$$MB_i = q_i - r_i u_i$$

I assume in this model that: $q_1 < q_2$ and $r_1 > r_2$.

---

[22] Every unit of used water contributes differently in terms of production and thus of monetary value (because the price fixed). The first unit of water contributes more than the second, and the second more than the third, and so on. This reduction of value with increasing use is called diminishing returns.

[23] The marginal product of a resource is the extra output that can be produced by using one more unit of the input, and can be derived by taking the derivative of the production function with respect to that input (in this case u_{it})

$q_1 < q_2$ because player 2 has more knowledge about farming activities, and has more resources. Tailenders are bigger farmers and because they are in the formal sector they have better access to credit and knowledge. Also, this relationship is maintained because rice and sugar have higher prices in the market than maize. Then, since q_i is the monetary value of the additional output generated by the first unit of irrigation water, player 2 can get a greater outcome for the first unit of water that he uses.

$r_1 > r_2$ holds because rice and sugar (which are the main crops produced by tailenders) are more water intensive crops than maize (the main crop produced by headenders). This happens because the next unit of water appropriated for a crop will contribute to production more if it is a crop that needs more water than other (because crops that do not need too much water fulfill they water demand with less amount of water). Then, because r_i determines how the marginal value changes as the amount of appropriated water changes, higher r implies higher changes which means less contribution from the next unit of water appropriated to production, which means less water intensive crop. This relationship also holds because there are more farmers downstream the canal (bigger player 2) than upstream the canal.[24] *Figure 11.* Water Marginal Benefit1 shows how the tailenders' MB_2 curve is less steep than headenders' MB_1 curve because $r_1 > r_2$.

---

[24] If we consider player 1 and player 2 as an aggregation of all headenders and all tailenders respectively we would have to add their water demands by summing water quantities at a given "price" (MB), an "horizontal summation". The more demands that we add less steep the aggregate demand curve is (i.e. the smaller r becomes)

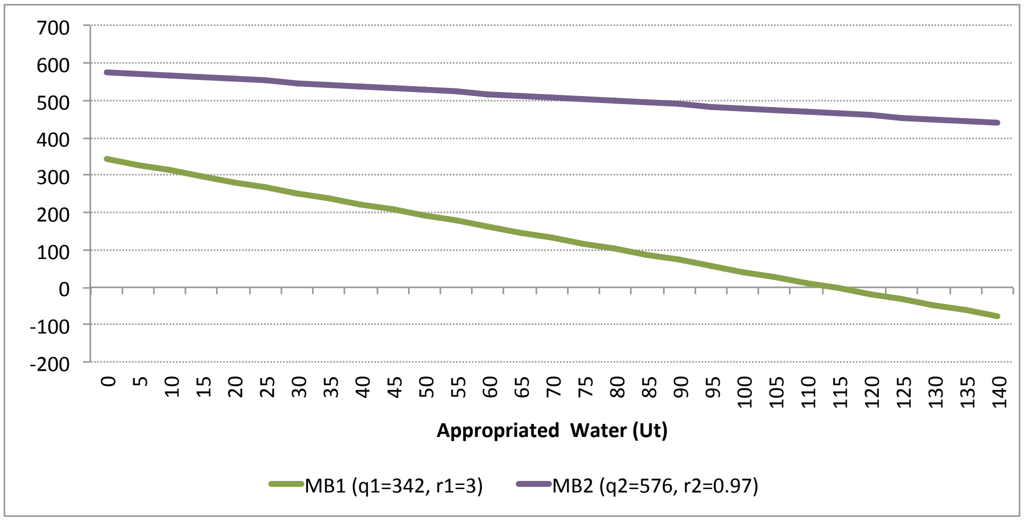


Figure 11. Water Marginal Benefit

To calculate the total benefit (TB) of water use we just need to multiply the production function by the crop price. Then we get:

$$PX_i = TB_i = qu_i - 0.5ru^2{}_i$$

The intuition behind these equations is that when players' water use is low, increases in water appropriation (u_i) will substantially increase players' crop production. As players' water appropriation gets higher, the effect of an increase of $u_i$on X_i will be smaller. In other words, u_i has diminishing returns. Moreover, $u_i$will not always contribute positively to crop production. Crops can only get a maximum amount of water, after that maximum amount, every increase of u_i will reduce the total crop production and thus, its total benefit (see *Figure 11.* Water Marginal Benefit2)

- ***Costs.*** There is a cost associated with water appropriation. For headenders, for example, this can be the electricity cost to pump water from the canal, and for tailenders water tariffs. For simplicity, I assume that the cost is the appropriated water, times a constant rate c$_i$ $(c_i u_i)$. Also, there is a cost related to the infrastructure maintenance m_i. As I will represent later, the infrastructure maintenance will affect payoffs of the period that follow the period of investment. Since this will be a two period game, each farmer may invest in period 1 to affect their payoffs in period 2. In the last period, neither of them will invest m_i, because there is no subsequent period in which they will use water for agriculture. Thus, farmers will potentially invest only in period 1.

The total cost (C) in each period is thus:

$$C_{i1} = m_i$$

$$C_{i2} = cu_{i2}$$

- ***Net Benefits.*** Benefits minus (net of) costs yield players' Net benefits (Π_i)

$$\Pi_{i1} = -m_{i1}$$

$$\Pi_{i2} = B_{i2} - C_{i2} = q_i u_i - 0.5 r_i u^2{}_i - cu_i$$

The net benefit $(\Pi_{i2(ui)})$ curve is concave with respect to u_i. This means that when u_i is low, appropriating more water will increase players' net benefit. This will happen until players reach the optimal amount of water appropriated. After that amount, appropriating more water would cause net benefits to decrease. This is the *individually* optimal u_i because it is the level that maximizes a farmer's net benefits, although it may not be optimal for the system (see Figure 12). Notice that with positive marginal costs of appropriation, individually optimal appropriation always occurs at a lower level of extraction than the level that maximizes total benefits (where marginal benefits (MB) equal zero). The shape and characteristics of the net benefits curve is mainly determined by q, r and c, which as I explained earlier are some of the external variables of the IAD framework that determine the payoffs tracing to particular actions and, therefore the incentive structure.

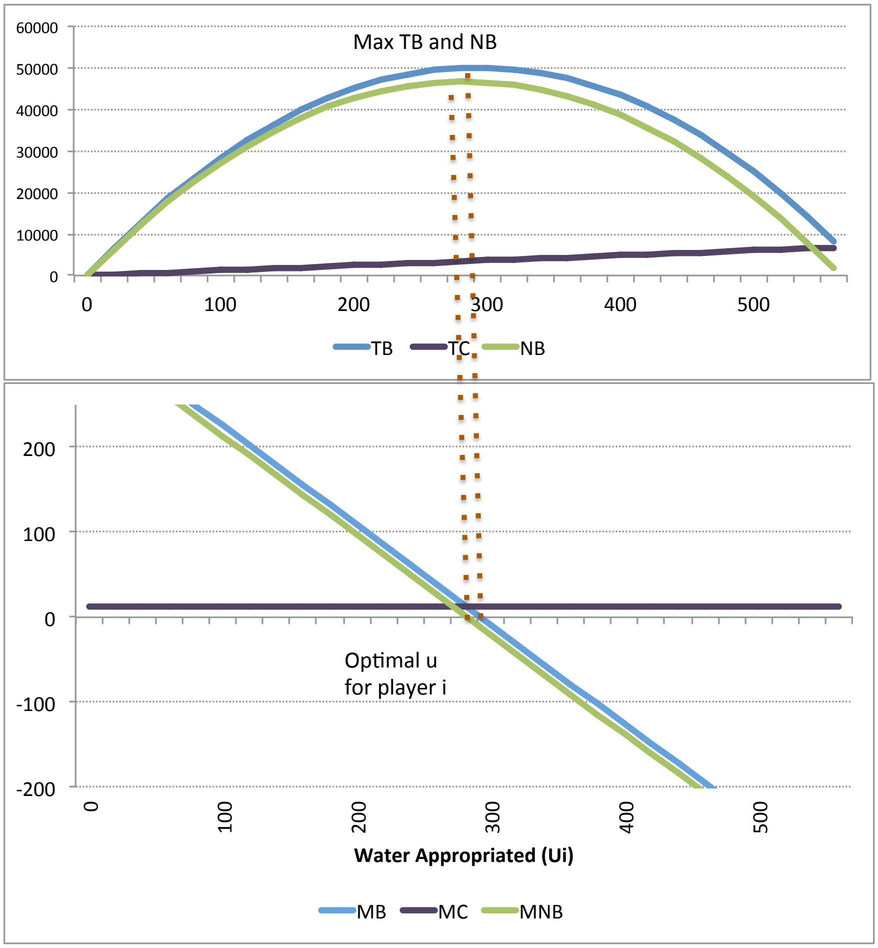


Figure 12. Total Benefit (TB), Cost (TC), Net Benefit (NB), and Marginal Benefit (MB), Cost (MC) and Net Benefits (MNB) Curves

Parameters meaning and Implications in the model

- *Monetary value of the additional output generated by the first unit of irrigated water (q) and in marginal value (r):* q and r convey information about farmers' production function, specifically about water productivity and crop prices. As I am presenting it in this case, it compiles every other factor that affects water productivity, such as soil quality, agricultural practices, salinization, type of crop etc. Thus, if we would like to analyze some physical attribute to incentivize farmers' behavior in a certain direction, we can analyze it through these parameters.

Also, if actors would like to invest in or to increase their knowledge to improve their agricultural practices, it could be also analyzed through q and r. As we can see in figure 13, increases in q shifts the marginal benefit curve to the right with the effect of shifting the total benefit curve upward and moving its peak to the right. This implies that same amount of water appropriation will lead, with a higher q, to higher benefits.

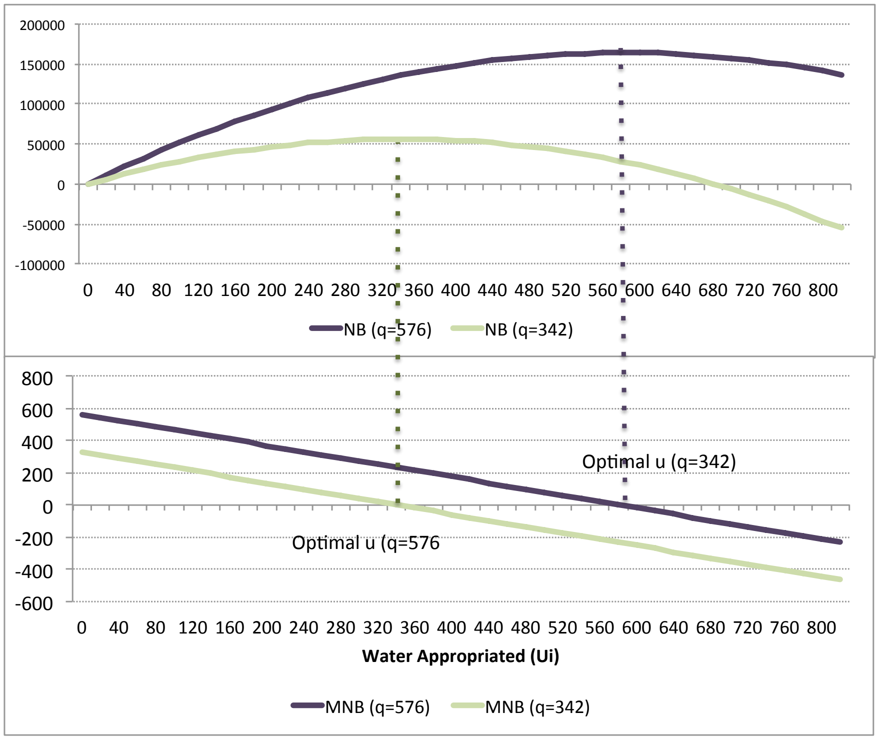


Figure 13. Shift in Net Benefit and in Marginal Net Benefit from changes in q

As we can see in figure 14, changes in *r* will change the slope of the NMB curve. If *r* increases, as for a change in crop production, then the marginal benefit will be less than before and thus for any additional appropriated water the net benefit will be increasingly smaller than if r were lower.

- *Changes in marginal cost (c)*: c can be interpreted as a rule if it represents water tariffs. This helps us to analyze what would happen if water tariffs were raised, or it can be interpreted as an economic parameter if it represents a cost associated with water appropriation (e.g. energy cost for pumping water). As we can see in Figure 15, in this case increases in water costs would cause a small reduction in u_i, but a significant benefits reduction.

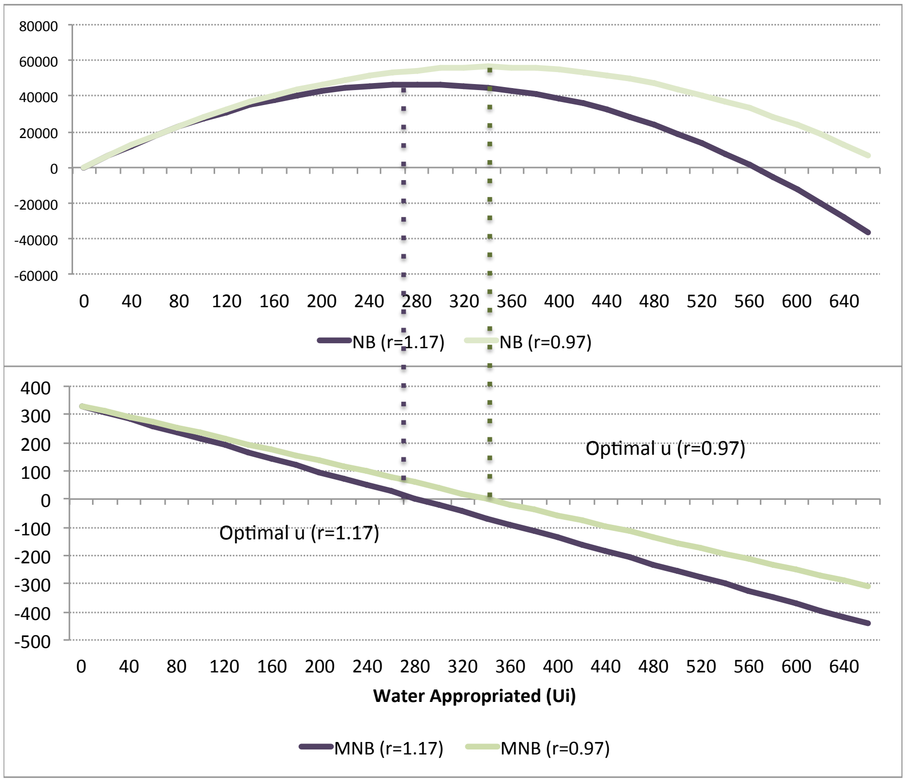


Figure 14. Shifts in Net Benefit and Marginal Net Benefit from changes in r

Note that we are assuming that the fixed costs of provision (m_i) are held constant here; while changes in these costs affect the overall level of realized benefits, they do not shift the MB/MC curves and therefore do not affect appropriation decisions.

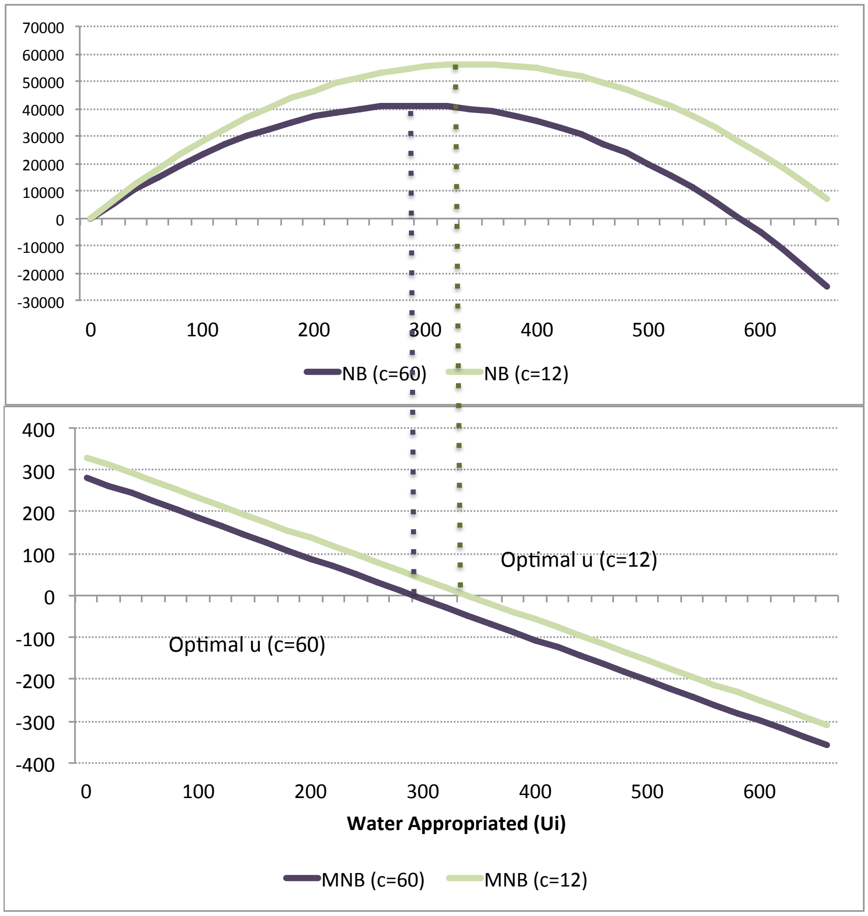


Figure 15. Shifts in Total Benefit from changes in

Also, the payoff structure is also affected by are other physical variables (as water availability and water delivery efficiency), and that constrain farmers' behavior (u_i and m_i).

Constraints. The lower limit of both control variables ($\boldsymbol{u_i}$ and $\boldsymbol{m_i}$) is zero**.**

$$0 \leq m_i \text{ , } 0 \leq u_1$$

The upper limit of u_i is the amount of water that player i receives in its field gate Q_i^{FG}, since players cannot appropriate more water than what it is available to them (see Figure 16). Then for headenders:

$$u_i \leq Q_i^{FG}$$

Q_1^{FG} depends on: how much water is at the source of the canal (Q^s), how much water is lost in the canal Q_1^l, irrigation infrastructure characteristics as water delivery efficiency (E_2) and the length of the canal l; and for tailenders it will also depend on how much water headenders appropriate (u_1). All these factors that delimit farmers' actions (except u_1), are considered in the IAD framework as physical attributes that affect the action situation. I define the relationship between $u_i\ and\ Q_{1t}^{FG}$ and all these other variables as follows:

$$\text{For player 1: } Q_1^{FG} = Q^s - Q_1^l$$

$$\text{For player 2: } Q_2^{FG} = Q^s - u_1 - Q_2^l$$

The amount of water that is lost in the canal Q_i^l :

$$\text{For player 1: } Q_1^l = aQ^s\,(1 - E_2)l_1$$

$$\text{For player 2: } Q_2^l = aQ^s(1 - E_2)(l_1 + l_2)$$

Where a is the proportion of Q^sthat is lost in a kilometer at zero efficiency ($E_2 = 0$), then aQ^s is the amount of water lost in one kilometer, $l_1$and l_1+ l_2 are the length (kilometers) of the canal to reach $P_1$and P_2's field gate respectively, and E_2 is the water delivery efficiency in period 2 after proportional losses due to evaporation and percolation.

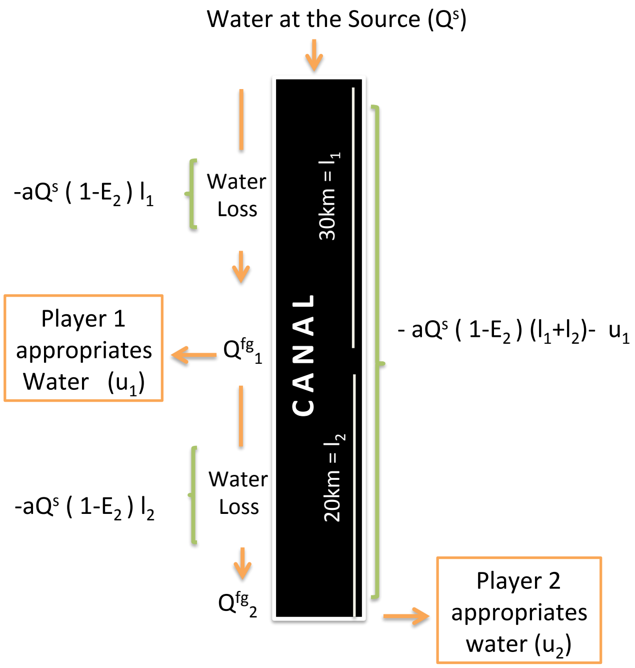


Figure 16. Water Flow Diagram

Then we can rewrite the amount of water that player i receives in its field gate Q_1^{FG}:

$$\text{For player 1: } Q_1^{FG} = Q^s - Q_1^l = Q^s - aQ^s(1 - E_2)l_1$$

$$\text{For player 2: } Q_2^{FG} = Q^s - Q_2^l = Q^s - u_1 - aQ^s(1 - E_2)(l_1 + l_2)$$

Then, we can rewrite the upper limit of u_{it} as:

$$\text{For player 1: } u_1 \leq Q^s - aQ^s\ (1 - E_2)l_1$$

$$\text{For player 2: } u_2 \leq Q^s - u_1 - a\ Q^s(1 - E_2)(l_1 + l_2)$$

Figure 17 shows how player 1's decision on water appropriation affects player 2's water availability

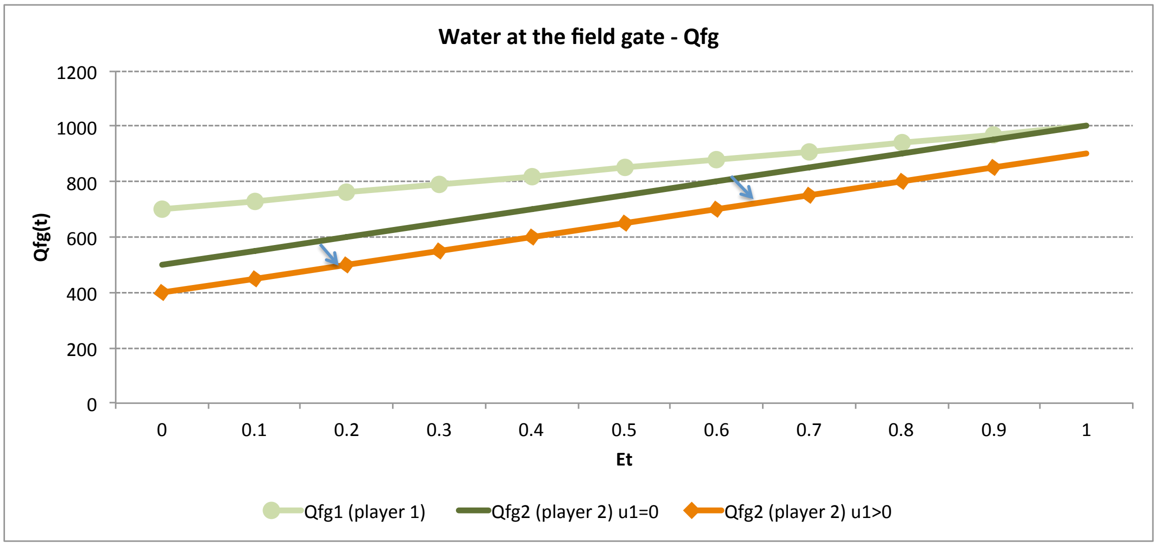


Figure 17. Water at The Field Gate as a Function of Efficiency and Player 1's Withdrawals

Water delivery efficiency. Players can change indirectly the level of the water delivery efficiency in ($\boldsymbol{E_2}$) by investing in the infrastructure maintenance in period 1. Then, $\boldsymbol{E_2}$ will depend on the total amount invested in infrastructure maintenance in period 1 $\boldsymbol{m_i}$ through the following "transformation function" (Ostrom, 2005)

$$E_2 = E_1 + e^{\overline{(m_1+m_2)}^{-1}} E_1(1 - E_1) - \Theta E_1$$

The intuition for this equation can be built up from first principles. First the infrastructure has a natural depreciation that for simplicity I will consider constant and exogenous to the model. This means that without any investment in its maintenance, the irrigation infrastructure loses $\theta 100\%$ of efficiency in the next period (t+1):

$$\frac{E2 - E1}{E1} = -\Theta$$

However, if farmers invest in the infrastructure maintenance, then in the next period (t+1) the water delivery efficiency will improve in percentage terms according to this transformation function:

$$\frac{E2 - E1}{E1} = e^{\frac{-1}{(m1+m2)}}(1 - E1)$$

Where $e^{\frac{-1}{(m1+m2)}}$ expresses diminishing returns of investment, which means that the first unit of investment will contribute more to the efficiency improvement than the second unit of investment, and so on. (1-E_1) is the sensitivity of efficiency improvement. The logic of this function relies on the fact that the contribution of the investment in maintenance to the efficiency improvement in the next period depends on the current level of efficiency: in the extreme case, if the system has already reached 100% of efficiency (E_1=1), no matter how much farmers invest, it cannot be improved, then the effect of investment will be zero. On the other hand, when efficiency is low, investment in infrastructure maintenance will have its maximum impact.

Combining both the depreciation and investment effects we have:

$$E2 = E1 + e^{\frac{-1}{(m1+m2)}} E1(1 - E1) - \varTheta E1, \qquad for\ m1 + m2 > 0$$

Note that since E is a percentage of performance it can only go from 0 to 1. Also note that if m goes to 0 then E2 will become:

$$E2 = E1 - \varTheta E1$$

because there is no effect of m in E_2. The relationship between E and m can be observed in Figure 18.

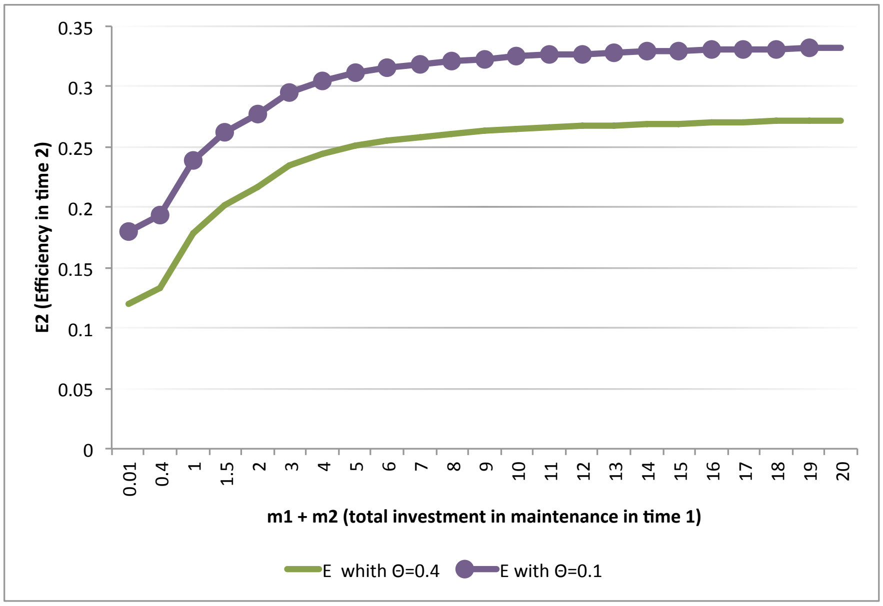


Figure 18. Water Delivery Efficiency as a Function of m

Notice that when the investment is too low its effect on efficiency is not enough to compensate for the depreciation rate and thus water delivery efficiency will still decline. The next level of investment will generate improvement in the efficiency level at an increasing rate because when efficiency is low small investment will go to leakages that affect the system the most. As the efficiency level increases it will be more difficult (or solutions will require more technology) to be able to improve it, then it will require every time a higher level of investment to see an efficiency improvement.

Game rules: The game will be played in two periods, and given players' location, in the following sequence (see figure 19):

At time one $(t = 1)$

1. Player one and player two simultaneously choose how much to invest in maintenance (m_1) and (m_2)[25]. This could happen when farmers are deciding if they will pay a water tariff or not (that will be invested later in infrastructure maintenance), or when water management ask for additional contributions specifically for irrigation infrastructure construction or maintenance. Both players will decide the amount of investment pursuing their aim of appropriating water in the future (next stage). We conceptualize this as a simultaneous move because neither player at this stage observes how much the other player is contributing.

At time two $(t = 2)$

Given a certain level of water at the source (Q^S) and Efficiency from investment in *t=1* ($E_{2(m)}$)*:*

1. Player one chooses how much to appropriate (u_1). Because player 1 is upstream, he acts first. His decision in regard to water appropriation does not affect him in the future, but will affect player 2.
2. Knowing u_1, player 2 chooses how much to appropriate (u_2). Because player 2 is downstream , he will be the last player to make a move in regard to water appropriation. His appropriation decision does not affect player 1.

---

[25] Note that in this time period players could also choose their level of water appropriation. However, this decision is separable from the investment decision and will also not affect farmers' payoffs in the future. Thus, it is not connected with the rest of the game and for this reason I will not consider it.

Figure 19 shows how by a given a level of efficiency E_1 in the first period, players will simultaneously decide how much they will contribute to the infrastructure maintenance. The combined amount of investment infrastructure (m) will affect the level of efficiency in the second period (E_2), which at the same time will affect water availability for both players. Because of their location with respect to the canal, player 1 will decide how much water he will appropriate to maximize his payoffs, which will affect player 2's water availability. Finally, player 2 will decide how much water he will appropriate to maximize his payoffs.

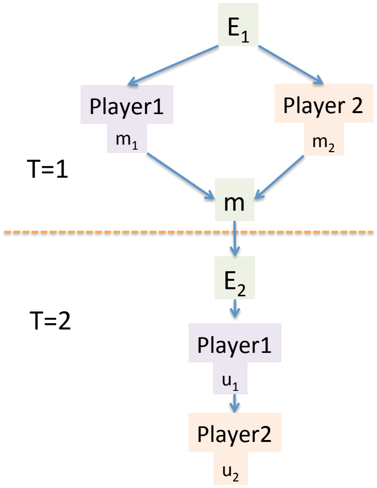


Figure 19. Game Flowchart

Strategies. Each player will try to maximize his own net benefit from the irrigation system given the other player's strategies in period 1 and period 2. Since they have complete information in time 1 they know their payoffs under all possible scenarios in t=2. Then, they will maximize the sum of their net benefits over the two time periods. Because we tend to value present outcomes more than future outcomes, the second period total benefit will be discounted by the parameter $\boldsymbol{w}$ such as, 0$< \boldsymbol{w} < \mathbf{1}$. $\boldsymbol{w}$ indicates the degree to which future payoffs are valued relative to the value placed on present payoffs – the "discount factor".

Then, we can define the present value of net benefits of the game as:

$$\psi_i = \Pi_{i1} + w\Pi_{i2}$$

Players maximize the present value of net benefits because present choices not only determine present outcomes, but can also influence future payoff structures. Replacing Π_{i1} we can rewrite ψ_i as

$$\psi_i = w\Pi_{i2} - m_i$$

Both players will simultaneously decide in the first period the amount that they are willing to invest in maintenance of the infrastructure (m_i) and for the second period of analysis how much water to appropriate (u_i). Notice that the decision of how much water to appropriate in period 2 can be affected, due to the change in availability of water due to efficiency improvements, by the total investment in period 1. These $(m_i \; and \; u_i)$ are the two control variables of the model, which means that are the two variables that farmers get to choose. Then, each player will choose the amount of water to appropriate u_i and the investment amount m_i that will maximize their discounted payoffs to a present value ψ_i.

Model Summary

For every variable that presents this notation x_{it}, it means:

$$i: player\ (i = 1, player\ 1;\ i = 2, player\ 2)$$
$$t\ = time\ (1,2)$$

Parameters and variables

m= total amount invested in maintenance

m_i= amount that player i invests in maintenance in time 1

u_i=water appropriated by player i in time 2

Π_{it}= player i*'s* benefits in time *t*

q_i= parameter giving the monetary value of the additional output generated by the first unit of irrigation water

r_i= parameter that determines how the marginal value changes as the amount of appropriated water changes

c_i= marginal cost of water appropriation

w= discount factor (less than 1, greater than 0)

l_i= length of the canal for player *i*

Q^S= Water at the source

${Q_i}^{FG}$ = water at the field gate for player *i*

a= coefficient of water loss

E_t = water delivery efficiency at time *t*

Θ= depreciation

Equations

Payoffs:

$$\Pi_{i1} = -m_i \tag{1}$$

$$\Pi_{i2} = q_i u_i - 0.5 r_i u_i^2 - c_i u_i \tag{2}$$

$$\psi_{i1} = w\Pi_{i2} - m_i \tag{3}$$

Water Delivery

$$Q_1^{FG} = Q^S - aQ^S(1 - E_2)l_1 \tag{4}$$

$$Q_2^{FG} = Q^S - u_1 - aQ^S(1 - E_2)(l_1 + l_2) \tag{5}$$

Water Delivery Efficiency

If $m > 0$

$$E_2 = E_1 + e^{\frac{-1}{(m1+m2)}}(E_1)(1 - E_1) - \Theta E_1 \tag{6}$$

If $m = 0$

$$E_2 = E_1 - \Theta E_1 \tag{7}$$

Conditions / constraints:

$$0 \leq u_1 \leq Q^s - a\, Q^S(1 - E_2)l_1 \tag{8}$$

$$0 \leq u_2 \leq Q^s - u_1 - aQ^S\,(1 - E_2)(l_1 + l_2) \tag{9}$$

For the sake of ease of interpretation, I propose some initial conditions and values for the parameters that are in keeping with broad realities in the Chancay-Lambayeque system. However, the purpose of this parameterization is not to provide precise numerical predictions for management (an unrealistic objective for a stylized game model such as this), but rather to generate a baseline for understanding the qualitative properties of the system under status-quo and counterfactual scenarios. I propose some initial conditions and values to the parameters. For those values that are unknown in the Chancay-Lambayeque System I will use those values used in Lee (1997). Later I will perform a sensitivity analysis. See Appendix C for calibration details.

Table 5

Values of the parameters

Parameters	Values	Units
q_1	342.6	Thousand of national currency/MCM
q_2	576.5	Thousand of national currency/MCM
r_1	1.17	Thousand of national currency
r_2	0.97	Thousand of national currency
c1	12	Thousand of national currency/MCM
c2	24.3	Thousand of national currency/MCM
a	0.01	1%
l1	30	km
l2	20	km
Θ	0.2	20%
w	0.8	80%
E1	0.37	37%
Qs	800	MCM

Chapter 7

GAME OUTCOMES

The investments in irrigation efficiency in the first period of the game have the potential to affect payoffs, and therefore the best choice of strategies for water appropriation, in the second stage of the game. When making their investments, players find it in their interest to consider the likely outcome of the appropriation game for each level of water supply (Q^S) and efficiency level (E_1) and project those outcomes forward in their decision of how much to invest in efficiency.

Optimal actions are defined as the actions that maximize players' individual payoffs after considering possible outcomes, such that given the strategy of all other players, no player has an incentive to individually change his action. A solution to this game consists of a full menu of possible responses (i.e. strategies) for every contingency in the first and second stages – not just the outcomes that are actually reached in the current situation of the basin. One common solution concept in non-cooperative game theory is that of Nash equilibrium (NE). Under NE, the strategies of each player must be a best response to the strategies of the other player so that neither player has an incentive to deviate on their own, given the menu of strategies of the other player.

In multi-stage games such as this one, there may be many potential NE. However, the sequencing of decisions in the game makes it such that not every menu of strategies that yields a NE from the perspective of the game as a whole is actually *credible,* in the sense that a player would find it in their own best interest to follow through with the prescribed strategy when they come to that point of the game. Specifically, in the appropriation stage of the game it is possible to envision Nash equilibria wherein player 1 (the headender) promises to exercise restraint, withdrawing less than their optimal allocation. However, in the absence of an external enforcer or context in which player 2 can punish player 1 for over-appropriation, such a promise will not be credible at the point in time when player 1 actually appropriates water. In order to enforce credibility of strategies in NE, we draw on the stronger equilibrium concept of subgame perfect Nash equilibrium (SPNE) (Gintis, 2009). SPNE requires that the strategy at each decision point in the game be a Nash equilibrium, not only from the perspective of the game as a whole, but from that point in the game forward. In our context this requires that the appropriation strategies used to predict behavior in the first stage (investment) game actually be a NE of the appropriation game. This also allows us to understand the game in a sequential fashion from the end back (a process known as backward induction); we first find the NE of the appropriation game for all possible plays of the second stage game and then roll this information back into our solution for the investment game.

Nash equilibria identified in the second stage are treated as given to identify players' optimal choice in the first period. In the first stage the decision is about the infrastructure investment. In this case players do not act in a sequential way but rather in a simultaneous manner. This implies that there is no leader in the decision making process, contrasting with the appropriation game in which player 1 has to decide the amount of appropriation first. When solving the game I find different scenarios that described different NEs so in chapter 8 I can explore the implications of particular solution options of the current appropriation – provision problem.

Second Stage: The Appropriation Dilemma

The first move of the second period is from player 1 in regard to his water appropriation. He will try to maximize his payoffs in period 2:

Replacing $\max_{(u_1)}[(\Pi_1)]$ by Equation (2):

$$= \max_{(u_1)}(q_1 u_1 - 0.5 r_1 {u^2}_1 - c_1 u_1)$$

Then we have the first order condition of maximization:

$$\frac{\partial \Pi_1}{\partial u_1} = q_1 - r_1 u_1 - c_1 = 0 \Rightarrow u_1^* = (q_1 - c_1)/r_1$$

However this will only happen if there is enough water in t=2 for player 1 to appropriate u_{12}^*

Then: $u_{12}^* = (q_1 - c_1)/r_1, \quad \text{if} \quad (q_1 - c_1)/r_1 \leq Q_1^{FG} = Q^S - aQ^S(1 - E_2)l_1$

If this condition is not fulfilled, e.g., if $\frac{(q_1 - c_1)}{r_1} > Q_1^{FG} = Q^S - aQ^S(1 - E_2)l_1$, Player 1 will only be able to appropriate the amount of water that is at his gate:

$$u_1^* = Q^S - a(1 - E_2)l_1 \qquad (10)$$

Combining these expressions, the strategy for u$_1$ is:

$$u^*{}_{1(m)} = Min[Q^S - a\, Q^S\big(1 - E_{2(E_1,m)}\big)l_1, (q_1 - c_1)/r_1] \qquad (11)$$

Where $u^*{}_{1(m)}$ is the optimal appropriation for player 1 for any investment in the infrastructure maintenance in time 1. Similarly, $E_{2(E_1,m)}$ is the efficiency level given a set of values of E$_1$ and *m*. We can notice that player 1’s strategy in this stage does not depend on player 2's strategy of the same period. Player 1 is a leader and his payoffs are decoupled from player 2's behavior in the appropriation game.

Similar to player 1, I start analyzing player 2's net benefits to identify the optimal appropriation level in t=2 We replace $\max_{(u_2)}[(\Pi_{22})]$ by Equation (2)

$$\max_{(u_2)}(q_2 u_2 - 0.5 r_2 u^2{}_2 - c_2 u_2)$$

The maximization solution in t=2 for player 2 will be similar to player 1's optimal solution.

$$u_2^* = (q_2 - c_2)/r_2 \tag{12}$$

And as in the case of player 1 this optimal solution will depend on how much water player 2 receives in his field gate. Then, $u_2^* = (q_2 - c_2)/r_2$ if

$$(q_2 - c_2)/r_2 \le Q_2^{FG} = Q^S - u_1^* - aQ^S(1 - E_2)(l_1 + l_2)$$

Notice that this can only happen in cases where player 1 and player 2 have excess water. This is the first possible case (Case 1). If player 2 does not have enough water to maximize its net benefits in t=2, then he will use all of the water that arrives at his field gate:

$$u_2^* = Q^S - u_1^* - aQ^S(1 - E_2)(l_1 + l_2) \tag{13}$$

as with player 1, player 2's strategy can be summarized as:

$$u^*{}_{2(E_1, m, u_{12})} = min(Q^S - u^*{}_1 - aQ^S\left(1 - E_{2(E1,m)}\right)(l_1 + l_2), \frac{q_2 - c_2}{r_2})$$

Player 2’s appropriation depends on the amount of water that player 1 will take in $t = 2$. Since we already analyzed player 1’s strategy in equations 10 and 11 we can use the two possible solutions for u_1 and replace them in Equation 13:

Then, there are two other cases

- Case 2: When water is abundant to player 1 but scarce to player 2: We replace u_1^* by Equation (10):

  $u_2^* = Q^S - (q_1 - c_1)/r_1 - aQ^S(1 - E_2)(l_1 + l_2)$

- Case 3: When water is scarce for player 1: If this is the case, player 1 will use all the available water and there will be no water for player 2. Then, player 2 will not farm in that period:

$$u_2^* = 0 \text{ , if } u^*{}_1 < (q_1 - c_1)/r_1$$

Three things can happen in time 2 for player 1 and 2. These three cases are Nash Equilibria of the second stage subgame ($t = 2$) for any $m = m_1 + m_2$ and are shown in table 6.

Physical attributes and economic parameters in the second stage Nash Equilibria. Before analyzing what will happen in stage 1 ($t = 1$), I want to reflect on the incentives (parameters) that will determine which Nash Equilibria players pursue. As we can see, it is not the value of only one parameter that matters but their combination that determines the incentive structure.

First, I analyze how different combinations of the two physical parameters Q^S (exogenous) and E_2 (endogenous), when the economic parameters of the system remain fixed, determine different Nash Equilibria of this Second Stage. Then, I analyze how the economic parameters are related to the frontiers of each NE.

Table 6

Nash Equilibria of the Appropriation Game

Case	Condition	Optimal Appropriation P1 (u_1^*)	Optimal Appropriation P2 (u_2^*)
Case 1: Water is abundant for both players	$Q^S - a\,Q^S(1-E_2)(l_1+l_2) \geq \frac{q_1 - c_1}{r_1} + \frac{q_2 - c_2}{r_2}$	$\frac{q_1 - c_1}{r_1}$	$\frac{q_2 - c_2}{r_2}$
Case 2: Water is abundant for player 1 and scarce for player 2	$Q^S - a\,Q^S(1-E_2)\,l_1 \geq \frac{q_1 - c_1}{r_1}$ $Q^S - a\,Q^S(1-E_2)(l_1+l_2) < \frac{q_1 - c_1}{r_1} + \frac{q_2 - c_2}{r_2}$	$\frac{q_1 - c_1}{r_1}$	$Q^S - \frac{q_1 - c_1}{r_1} - aQ^S(1-E_2)(l_1+l_2)$
Case 3: Water is scarce for both players	$Q^S - aQ^S(1-E_2)l_1 < \frac{q_1 - c_1}{r_1}$	$Q^S - aQ^S(1-E_2)l_1$	0

Physical Attributes. From Figure 20 we can observe that there are three sets of combinations of Q^s and E_2 that will determine in which Nash equilibrium (NE) players end. For example, when Q^s is high (in this case 1,703 or higher), for any level of efficiency, players will have water abundance and the NE of the appropriation game will follow case 1. However, when Q^s is less than 1,703 but higher than 856, the level of efficiency will determine in which case (1 or 2) players will end. Similarly, when Q^s is less than 856 but greater than 403, the NE will follow case 2, and when Q^s is less than 403 but greater than 283 the efficiency level will determine in which case they are (2 or 3). Intuitively, the quantity of water supply and efficiency are substitutes. However, if Q^s is less than 283, the substitution potential of efficiency for water supply reaches its limit and players will be in Case 3, where player 2 does not farm in that period.

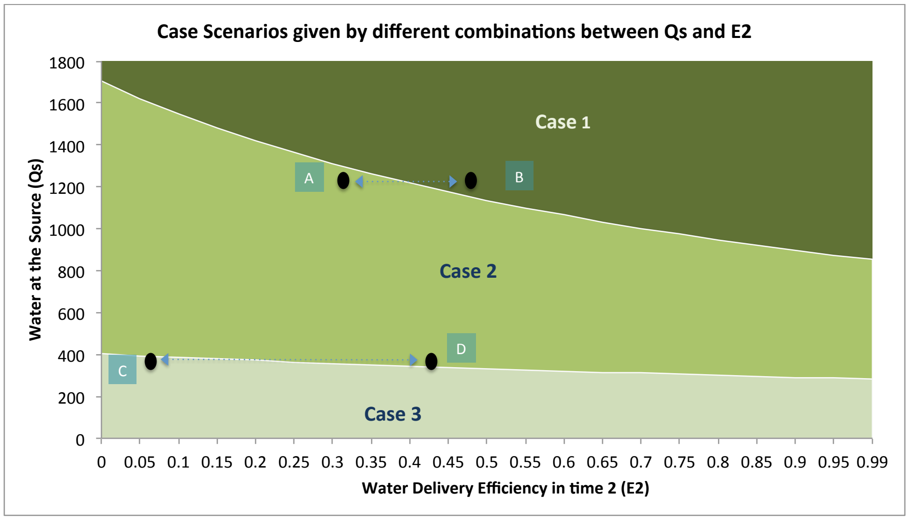


Figure 20. Nash Equilibria of the Second Stage Subgame Regions

For example, in figure 20 from point A to point B we can see that a change in efficiency (an improvement) will change the NE from case 2 to case 3. From point C to point D the NE has change from Case 3 to Case 2, we can notice thought that a larger improvement in efficiency is needed in order to make that transition. The shallower slope of the Case 2/3 frontier compared to the Case 1/2 frontier has to do with the fact that achieving a given absolute increase in water supply to the tailender at low levels of water flow (Q^s) requires a larger increase in efficiency since losses from inefficiency are proportional to Q^s. E_2 is affected by the initial level of efficiency (E_1) but also by m, the collective investment in infrastructure maintenance in stage 1, a choice I analyze below.

Economic Parameters.

1. *Parameters that determine water demand and productivity (q) and (r):* this parameter determine together profits from water use, which at the same time is related to crops prices, agronomic practices and crops water demand. The values of these parameters affect the incentive structure because they determine the economic gain from water use. Graphically, values of these parameters determine the size of the area of each case in figure 20.

   When *q* is low and *r* is high, farmers' water demand is low. It could be because of low efficiency in their production process, or because prices are too low that there is not too much incentive to grow too much crops, or because the crops that are growing does not need too much water to grow. Then, it is more likely that farmers will face case 1.

   Similarly, when *q* is high and *r* is low, farmers' water demand is high. It could be because of high efficiency in their production process, high crop prices that incentivize farmers to grow more crops, or because they are growing high water intensive crops. Then, it is more likely that farmers will face case 3.

Farmers will more likely end up in case 2 in intermediate values of q and r from those extreme cases that I just explained to illustrate how these two parameters, by affecting the incentive structure, affect outcomes of the game too.

2. *Water appropriation costs (c):* Appropriation costs reduce water demand because they also affects the profitability of water use. Then, when these costs are low (compare to the income that they could get from using water to farm), there is more incentive to withdraw more water and increases that chances of ending up in case 3.

First Stage: The Provision Dilemma

In this stage, players will have to decide their optimal amount of investment m_1 and m_2 (the levels that maximize their discounted payoff), keeping in mind the implications of their choice for outcomes in the appropriation game, as reflected by the Nash equilibrium outcomes associated with any given E1 and Qs. Players face the provision dilemma of a public good. As we saw in the second stage, both players will benefit from an investment in infrastructure regardless of who invests. The investment will affect E_2, and this, in combination with the exogenous supply of water Qs, will determine which of the second stage NE cases result.

For this first stage there are four qualitatively different scenarios in regard to this decision:

- Scenario A: Neither player contributes to the infrastructure maintenance: m_1 =0 and $m_2 = 0$
- Scenario B: Only player 2 invests: m_1 =0 and $m_2 > 0$
- Scenario C: Both players invest: m_1 >0 and $m_2 > 0$
- Scenario D: Only player 1 invests: m_1 >0 and $m_2 = 0$

I will explore under which conditions each of these four scenarios would be likely to happen.

Scenario A : *Players do not contribute to the infrastructure maintenance;* $\mathbf{m_1}$ *=0 and* $\boldsymbol{m_2 = 0}$

This is likely to happen when water is abundant enough (Q^s high) or the initial efficiency of the system is sufficiently high (E^1 high) that both players that they can get their unconstrained optimal water appropriation level in the second stage without investing in the first stage. This would happen then when (from case 1 of the second stage):

$$Q^S - a\, Q^S\left(1 - E_{2(m=0,E1)}\right)(l_1+l_2) \geq \frac{q_1 - c_1}{r_1} + \frac{q_2 - c_2}{r_2}$$

we replace E_2 by equation 7

$$Q^S(1 - a\,(\Theta - 1)E_1)(l_1+l_2) \geq \frac{q_1 - c_1}{r_1} + \frac{q_2 - c_2}{r_2}$$

Then, when this condition holds, neither player 1 nor player 2 will invest in infrastructure maintenance, since doing so involves present costs with no added future benefit relative to the no contribution scenario.

<u>*Second and First Stage connection*</u>: If this is the case in the first stage, players will find themselves in the first NE (Case 1) of the second stage because both can get their unconstrained optimal water appropriation level.

<u>Scenario B</u>: Only player 2 contributes to the infrastructure maintenance; $\boldsymbol{m_1}$ =0 and $\boldsymbol{m_2 > 0}$

This will happen only when, first, player 1 can contribute nothing and fully appropriate in the second stage, and, second, player 2 cannot reach their unconstrained optimal amount of water without investing, but it is still profitable for him to remain in the system after making their optimal investment in the first stage with player 1 contributing nothing. In this case, player 1 will free ride and will not invest. If player 2 finds it profitable to invest, then it must be true that he is getting some water. That implies that player 1 will have enough water to reach its optimal unconstrained water appropriation $u_1^* = \frac{(q_1 - c_1)}{r_1}$ because otherwise he would get all the available water and player 2 would not receive any. Then, player 1 will have his optimal unconstrained appropriation, but player 2 will have his optimal constrained water appropriation[26] (Q_2^{FG})

---

[26] Player 2 does not invest up until the point where he gets his unconstrained amount of water because that would entails costs that change his maximization results: the last unit of water in the unconstrained case gives zero marginal net benefit and so it would make no sense to invest to achieve it.

. Thus, they will find themselves in Case 2 of the second stage. Then for this to happen it has to be true that:

First, player 2's discounted net benefits (ψ_2) when substituting in his best response function ($u^*{}_{2(m)}$), must be at least zero after contributing to the infrastructure maintenance by himself; otherwise he would not do it:

$$\psi_2 = w\left(q_2 u^*{}_{2(m)} - 0.5 r_2 u^{*2}{}_{2(m)} - c_2 u^*{}_{2(m)}\right) - m_2 > 0$$

Also, in the second period player 2 will decide the level of appropriation that maximizes profits conditional on the state of infrastructure and water supply, which depends in turn on period 1 investment (m), $u^*{}_{2(m)}$. Therefore the problem of maximizing discounted net benefits through appropriation and provision decisions can be collapsed into a single choice of period 1 investment.

$$\max_{m2} \psi_2(u^*{}_{2(m)})$$

The first order necessary condition for solving this problem is:

$$\frac{d\psi_2}{dm_2} = \frac{\partial\psi_2}{\partial u_2}\frac{\partial u^*{}_2}{\partial m_2} - \frac{\partial\psi_2}{\partial m_2} = 0$$

where,

$$\frac{\partial \psi_2}{\partial u_2} = \mathrm{w}(q_2 - r_2 u_2 - c_2)$$

$$\frac{\partial \psi_2}{\partial m_2} = 1$$

To find $\frac{\partial u^*{}_2}{\partial m_2}$ we need to remember that $u^*_{2(m)}$ comes directly from the previously derived solution for Case 2 of the second stage. This is the optimal appropriation for the case in which player 2 faces water scarcity but player 1 does not:

$$u^*{}_{2(m)} = Q^S - \frac{(q_1 - c_1)}{r_1} - aQ^S(1 - E_{2(E1,m)})(l_1 + l_2)$$

replacing E_2 with Equation 6 and assuming m1=0

$$u^*{}_{2(m)} = Q^S - \frac{(q_1 - c_1)}{r_1} - aQ^S(1 - E_1 - e^{\frac{-1}{(m2)}}(E_1)(1 - E_1) + \Theta E_1)(l_1 + l_2)$$

for simplicity:

$$B = Q^S - \frac{(q_1 - c_1)}{r_1} - aQ^S(l_1 + l_2)[1 + E_1(1 - \Theta)]$$

$$A = aQ^S E_1(1 - E_1)(l_1 + l_2)$$

The relationship between $u^*{}_{2(m2)}$ and m_2 is shown in Figure 25

then,

$$u^*{}_{2(m2)} = B + Ae^{\frac{-1}{(m2)}} \qquad (14)$$

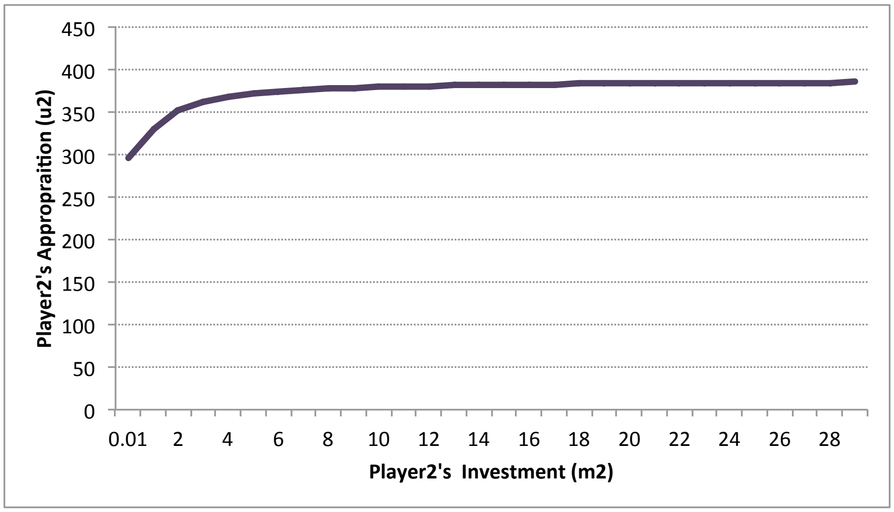


Figure 21. Player 2's Water appropriation in second stage and his investment in stage 1

Then,

$$\frac{\partial u_2}{\partial m_2} = \frac{Ae^{-1/m2}}{m_2^2}$$

$\frac{d\psi_2}{dm_2}$ can finally be written as follow:

$$\frac{d\psi_2}{dm_2} = \mathrm{w}\left(q_2 - r_2(\mathrm{B} + \mathrm{A}e^{-\frac{1}{m2}}) - c_2\right)\frac{Ae^{-\frac{1}{m2}}}{m_2^2} - 1 = 0$$

The amount that player 2 will decide to in invest in the infrastructure maintenance will be determined by the combination of the values of these parameters. Notice that A and B are also parameters that can be expressed in terms of the economic parameters and of $E_1$and Q^S. Given the other parameters of the problem, this expression provides a solution for player 2's investment behavior as a function of initial efficiency and water quantity. Implicitly they define a function $m_2^*(Q^s, E_1)$.

Some conditions must be true to be in this scenario. These conditions define combinations of Q^s and E_1 that yield this equilibrium and refer to the amount of water that is at player 2’s field gate (he gets some water but not as much as to get his unconstrained optimal amount of water).

$$Q^S \ - \ a\,Q^S(1-E_2)\,l_1 \quad \geq \frac{q_1 \ - \ c_1}{r_1}$$

$$Q^S - a\,Q^S(1-E_2)(l_1{+}l_2) < \ \frac{q_1 \ - \ c_1}{r_1} + \frac{q_{\,2} - \ c_2}{r_2}$$

replacing E_2 with Equation 6 and assuming m_1=0

$$Q^S\,(1 - \ a\left(1-E_1-e^{\frac{-1}{(m^*2)}}(E_1)(1-E_1)+\Theta E_1\right))l1 \quad \geq \frac{q_1 \ - \ c_1}{r_1}$$

$$Q^S\,(1 - \ a\left(1-E_1-e^{\frac{-1}{(m^*2)}}(E_1)(1-E_1)+\Theta E_1\right))\,(l_1{+}l_2) < \ \frac{q_1 \ - \ c_1}{r_1} + \frac{q_{\,2} - \ c_2}{r_2}$$

Second and First Stage connection: If this is the case in this first stage, players will find themselves in the second NE (Case 2) of the second stage because only player 1 can get his unconstrained optimal water appropriation level.

Scenario C: Both players invest; $\boldsymbol{m_1}$ ***>0 and*** $\boldsymbol{m_2 > 0}$

This is a scenario in which, water is scarce for both players if they do not invest. However, unlike in Scenario B where it was a SPNE for Player 1 to completely free ride on the investments of Player 2, in this case it will not be profitable for Player 2 to invest at all if Player 1 contributes nothing to maintenance. Intuitively, this corresponds to settings in which water is so scarce (or initial efficiency so low) that a substantial investment is required to first satisfy Player 1's demands for water (recall in SPNE that Player 1 must get his unconstrained optimum amount of water) before any water flows to player 2. At critical threshold combinations of Q^s and E_1, Player 1's optimal investment/appropriation combination will lead that player 2 to just break even – any degradation of infrastructure or supply below this point will cause player 2 to quit farming and yield zero investment – making a Scenario B equilibrium impossible. Knowing this, player 1 may find it profitable to invest in the infrastructure maintenance. However, the tendency to free-ride remains, and Player 1 will not find it in their best interest to contribute any more to infrastructure maintenance than the level needed to just induce Player 2 to remain in the system given their optimal investment/appropriation decision (i.e. their breakeven point).

It is different from scenario B -when player 1 has an incentive to completely free ride- because in this scenario player 1 knows that if he does not invest, player 2 will not farm and thus not invest in infrastructure maintenance, and being the only contributor will imply less profits for player 1 (because of the tradeoff between investing and appropriating).

Like scenario B, players will still find themselves in Case 2 for the second stage game. If player 2 is also investing it is because he will be farming in second stage, but since he is investing he will not get his optimal unconstrained appropriation; player 1 on the other hand, because of his privileged location will appropriate his unconstrained optimal amount.

Then because, it will not be profitable for Player 2 to invest at all if Player 1 contributes nothing to maintenance, one condition that must hold to be in this scenario is that Player 2's discounted net benefits (ψ_2) must be negative when he contributes to maintenance and appropriates optimally unilaterally (m_1=0). Furthermore, his profits must be at least zero after Player 1 has contributed to infrastructure maintenance – otherwise Player 2 has no incentive to farm. Then:

$$\psi_2 = w\left(q_2 u^*{}_{2(m)} - 0.5 r_2 u^{*2}{}_{2(m)} - c_2 u^*{}_{2(m)}\right) - m_2 < 0, \text{ when } m^*_1=0$$

$$\psi_2 = w\left(q_2 u^*{}_{2(m)} - 0.5 r_2 u^{*2}{}_{2(m)} - c_2 u^*{}_{2(m)}\right) - m_2 \geq 0, \text{ when } m^*_1>0,\ m_2>0$$

replacing $u^*{}_{2(m)}$ with Equation 14:

$$w\left(B + Ae^{\frac{-1}{(m2)}}\right)\left(q_2 - 0.5 r_2\left(B + Ae^{\frac{-1}{(m2)}}\right) - c_2\right) - m_2 < 0,\ \ when\ m_1 = 0,\ m^*_2>0$$

$$w\left(B + Ae^{\frac{-1}{(m2+m1)}}\right)\left(q_2 - 0.5 r_2\left(B + Ae^{\frac{-1}{(m2+m1)}}\right) - c_2\right) - m_2 \geq 0,\ \ when\ m^*{}_1 >,\ m^*_2>0$$

On the other hand, player 1 has to consider how much to invest. If investing so that player 2 can remain in the system is less profitable than farming by himself, then player 1 will only invest considering his needs; otherwise he will invest just enough so player 2 can also contribute to the system. Then, player 1 will compare the amount of investment that maximizes his profits if player 2 is out (m_1') and the amount of investment that he will need for player 2 to remain in the system (m_1''). Player 1 will choose the one that maximizes his payoffs. To be in this scenario player 1 is choosing m_1'' otherwise, we would be in another scenario in which only player 1 invest and farm (this will be scenario D, which I will explain later). In other words, as long as the level of investment that just makes player 2 break even is less than the level required for player 1 to farm optimally by himself, player 1 will choose the former. m_1'' will satisfy this condition that embodies the optimal appropriation choice for player 2 (m^*_2):

$$w\left(B + Ae^{\frac{-1}{(m^*2+m_1'')}}\right)\left(q_2 - 0.5r_2\left(B + Ae^{\frac{-1}{(m^*2+m_1'')}}\right) - c_2\right) - m^*{}_2 = 0$$

From this expression we will have a set of combinations of m_1 and m_2 that satisfy that $\psi_2 = 0$ of that set, player 1 will choose the minimum m_1. See Figure 22.

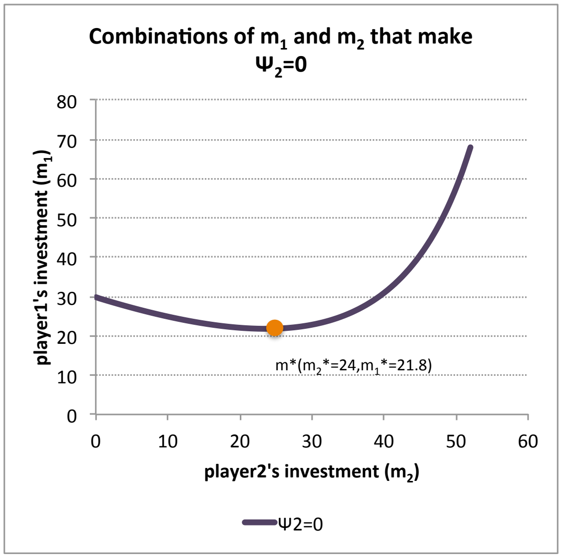


Figure 22. Combinations of m_1 and m_2 that make Ψ=0

This happens because Player 2’s profits are exactly zero due to player 1’s choice. Player 1, in this NE will not choose more m_1 than needed to just induce Player 2 to have zero profits at their optimal investment level. Once player 1 chooses m^*_1, player 2 finds his optimal investment level m^*_2 and the subsequent optimal appropriation level (u^*_2)

The conditions that must be true to be in this scenario are:

$$Q^S - a\,Q^S(1-E_2)l1 > \frac{q_1 - c_1}{r_1}$$

$$Q^S - a\,Q^S(1-E_2)(l_1+l_2) < \frac{q_1 - c_1}{r_1} + \frac{q_2 - c_2}{r_2}$$

Both expressions talk about water availability. The first condition is that there must be some water at player 2’s field gate, and the second condition is in regard to the upper limit of water availability to be in this scenario (player 2 does not have enough water to optimize without constraints).

After replacing E_2 with equation 6, we have:

$$Q^S\,(1- a\left(1-E_1-e^{\frac{-1}{(m1+m2)}}(E_1)(1-E_1)+\Theta E_1\right))l1 \geq \frac{q_1 - c_1}{r_1}$$

$$Q^S\,(1- a\left(1-E_1-e^{\frac{-1}{(m1+m2)}}(E_1)(1-E_1)+\Theta E_1\right))(l_1+l_2) < \frac{q_1 - c_1}{r_1} + \frac{q_2 - c_2}{r_2}$$

First and Second Stage connection: In this scenario, players will find themselves in the NE of Case 2. Player 2 will also invest to bring some water to his gate, then player 1 will have more than enough to get his unconstrained optimal amount of water, but player 2, because he is investing, he will only get his constrained optimal amount of water (Q_2^{FG})

Scenario 4: Only player 1 invests; $\boldsymbol{m_1}$ *>0 and* $\boldsymbol{m_2 = 0}$

In this scenario water is scarce for both players if they do not invest, so they both have some incentive to considering investing. However, in this case according to Player 2's payoffs it will not be profitable for him to keep farming. Even with player 1's investments in infrastructure maintenance to reach his own optimal amount, it is not profitable for player 2 to invest in efficiency. Only player 1 would farm and he will have to decide by himself how much to invest (Case 3). The result is a scenario in which there is no excess water beyond Player 1's demands.

What is happening in this scenario is that the water supply is so low (or the initial infrastructure efficiency is so poor) that the level of investment by player 1 that is required to make player 2 willing to invest is actually larger than the level player 1 would choose for his own profit maximization purposes.

To solve, we find first Players 1's discounted net benefits in terms of m

$$\psi_1 = w(q_1 u^*{}_{1(m)} - 0.5 r_1 u^{*2}{}_{1(m)} - c_1 u^*{}_{1(m)}) - m_1$$

Since in the second stage players will find themselves in Case 3, we can express $u^*{}_1$ as:

$$u^*{}_1 = \quad Q^S - a\, Q^S\, l_1 \left[1 - E_1 - e^{\frac{-1}{(m1)}} E_1 (1 - E_1) + \Theta E_1\right]$$

Note that m$_2$= 0. Also, because player 1 will only use water that is at his field gate.

$$u^*{}_1 = \quad Q^S\left(1 + a \;\; l_1(\,E_1(1-\Theta)-1)\right) \qquad + aQ^S\, l_1 E_1(1-E_1)e^{\frac{-1}{(m1)}}$$

for simplicity:

$$D = Q^S\left(1 + a \;\; l_1(\,E_1(1-\Theta)-1)\right)$$

$$H = aQ^S\, l_1 E_1(1-E_1)$$

$$u^*{}_1 = D + He^{\frac{-1}{(m1)}}$$

The relationship between $u_{2(m2)}$ and m_2 is shown in figure 23

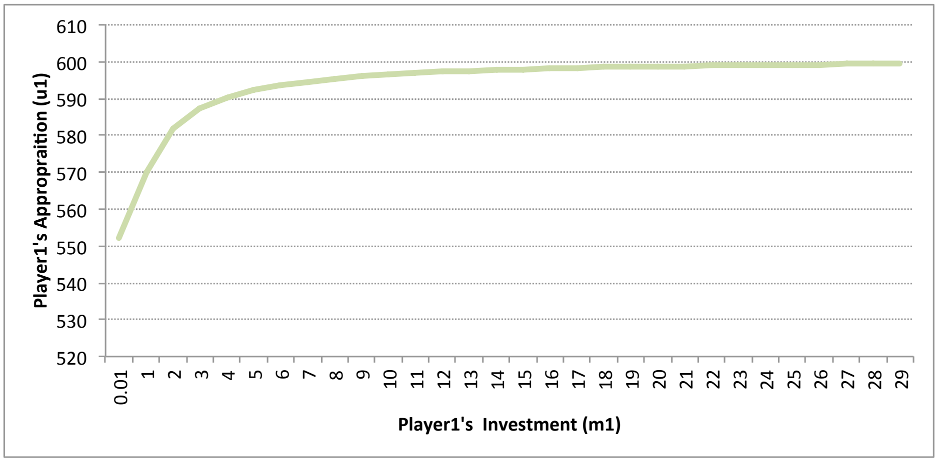


Figure 23. Player 1's water appropriation in second stage and his investment in stage 1

We use this equation to maximize player 1's discounted net benefits:

$$\max_{m2} \psi_1(\,u_{1(m1)})$$

The first order necessary condition is:

$$\frac{d\psi_1}{dm_1} = \frac{\partial\psi_1}{\partial u_1}\frac{\partial u_1}{\partial m_1} - \frac{\partial\psi_1}{\partial m_1} = 0$$

Player 1's discounted net benefits are:

$$\psi_1 = w(q_1 u^*{}_{1(m)} - 0.5 r_1 u^{*2}{}_{1(m)} - c_1 u^*{}_{1(m)}) - m_1$$

then,

$$\frac{\partial \psi_1}{\partial u_1} = \mathrm{w}(q_1 - r_1 u^*{}_1 - c_1)$$

$$\frac{\partial \psi_1}{\partial m_1} = 1$$

and from

$$u^*{}_1 = D + He^{\frac{-1}{(m1)}}$$

$$\frac{\partial u_1}{\partial m_1} = \frac{He^{-1/m1}}{m_1^2}$$

$\frac{d\psi_1}{dm_1}$ can be rewritten as follow:

$$\frac{d\psi_1}{dm_1} = \mathrm{w}\left(q_1 - r_1(D + He^{\frac{-1}{(m1)}}) - c_1\right)\frac{Ae^{-\frac{1}{m1}}}{m_1^2} - 1 = 0$$

The amount that player 1 will decide to in invest in the infrastructure maintenance will be determined by the combination of the values of these parameters. Notice that D and H are also parameters that depend on economic parameters and on $E_1$and Q^S.

Some conditions must be true to be in this scenario:

$$Q^S - aQ^S(1 - E_2)l_1 < \frac{(q_1 - c_1)}{r_1}$$

Water is scarce for player 1, and economically and physically impossible for player 2 to bring water to his field. This also implies that player 1 will not reach his unconstrained optimal amount of appropriated water (as we saw in Case 3). We replace E_2 by Equation 6:

$$Q^S - aQ^S(1 - E_1 - (E_1)(1 - E_1) + \Theta E_1)l_1 < \frac{(q_1 - c_1)}{r_1}$$

<u>Second and First Stage connection</u>: In this scenarios players will find themselves in the third NE (Case 3) of the second stage because player 1 will be the only farmer.

Figure 24 shows the tradeoffs between Q^S and E_1 given values of physical (θ, l_1, l_2, a) and economic (q_i, c_i, r_i, w) parameters, that will determine when players will end in a different scenario.

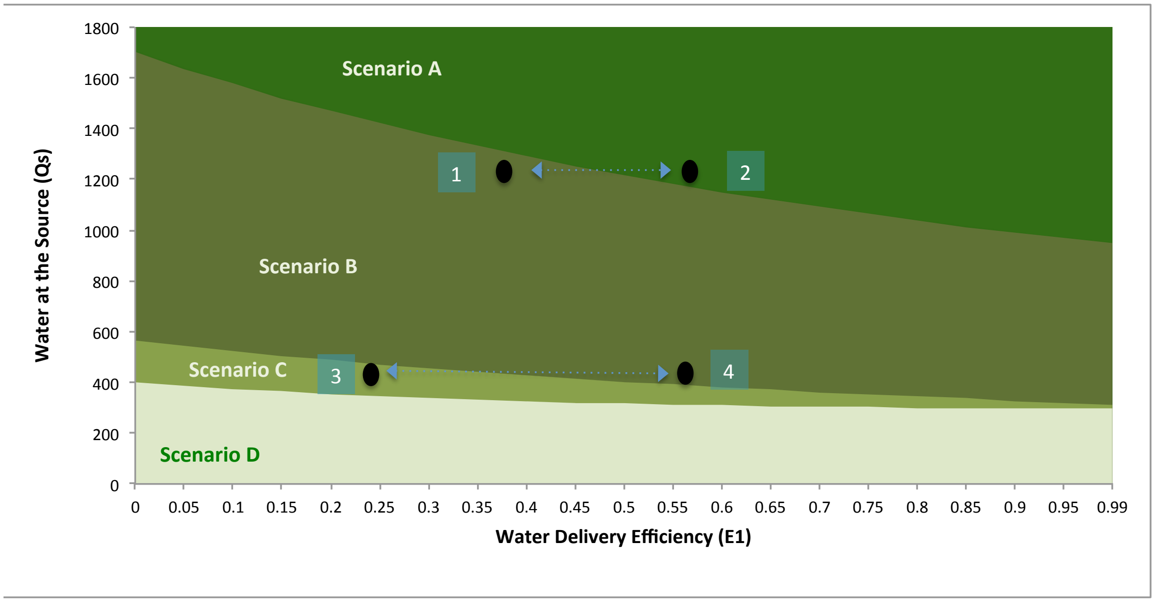


Figure 24. Nash Equilibria of the Game

The relevance of this graph is that it shows what would happen with perturbations in the water resource, issue very important for the basin given that one of its main biophysical threats is climate change and a consequent reduction in water availability (Bustamante 2008).

Table 7 *Game Nash Equilibria and their Conditions*

Nash Equilibrium	**Condition**	**Optimal Individual Appropriation**		**Optimal Individual Investment**	
		u_1^*	u_2^*	m_1^*	m_2^*
Scenario 1: Players do not contribute to the infrastructure maintenance	$Q^S - a\,Q^S(1+(\theta-1)E_1)(l_1+l_2) \geq \frac{q_1 - c_1}{r_1} + \frac{q_2 - c_2}{r_2}$	$\frac{q_1 - c_1}{r_1}$	$\frac{q_2 - c_2}{r_2}$	0	0
Scenario 2: Only player 2 contributes to the infrastructure maintenance	$Q^S\,(1 - a(1 - E_1 - e^{\frac{-1}{(m^*2)}}(E_1)(1 - E_1) + \theta E_1)\, l1 \geq \frac{q_1 - c_1}{r_1}$ $Q^S - a\,Q^S(1 - E_2)(l_1+l_2) < \frac{q_1 - c_1}{r_1} + \frac{q_2 - c_2}{r_2}$ $w(q_2 u^*_{2(m)} - 0.5 r_2 u^{*2}_{2(m)} - c_2 u^*_{2(m)}) - m_2 > 0$	$\frac{q_1 - c_1}{r_1}$	$Q^S - \frac{(q_1 - c_1)}{r_1} - aQ^S(1 - E_1 - e^{\frac{-1}{(m^*2)}}(E_1)(1 - E_1) + \theta E_1)(l_1+l_2)$	0	$e^{\frac{-1}{(m_2^*)}} wA\left(q_2 - r_2 B - c_2 - A r_2 e^{\frac{-1}{(m_2^*)}}\right) = m_2^{*2}$
Scenario 3: Both players invest	$Q^S\,(1 - a(1 - E_1 - e^{\frac{-1}{(m^*1+m^*2)}}(E_1)(1 - E_1) + \theta E_1)\, l1 \geq \frac{q_1 - c_1}{r_1}$ $Q^S - a\,Q^S(1 - E_2)(l_1+l_2) < \frac{q_1 - c_1}{r_1} + \frac{q_2 - c_2}{r_2}$ $w(q_2 u^*_{2(m)} - 0.5 r_2 u^{*2}_{2(m)} - c_2 u^*_{2(m)}) - m_2 < 0$ *when m1=0 and >0 when m1 and m2>0* $\Psi_{1(m_1'')} \geq \Psi_{1(m_1')}$	$\frac{q_1 - c_1}{r_1}$	$Q^S - \frac{(q_1 - c_1)}{r_1} - aQ^S(1 - E_1 - e^{\frac{-1}{(m^*1+m^*2)}}(E_1)(1 - E_1) + \theta E_1)(l_1+l_2)$	$w\left(B - Ae^{\frac{-1}{(m2+m_1'')}}\right)\left(q_2 - 0.5 r_2\left(B - Ae^{\frac{-1}{(m2+m_1'')}}\right) - c_2\right) - m_2 = 0$	
Scenario 4: Only player 1 invests	$Q^S - aQ^S(1 - E_1 - (E_1)(1 - E_1) + \theta E_1)l_1 < \frac{(q_1 - c_1)}{r_1}$	$Q^S - aQ^S(1 - E_{2(E1,m)})l_1$	0	$e^{\frac{-1}{(m1)}} wH\left(q_1 - r_1 D - c_1 - r_1 H e^{\frac{-1}{(m1)}}\right) = (m_1)^2$	0

When Q^s is high (in this case 1703 or higher), for any level of efficiency, players will have water abundance and thus, no investment in efficiency is needed (m=0), while both players achieve their unconstrained optimal appropriation. This means, that when Q^s is higher than 1703 the game will follow Scenario A. However, when Q^s is less than 1703 but higher than 950, the level of efficiency will determine in which Scenario (A or B) players will end. Intuitively, the quantity of water supply and efficiency are substitutes.

Similarly, when Q^s is less than 950 but greater than 565, the NE of the game will follow Scenario B, and when Q^s is less than 565 but greater than 400 the efficiency level will determine in which Scenario they are (B or C). Farmers will face Scenario C or D, depending on the combination of Q^s and E_1, when Q^s is between 400 and 313. However, if Q^s is less than 313, the substitution potential of efficiency for water supply reaches its limit and players will be in Scenario D, where player 2 does not farm in that period.

For example, in figure 24 from point 1 to point 2 we can see that a change in efficiency (an improvement) will change the NE from Scenario B to A. From point 3 to point 4 the NE has changed from Scenario C to D, we can notice thought that a larger improvement in efficiency is needed in order to make that transition. The shallower slope of the Scenario D/C frontier compared to the Scenario B/A frontier has to do with the fact that achieving a given absolute increase in water supply to the tailender at low levels of water flow (Q^s) requires a larger increase in efficiency since losses from inefficiency are proportional to Q^s.

In the next chapter I analyze the scenario that the system currently faces, and how changes in water rights, increases in agricultural knowledge or a switch of crops, or changes in the price of water, could affect these farmers' behaviors.

Chapter 8

WHAT CAN THE MODEL TELL US ABOUT THE CHANCAY- LAMBAYEQUE SYSTEM?

Recalling the issues covered in chapters 6 and 7, and the scenarios examined, it is now important to make some general reflections on the consequences and implications of the models predictions and its eventual application to practical scenarios within the physical actuality of the Chancay-Lambayeque basin situation[27].

The efficiency level in the basin is 0.37 and the average water flow that is delivered into the canal is 800 MCM[28] (ANA 2008, Regional Presidency 2010). As shown in figure 25, this combination of efficiency and water flow predicts that farmers will face Scenario B (see table 8). The prediction from the model is consistent with what is happening in the basin: headenders are appropriating water without any control and they are free riding from infrastructure, while tailenders are using all the water that is left (less than the demanded amount), and are the main payers for the infrastructure maintenance.

One interesting finding of the model is that at the current level of water flow, the efficiency level is not relevant for determining which scenario farmers will face. Also,

---

[27] The parameters value were changed replacing values using the same criteria of Appendix C and were acquired from the same sources.

[28] Million cubic meters

small perturbations in water availability will not change the scenario outcome. Only if water availability falls beyond 500 MCM, farmers will face Scenario C, in which case both farmers will invest in infrastructure maintenance (see table 8).

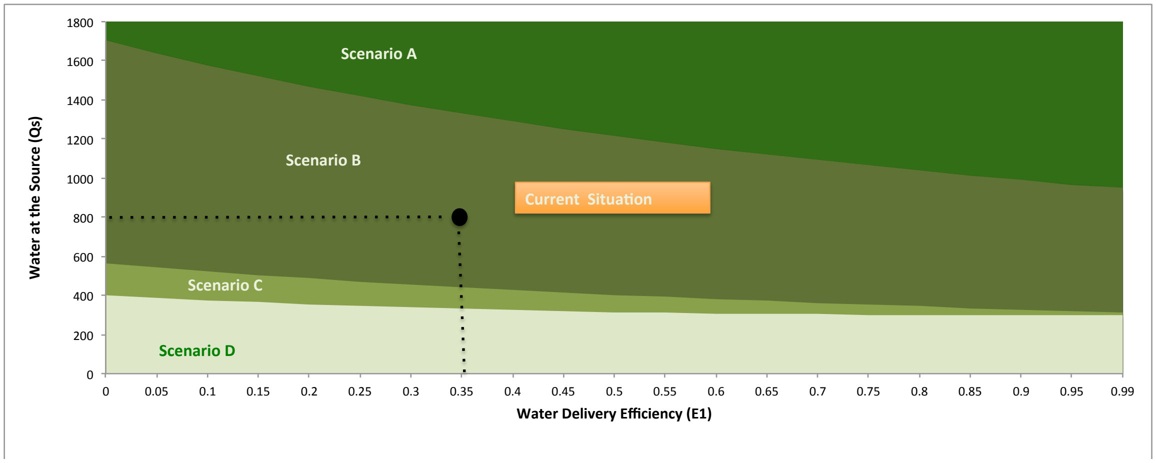


Figure 25. Nash Equilibria of the Game - Current State

However, changes in the water delivery efficiency level and in water availability, may change their individual performance in terms of production and benefits, but do not change the qualitative nature of the equilibrium for the appropriation and provision dilemma.

Table 8

Possible Scenarios

Scenario	Provision	Appropriation
A	Neither player contributes to the infrastructure maintenance	Both get their unconstrained optimal amount of water
B	Only player 2 invests	Player 1 gets his unconstrained optimal amount of water; player 2 faces some constraints.
C	Both players invest	
D	Only player 1 invests	Player faces some constraints; player 2 does not farm.

Also, from Figure 25 we can observe that the scenario in which both farmers pay for the infrastructure maintenance (Scenario C) is very narrow. Given the current incentives, it is unlikely for farmers to face that scenario. Scenario C is more likely at moderately low water supply and low efficiency situations because in this combination it is not profitable for player 2 to invest in water delivery by himself (because water supply is moderately low), but there is still a chance to invest together in efficiency to significantly increase water availability (because of low efficiency) and still make it profitable for player 2. Moreover, this simultaneous contribution equilibrium is not very robust in the sense that relatively small perturbations alter it, having as a result a change in the scenario situation: either to the free-riding Scenario B (by an increase in water availability or efficiency), or to the headenders only Scenario D (by a decrease in water availability or efficiency).

In chapter 5, I proposed some solution options to be explored with the game theoretic model. The first solution option proposed, changing water rights, follows a vast literature reviewed in chapter 2 that suggests that property rights are a key factor that affects water allocation and that creates incentives that also inform farmers behaviors in regard to the provisioning dilemma. The other solution options proposed: increasing water tariffs, and investing in agronomic or entrepreneurial knowledge, are the common policies proposed by previous reports (Regional Government 2012, Regional Presidency 2010) and by experts (MINCETUR 2003, Herrera and Caferata 2009) that do not imply major institutional change. These policies, as I will demonstrate in this section, while they may alter the situation,do not solve the main cause of the provision and appropriation problem. I explore here these solution options in light of my model results and analyze the efficiency improvement of water rights as a benchmark comparison point.

Water Rights

One way to analyze economic efficiency is to compare how different the current situation is from the situation in which the social net benefit is maximized. This is: how far are we now, in a situation where farmers maximize their own net benefits, compared to a situation when both group of farmers collectively make decisions aiming to maximize the social or joint net benefits? Maximizing jointly is similar to saying that there is only one owner (or that all farmers see themselves as one owner). A well-defined property right (e.g tradable rights to water with no problems of measurement, enforcement, etc.) is that which makes the system outcome be the same as the sole owner solution.

A benchmark of a property right that leads to an economically efficient outcome is that it results from the analysis of the one owner maximization in the sense that net benefits are maximized, and thus “there are no benefits being wasted” (Stavins et al 2003), but there is one other required condition; a “potential Pareto improvement”[29]. Changing water rights may imply both people who lose and a people who gain, and to be a Pareto improvement situation those who gained should entirely compensate those who lost, for their loss and still be better off than in the status quo. I next find the outcome of

---

[29] Kaldor (1939) and Hicks (1940) introduced the notion that an improvement in the social welfare is a ‘potential Pareto improvement’ but it is not necessarily a Pareto improvement.

the one owner maximization. This will serve as a benchmark of a potential Pareto improvement and then reflect on compensation mechanisms.

One owner solution. The subscript *i* for this exercise, will mean land upstream for 1, and land downstream for 2. Again, we start in the second stage.

Second Stage: Identifying Optimal Water Appropriation. The sole owner will maximize its net benefit considering both lands:

$$\max_{(u_1,u_2)}(q_1u_1 - 0.5r_1{u^2}_1 - c_1u_1 + q_2u_2 - 0.5r_2{u^2}_2 - c_2u_2)$$

As we saw in chapter 7, for $Q^s = 800$ farmers are in scenario B where there is not enough water to allow both lands to use unconstrained optimal amounts of water. For an analysis of joint maximization, since this case features a sole owner (with two parcels of land, one upstream and one downstream), the farmer will decide to allocate every unit of water to the land that will bring higher value for that additional allocated unit of water. The sole owner will allocate the next unit of water to the land parcel in which using that additional amount of water (at the margin) will have greater value (higher marginal net benefit with respect to water). Because water used in both land parcels has diminishing returns, the owner will allocate water in such a way that the marginal net benefit value for both lands are equal:

$$MNB_1 = MNB_2$$

$$u^*{}_2 = 1.2\,u^*{}_1 + 229$$

And because of water flow constrains:

$$u^*{}_2 = Q^S - u^*{}_1 - aQ^S(1 - E_2)(l_1 + l_2)$$

$$u^*{}_2 = 322 - 219E_2$$

$$u^*{}_1 = 78 - 182E_2$$

$u^*{}_2$ and $u^*{}_1$ are the optimal amounts of water for any given level of efficiency in period 2.

First Stage: Identifying Optimal amount of investment on the Infrastructure Maintenance. As we saw in chapter 7, in the case of individual net benefit maximization, the sole owner will maximize his net benefits, given the best response function for appropriation found in the second stage.

$$\max_m \psi(u^*{}_{(m)})$$

The first order necessary condition for solving this problem is[30]:

$$\frac{d\psi}{dm} = \frac{\partial\psi}{\partial u_2}\frac{\partial u^*{}_2}{\partial m} + \frac{\partial\psi}{\partial u_1}\frac{\partial u^*{}_1}{\partial m} - \frac{\partial\psi}{\partial m} = 0$$

$$\left(242.5 + 42\, e^{\frac{-1}{(m)}}\right)\frac{99\, e^{\frac{-1}{(m)}}}{m^2} = 1$$

Solving this equation we find the optimal amount of investment in infrastructure. However, this solution does not indicate who should pay for the infrastructure maintenance since efficiency does not include equity issues. For the purpose of simulating only one owner in the system it does not make a difference whether the

---

[30] As it can be seen from this equation, finding the optimal contribution for this one owner case, implies that the sum of net benefits to both players is balanced with the costs of contributing to infrastructure. When each player maximizes his individual net benefit that player does because farmers just consider their own private benefit. Then we can expect to see larger contributions in the one owner case.

investment comes from one land or another. Yet it does indicate if the infrastructure is underprovided or not. As we can see in table 9, when maximizing jointly the total investment is greater than when farmers maximize individually.

Table 9

Compared Outcomes: Individual vs. Joint Benefit Maximization

	Current Situation	**Joint Maximization**
u^*_1	283 MCM	173 MCM
u^*_2	328 MCM	438 MCM
m^*	S/. 119 thousands	S/. 150 thousands

In regard to appropriation, joint maximization suggests that the appropriation of water upstream should be less than in the case of individual maximization, and downstream it should be greater (see table 10). This implies that upstream users are the potential losers of an improvement in water rights, losing 15% of their current net benefits. To reach a Pareto improvement, compensation from downstream users to upstream users is needed.

Table 10

Net Benefits: Individual vs. Joint Net Benefit Maximization

	Current Situation	Joint Maximization	% Change
Total	140,548	150,761	7%
Player 1	37,366	31,673	-15%
Player 2	103,182	119,088	15%

Notice in table 11, that if downstream users compensate upstream users exactly the same amount that upstream users would lose (so upstream users have the same net benefit than in the current situation), downstream users would still experience some net benefits improvements.

Table 11

Net Benefits after compensation policies

	Current Situation	Joint Maximization	% Change
Total	140,548	150,761	7%
Player 1	37,366	37,366	0%
Player 2	103,182	113,395	10%

It is important to notice that this solution is not addressing equity issues, and will depend on policy makers' goals (e.g. policy makers could target a solution, which improves current net benefits to both groups). However, knowing that changing water rights with compensation mechanisms could bring higher social welfare without making any group worse off is a very important piece of information that delivers one criteria for policy making when aiming to achieve sustainable management.

As I mentioned before, these findings set up a benchmark of economic efficiency. Thus, policies aiming to improve economic efficiency by improving property rights should try to have the closest rules that incentivize farmers to get this outcome. Some options to improve water rights are to set up the mechanism of tradable water rights[31] or to impose pigouvian taxes[32]. However, these options may not be applicable to this case because the government is not strong or present enough to make either of these polices enforceable, and because farmers have lost trust among themselves and in the government too. Pigouvian taxes are less likely because they imply taxing headenders, which are the group of farmers that are not even paying water tariffs. Moreover, headenders are the potential losers and since there are low government capacities, it would be very unlikely that the government will invest in the system collected paid taxes to compensate headenders losses.

Work on trust building needs to be done to convince both groups of farmers to dialogue, because, as explained in chapter 5, both group of farmers have different perceptions of what is fair. Part of this trust building work may imply giving information

---

[31] The regulator sets an amount of water rights as it is done with grandfather rights but with the possibility to sell and buy them in a market. Then if the farmer can get higher profits from selling his water rights than from farming, he will do so. Like this, water is allocated to the more efficient farmers and potential losers are compensated (by sales of their water rights).

[32] In this case a pigouvian tax would imply to tax upstream farmers to incentivize them to use less water. For improving economic efficiency collected taxes are reintroduced through benefits to users, especially for potential losers.

on how cooperating could improve benefits to both groups at the same time. It is also important that tailenders acknowledge that headenders also have the right to use water from the basin for agricultural purposes. Once both groups of farmers decide to dialogue and negotiate a solution, they could have an agreement that should include the following items (among others that they may propose):

- They need to include headenders officially in the physical infrastructure of the system. This means that they should have small canals that bring water to their fields. Otherwise the only way for them to appropriate water is through pumps, which imply appropriation costs for them and no control of the appropriated amount. This is critical, otherwise it does not matter which agreement they reach they will have high incentives to not cooperate. The government should invest in building these canals.
- They need to talk about how headenders will benefit from cooperation. Potential benefits to headenders may be (compensation mechanisms): no water tariff charges for them, the option to sell their water right to tailenders, and investment in basic services for their communities.
- Discuss about tailenders participation in the irrigation association with right to also elect their representatives.
- Benefits for tailenders come from appropriating more water.
- To avoid future conflicts, water rights should involve not allowing agricultural land expansion without prior increase of water sources in the basin.

Water Cost

Other solution option proposed in chapter 5 and that has been proposed by previous reports as (Regional Government 2010) is to increase water tariffs. The aim of this policy option is to bring water price to its real marginal cost, including environmental externalities and other opportunity costs[33], and to use the collected tariffs to invest in infrastructure maintenance. However, as we saw in the previous solution option analysis, this would imply increasing water costs for headenders (pigouvian tax solution), which is not feasible. On the other hand, increasing water tariffs for tailenders will potentially solve the under investment in infrastructure maintenance if the collected money is reinvested, but will not solve the appropriation and provisioning conflict between both groups of farmers.

Table 12 shows how the net benefits for each group of farmer and the total net benefits would change if water managers apply a water tariff increase to solve the under provisioning problem.

Table
12 Net Benefits Comparison - Increases in Water Tariffs

	Current Situation	Joint Maximization	Increase in water tariffs	% Change / Current Situation	% Change / Joint Maximization
Total	140,548	150,761	140,551	0%	-7%
Player 1	37,366	31,673	37,366	0%	18%
Player 2	103,182	119,088	103,185	0%	-13%

---

[33] "In principle, if water price includes all real marginal costs, an efficient resource allocation can be reached: marginal net economic benefits of water are equal across different uses, and society's water-related welfare is maximized." (Ward, Pulido-Velazquez 2008)

Modifying water prices could be a useful tool for other objectives; however, it is unlikely that it will solve conflicts between users in this case.

Changing Farming Decisions:

As we could see in chapter 7, the outcome of the game in terms of appropriation and public infrastructure provisioning is also determined by a production function. This production has two main economic parameters: q, r. As we have been discussing in previous chapters, these parameters both convey information about the type of crop grown, agronomic knowledge, irrigation techniques, etc. Changes in these parameters may affect the game outcome and this is what I am analyzing in this section. As an example, I use what would happen if farmers decide to grow different crops, but the effect would be similar if the assumption was that they change their agronomic knowledge, etc[34]. Government agencies are strongly encouraging downstream farmers to switch crops to more aggregate value ones like pepper, mango and legumes. Near the Chancay-Lambayeque basin, indeed in the same region, there are some farmers already switching to pepper. Then, I analyze here what would happen if downstream farmers followed the government advice and switched to pepper[35].

As we can see in table 13, a switch in crops will bring in significantly improvement in net benefits. However, even when net benefits for player 2 increase, the appropriation – provision problems remains the same. There could be even more water

---

[34] Also, note that a switch in crops also implies a change in knowledge on how to grow this new crop, marketing, knowledge, etc.

[35] This does not imply that I am proposing, nor the government, that they farm only one crop. This is just an exercise to analyze the implications of changes in crop decisions.

demand from player 2 because now the water resource has a higher value (in terms of crop production value). If this solution is combined with an improvement in water rights, the increase in net benefits could be even higher. Again, increasing economic efficiency also implies to compensate potential losers and in this case there would be more benefits to distribute, and the same recommendation that I mentioned when analyzing changes in water rights previously in this chapter, applies for this case.

Table 13

Net Benefits Comparison - Switch in Tailenders' Crop and/or Water Rights

	Current Situation	Joint Maximization and Switch in Crops	Switch in Crops	% Change / Current Situation	% Change / Joint Maximization
Total	140,548	376,181	325,088	131%	-14%
Player 1	37,366	21,012	37,366	0%	78%
Player 2	103,182	355,169	287,722	179%	-19%

Moreover, one challenge for implementing a switch in crops is to solve credit constraints that tailenders face and that are driving their decision to grow rice and sugar cane. Some subsidies or credit facilities to encourage farmers to grow value added crops could be some policies to consider for this end.

Brief reflection of this chapter

Farmers have conflicts between them because the incentive structure is such that drives non-cooperative behaviors. Then upstream farmers get their unconstrained water optimal appropriation level, while tailenders have to limit their appropriation while being the only contributors to infrastructure maintenance.

I explored in this chapter how different solution options may change this outcome. I found that while changing water tariffs, switching crops or increasing agronomic knowledge may improve some farmers´ benefits, it does not solve the appropriation – provision problem. Changes in water rights that involve compensation to potential losers may solve the problem. The challenge is, then, to identify the improvement in water rights and the compensation mechanism that will convey this economic efficiency improvement and that is feasible in the basin. The government needs to step in to start building trust among farmers, trust in the government, and to start a dialogue that emphasizes the potential gains for both group of farmers, and analyzes different compensations mechanisms to agree on.

Chapter 9

CONCLUDING THOUGHTS

In the first part of this research I described and analyzed the quandary in the Chacay – Lambayeque Basin in regard to the sustainability of water management for agricultural use. There are violent conflicts between users caused by a lack of collaborative behavior in regard to water appropriation and infrastructure provisioning decisions. Moreover, water management in the basin is far from being economically efficient[36] which means that there is some room for improving social welfare.

Then, one of the objectives that motivated this research was: to study how current water rights in combination of other factors as biophysical attributes, community attributes and other related rules determine a certain incentive structure for the Chancay-Lambayeque community, and determine under what conditions farmers will seek collaboration.

With this objective in mind, and recognizing the importance of institutions for the study of a common pool resource management and the requirement of its joint study with biophysical and social aspects, I used the IAD framework. This generated an understanding of why actors interact in a non-cooperative way having as a result conflicts between two different groups of farmers – headenders and tailenders – and very inefficient outcomes.

---

[36] Since there is not an agreed and concrete criteria to assess "sustainability" I used economic efficiency as my evaluative criteria because, as I explain in chapter 1, even though this is not a sufficient condition to achieve sustainability it is a necessary condition. Thus achieving economic efficiency is moving towards sustainable outcomes (Stavins et al 2003).

Among many factors mentioned in chapter 5, cooperation and efficiency is challenged in this Basin because of farmers' insufficient agronomic knowledge, because they come from different socio-demographic regions, because they are in a semi-arid area of low precipitation where water is even more scarce, because they are growing very water intensive crops of low value added, as rice and sugar cane, and because they have been affected by erratic governmental participation at different levels. However, while all these factors may exacerbate the conflict in regard to water appropriation and infrastructure provision problem, as they were identified also in previous research in the basin (Alfaro 2008 and ANA 2008, Regional Presidency 2010), they are not root causes of the problem.

My analysis has shown that the institutional arrangements that define rights to land and water, and that motivate payments for infrastructure maintenance, have strong implications for the efficiency of irrigation infrastructure and for overall water demand. In chapter 7, with the use of a game theoretic model it was possible to understand how the incentive structure drives farmers' behavior into non-cooperative actions: upstream farmers appropriate water without restriction and do not invest in the infrastructure maintenance, while downstream farmers limit their water demand and are the only contributors of the common irrigation infrastructure. This incentive structure is influenced by biophysical and community attributes and economic factors, but it is determined by unclear and non-enforceable water rights.

The second objective that motivates this research was: to explore some solution options to enable cooperation among farmers and to increase economic efficiency as one step towards a sustainable water management. Then, after doing a qualitative analysis I proposed to explore with the development of a game theoretic model some solution options that are proposed either by the literature of common pool resources management, or by previous reports of the water conflict problem in the Basin. All these solution options may have initially appeared to be equally efficient, but in chapter 8, with the use of the game theoretic model, I demonstrated that this is not true, which also demonstrates how the use of modeling methods helps to arrive to more precise conclusions (Ostrom, Gardner and Walker 1994).

The solution options which are commonly proposed– switch to less water intensive and more added value crops, improvement in the agronomic and entrepreneurial knowledge, or increases in water tariffs - can mitigate or exacerbate the loss of benefits that come from the poor incentives in the system; but they do not change the nature of the outcome. While these solution options may change individual benefits, these changes are insufficient to help farmers escape from the incentive structure that lead to the economic inefficiency. Improving water rights was the strongest solution among all explored and it is because is the factor that is fundamental to the problem. This finding corroborates previous results of common-pool resources management studies (Schlager and Ostrom 1992, Libecap 1989, North 1978, De Alessi 1980, Libecap 1986, and Ostrom 1990). The model suggested that an economic efficiency improvement is when some water is diverted from headenders to tailenders. This implies that headenders are potential losers and in order to achieve such economic efficiency it is also required to use compensation mechanisms to ensure that both groups can be better of, or that at least no one is worse of.

Challenges for doing the institutional reform proposed are also analyzed in chapter 8 and involve: an active role for public sector to act as an intermediary among the headenders and tailenders, specially to work in building trust among actors; possibility to consider co-management between both group of farmers, agree on compensation mechanisms such as an exemption from water tariffs for headenders, or the possibility to sell their water rights, and the need to improve headenders water appropriation accountability.

The findings of this research are highly relevant in light of the water national authority interest to invest in the Chancay – Lambayeque basin. The work could help decision makers in identifying where the need for institutional reform lies. However, one limitation of this analysis is that it does not fully address a solution for equity issues. I could only interview one headender, and thus I could not capture headenders perspectives of the problem analyzed here. I suggest further research that includes headenders view of equity, economic challenges, collective actions between them and to look if they have rules and norms between them in regard to water appropriation. Also, I have not proposed any solution on how to solve corruption issues or low governmental capacities that affects policymaking in the basin. These need to be addressed in further research.

Some changes in the model could be examined to address other questions of institutional change that would require changing the nature of the interactions between players. This could imply an analysis of how the results may change when player 2 is the manager and have some control on the decision of how much water to bring into the system – canal; or that incorporates some moderation of headenders appropriation to avoid conflicts, etc. Also, since trust building is needed, one method to approach some solution options in this direction may be the development of experimental games that study how farmers playing games that involve potentially conflictive situations actually behave in several iterations as an opportunity for social learning and enhancing collaboration on the ground (Janssen et al 2012).

Other Research Implications

This research shows how the use of IAD framework combined with a game theoretic model helped to evaluate sustainability challenges in a dynamic, conflict-ridden context such as the Chancay – Lambayeque basin.

The study also shows the applicability of game theory for illuminating the linkage between institutional structure (the “rules of the game”), the economic and physical parameters of a water provision system and the ultimate productivity of water resources for the users that depend upon them. Game theoretic models serve a useful diagnostic role to help understand the underlying causes of the status quo level of (in)efficiency and allocation of resources across user groups in complex systems. Also, game theoretic models help to predict the consequences of interventions by users or policymakers – helping to assess whether well-intentioned policies are likely to generate substantial net benefits as well as helping to assess the distribution of these benefits across users. In many cases, these models show that these interventions may fall well short of solutions that fundamentally address the poor incentives in the system for cooperation in appropriation of water and maintenance and investment in critical conveyance infrastructure. In this sense, game theoretic modeling is a useful method for helping to understand the potential success of different changes to the rules of the game.

This research also contributes to the common pool resource literature. The findings could be of relevance to other similar situations of conflict. Moreover, researchers that study similar water problems could also use the structure of the developed model to study similar research questions, or to address other research questions with models that build on the developed one in this research.

REFERENCES

Autoridad Nacional del Agua – ANA (2008). Proyecto de modernización de la gestión de recursos hídricos. Diagnóstico de problemas y conflictos en la gestión del agua en la cuenca Chancay – Lambayeque.

Alfaro, J. (2008). Conflictos, gestión del agua y cambio climático. Propuesta de adaptación al cambio climático y gestión del agua en Lambayeque, Piura y Cajamarca. Lima: *Soluciones Prácticas-ITDG*

BCRP, Banco Central de Reserval Del Perú Sucursal de Piura. (2013). Síntesis Económica de Lambayeque Enero 2013. Retrieved January 18, 2013, from http://www.bcrp.gob.pe/docs/Sucursales/Piura/2013/sintesis-lambayeque-01-2013.pdf

Bustamante, M.J. (2010). Cambio climático en el Peru. Costa Norte. *Fundación M.J. Bustamante De La Fuente*. Lima, Perú.

Burness, H. & Quirk, J. P. (1979). Appropriative Water Rights and the Efficient Allocation of Resources. *American Economic Review*, 69(1): 25–37.

Burness, H. & Quirk, J. P. (1980). Water Law, Water Transfers, and Economic Efficiency: The Colorado River. *Journal of Law and Economics*, 23(1): 111–34.

Bromley, D.W. (1992). Making the Commons Work: Theory, Practice and Policy. SanFrancisco, CA.: *Institute of Contemporary Studies Press*.

Carpenter, S. R., & Brock, W. A.. (2008). Adaptive capacity and traps. Ecology and Society 13(2): 40. [online] URL: http://www.ecologyandsociety.org/vol13/iss2/art40/

Castillo, D., Saysel, A. (2005). Simulation of common pool resource field experiments: a behavioral model of collective action, *Ecological Economics*, Volume 55, Issue 3, 15 November 2005, Pages 420-436, ISSN 0921-8009, Retrieve November 18, 2012, from http://www.sciencedirect.com/science/article/pii/S0921800904004422

Chambers, R. (1988). Managing Canal Irrigation: Practical Analysis from South Asia, New Delhi, Bombay, Calcutta, *Oxford and IBH Publishing Co Pvt Ltd.; and Cambridge University Press*

Coase, R. (1960). The Problem of Social Cost. *Journal of Law and Economics* **3** (1): 1–44.

Coward, E. W. (1979). Principles of Social Organization in an Indigenous Irrigation System.*Human Organization* 38(1): 28–36.

Crawford, S., & Ostrom, E. (1995). A Grammar of Institutions. *American Political Science Review* 89(3): 582-600.

De Alessi, L. (1980). The Economics of Property Rights: A Review of the Evidence, *Research in Law and Economics* 2, l-47.

Dietz, T., Ostrom, E. & Stern, P. C. (2003) The Struggle to Govern the Commons. *Science* 302.

Gardner, R., Ostrom, E, & Walker, J.E.M. (1990). The nature of common-pool resource problems, *Rationality and Society*, 2: 335-58.

Gibbons, R. (1997). An Introduction to Applicable Game Theory, *Journal of Economic Perspectives*, Winter vol. 11, 1, 127-49.

Gibson, C., McKean, C., & Ostrom, E. (2000). People and forests: Communities, institutions, and governance, Cambridge, M.A.: *The MIT Press*.

Gintis, H. (2009). Game Theory Evolving, *Princeton University Press, Second Edition*.

Green, S., L., (2002). Rational Choice Theory: An Overview, *Baylor University Faculty Development Seminar on Rational Choice Theory*

Hardin, G. (1968) The Tragedy of the Commons, *Science* 162(3859).

Herrera, P. & Paz Caferata, J. (2012). Aprovechando Mejor el Agua en la Agricultura: El Caso de los Cultivos de Agroexportación, *Centro de Estudios Estratégicos*, IPAE.

Hicks, J.R., (1940). The valuation of the social income, *Economica* 7, 105–124

Hussain, I. (2007) Poverty-reducing impacts of irrigation: evidence and lessons, *Irrig. and Drain*., 56: 147–164. doi: 10.1002/ird.298

Imperial, M. T. & T. Yandle (2005). Taking institutions seriously: using the IAD framework to analyze fisheries policy, *Society and Natural Resources* 18(6): 493-509.

Janssen, M.A., Bousquet, F., Cardenas, J.C., Castillo, D. & Worrapimphong, K., (2012). Field Experiments of Irrigation Dilemmas, Agricultural Systems 109: 65-75

Kaldor, N., (1939.) Welfare propositions of economics and interpersonal comparisons of utility, *The Economic Journal* 49, 549–552.

Kiani, A., and Abbasi, F. (2012). Optimizing Water Consumption Using Crop Water Production Functions. Chapter 4, *Agricultural and Biological Sciences. Crop Production Technologies. ISBN* 978-953-307-787-1

Lam, W.F. (2005) Designing Institutions for Irrigation Management. Comparing irrigation agencies in Nepal and Taiwan. *Emeral group publishing limited*.

Lee, M. (1994) Institutional Analysis, Public Policy, and The Possibility Of Collective Action In Common Pool Resources: A Dynamic Game Theoretic Approach, *Ph.D. Dissertation, Indiana University*, 1994, Retrieved February 2, 2013, from: http://hdl.handle.net/10535/3591

Levine G. (1980) The relationship of design, operation and management. In: Irrigation and Agricultural Development in Asia, pp. 51-62. Coward E.W. Jr. (ed.). *Cornell University Press*, Ithaca, NY.

Libecap, G. D. (1986), The Political Economy of Cartelization by the Texas Railroad Commission, 1933-1972. *Working paper, Department of Economics and Karl Eller Center*, Univ. of Arizona.

Libecap, G., D. (1989). Contracting for Property Rights. Cambridge: *Cambridge University Press*.

Luna Huamán, J. (2007). Programa De Rehabilitacion Y Mejoramiento De La Infraestructura Mayor De Riego Y Drenaje Del Sistema Tinajones. Estudio De Preinversión A Nivel De Perfil. *Gobierno Regional Lambayeque, Proyecto Especial Olmos Tinajones*.

Madani, K., (2010) Game theory and water resources, *Journal of Hydrology*, 381(3–4): p.p. 225–238

Maass, A., and Anderson, R. L. (1978). And the Desert Shall Rejoice: Conflict, Growth and Justice in Arid Environments, *The MIT Press*, Cambridge.

Martin, B. (1978). The Selective Usefulness of Game Theory, *Social Studies of Science*, Vol. 8, pp. 85-110.

McCubbins, M. D.& Thies, M. F. (1996). Rationality and the Foundations of Positive Political Theory, *Rebaiasan* [Leviathan], Vol. 19, Autumn, pp. 3-32.

Meinzen-Dick, R. (2007). Beyond panaceas in water institutions, *PNAS* (Proceedings of the National Academy of Sciences) 104 (39)

Messick, D. M. & M. B. Brewer. (1983). Solving Social Dilemmas: A Review. Review of Personality and Social Psychology, eds. L. Wheeler and P. Shaver. Vol.4: 11-44.

Milgrom, P., North, D, & Weingast, B. (1990). The Role of Institutions in the Revival of Trade: The Medieval Law Merchant. *Econ. and Politics* 2, 1–23.

MINCETUR, Ministerio de Comercio Exterior y Turismo. (2004). Plan Estratégico Nacional de Exportaciones: Lambayeque.

North, D. C. (1978), Structure and Performance: The Task of Economic Histor, *Journal of Economic Literature* 16(3), 963-978.

Olson, M. (1965). The Logic of Collective Action: Public Goods and the Theory of Groups (Revised edition ed.). *Harvard University Press*. ISBN 0-674-53751-3

Ostrom, E. (1990). Governing the Commons: The Evolution of Institutions for Collective Action. *Cambridge University Press*.

Ostrom, E. (1999). Coping with tragedies of the commons. *American Review of Political Science*, 2: 493-535.

Ostrom, E. (2005). Understanding Institutional Diversity. *Princeton, NJ: Princeton University Press*.

Ostrom, E. (2007) Challenges and growth: the development of the interdisciplinary field of institutional analysis, *Journal of Institutional Economics*, 3, 239-264

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems, *Science* 325, 419.

Ostrom, E. (2011). Background on the Institutional Analysis and Development Framework, *The Policy Studies Journal*.

Ostrom, E., R. Gardner, & J. Walker. (1994). Rules, Games, and Common-Pool Resources. Ann Arbor: *University of Michigan Press*.

Ostrom, E., M. A. Janssen, & J. M. Anderies. (2007). Going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America* 104, no. 39:15176-15178.

Perman, R., M. Yue, J. McGilvray & M. Common. (2003). Natural Resource and Environmental Economics. 3rd edition. Harlow, UK: *Pearson*.

Poteete, A. and E. Ostrom. (2002). An Institutional Approach to the Study of Forest Resources, *International Forest Resources and Institutions Program.*

Regional Government, Lambayeque. (2012). Plan Estratégico 2012 – 2016.

Regional Presidency. (2010). Propuesta Tecnica Para La Creación Del Consejo De Recursos Hídricos De La Cuenca Chancay – Lambayeque. Gobierno Regional de Cajamarca, Gobierno Regional de Lambayeque.

Schlager, E. & Ostrom, E. (1992). Property-Rights Regimes and Natural Resources: A Conceptual Analysis. *Land Economics* 68:249–262.

Selten, R. (1975) A reexamination of the perfectness concept for equilibrium points in extensive games. *International Journal of Game Theory* 4:25-55.

Shughart, W. (2008 ed.) The Concise Encyclopedia of Economics Public Choice.

Shubik, M. (1982). Game theory in the social sciences, volume 1. Cambridge, MA: *MIT Press*.

Stavins, R., Wagner, A. & Wagner, G. (2003). Interpreting sustainability in economic terms: dynamic efficiency plus intergenerational equity. *Economics Letters*, Elsevier, vol. 79(3), pages 339-343.

Tsebelis, G. (1990). Nested Games: Rational Choice in Comparative Politics, Berkeley: *University of California Press*.

Uphoff, N. (1986). Improving International Irrigation Management with Farmer Participation: Getting the Process Right. *Westview Press*, Boulder, CO

Ward, K., & Pulido-Velazquez, M. (2008). Incentive pricing and cost recovery at the basin scale, *Journal of Environmental Management*, doi:10.1016/j.jenvman.2007.09.00

APPENDIX A

INTERVIEWS PROTOCOL

How many farmers are there in the basin? Upstream, downstream, for the main crops production and of those of high value added? How are they organized?

How water is delivered? How is treated? How the water allocation is decided? Who gets better right? Which is the dynamic for getting water? Water prices? Water sources? Groundwater?

Infrastructure maintenance? In farm? How is it done? Of the system: how does it? And how they decide to do it?

Who are the water managers? Irrigation District? How is it conform? How they take decision? Do they coordinate with other stakeholders? How? With who? Local and national authorities? Which is their role?

Soil quality? Water availability? Climate changes?

In the last several decades, what has been the primary driver(s) of change in crop production in the basin?

Crop prices: how they drive decision / Input prices

Governmental policies about water management and agricultural policies

Governmental support for agriculture

For those who farm in the basin, what drives the amount of water they apply to their fields? Is there a heterogeneity among farmers for these decisions?

How do farmers respond to water scarcity, i.e. drought conditions? Do they respond? Are they sensitive to changes in water availability more generally? Who are more sensitive to it.

What policies provide incentives for farmers to adopt water conservation practices?

What policy changes could be made to increase the adoption of innovative and best management practices?

What other changes would need to occur; for instance with agricultural finance or government incentive programs?

What are the most relevant policy changes affecting the <u>type of crop</u> production in the basin over the past few decades?

How does the new water law affect current water management in the basin?

Has urbanization been a problem for agriculture in the basin?

What role has the Irrigation District / Local Authorities/ National Water Authority / others played in agricultural policy that affects agricultural production? What role have they played in water policies?

Who would you consider the most innovative farmer in the basin with regard to water conservation practices? What technologies or practices has she/he adopted? Why did he/she make these changes?

How long have you been a farmer?

Have you made changes on your farm? Why? How?

Do you rotate crops? If so, what spurs a rotation, how often do you rotate, and what crops do you rotate into?

What irrigation technique do you use for farming?

Can you describe your typical irrigation regiment over the course of the season?

How do you initiate an irrigation event? Is it planned before the season, or do you decide when you want an irrigation and the district responds?

What influences your water use decisions?

Does the irrigation district limit/regulate your water allocation? If so, how?

Does irrigation district pricing/deliveries/policy affect farmers? How?
Have droughts affected your decision-making? If there are continued droughts, will that affect production or water conservation?
What are the labor demands for your farm? Is labor available?
What are the most important issues facing the agricultural industry?
What are the main barriers for the agricultural activity

APPENDIX B

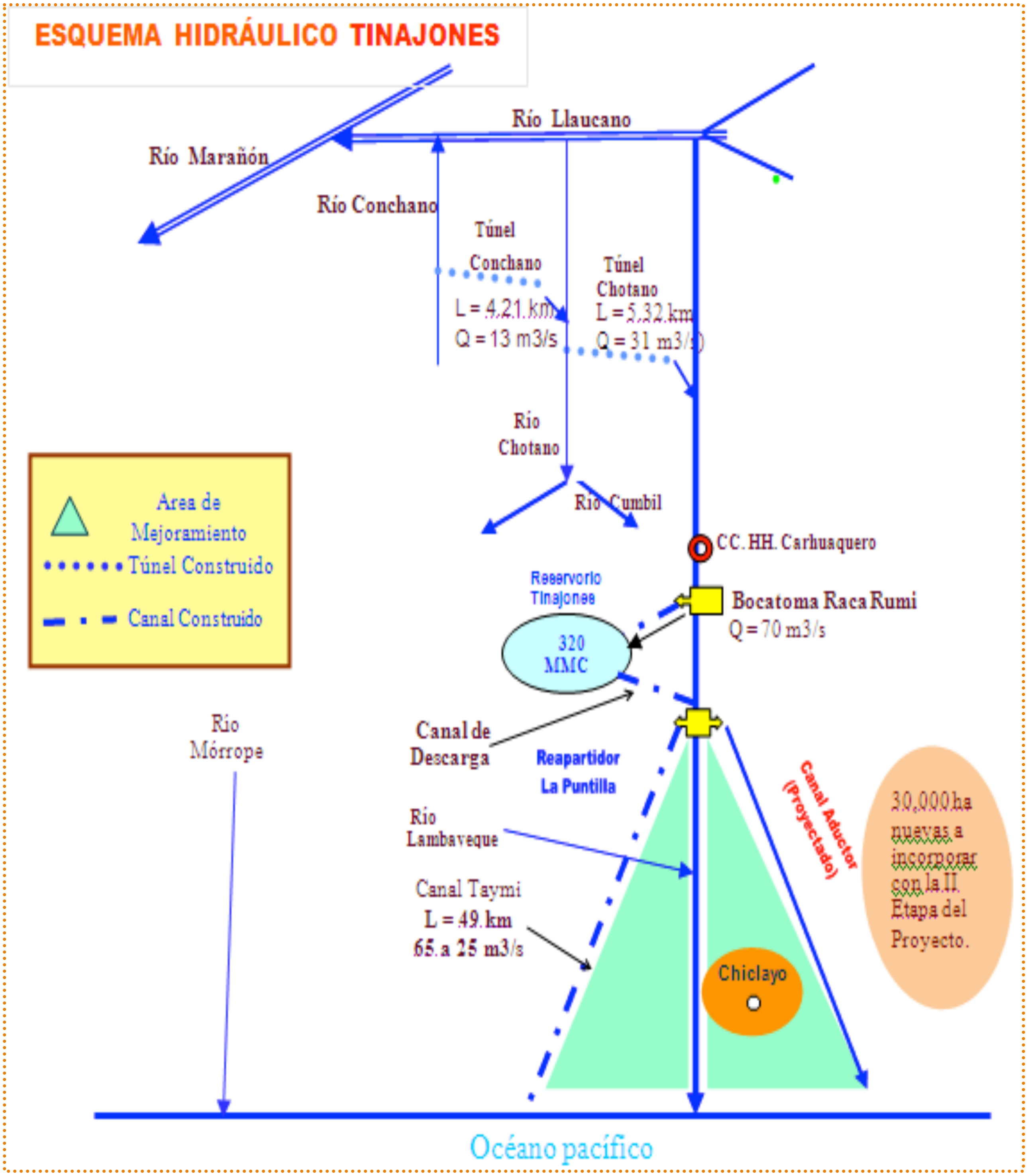
TINAJONES PROJECT HYDROLOGICAL SYSTEM

Tinajones Project Hydrological System

Tinajones Project Hydrological System components:

- Tunnel Conchano: 4,2 km long, with capacity of 13 m3/s, which increase the water availability for the valley in 100 MMC per year.
- Tunel Chotano: of 4,76 km long, diversion capacity of 32 m3/s.
- Tinajones Reservoir: with 320 MMC of storage capacity, built in an area of 20 km2 (see figure 1)
- Intake Raca Rumi: with a capacity of retension of 80 m3/s.
- Tributary Canal: 16,2 km long, with a delivery capacity of 70 m3/s.
- Canal for discharge: 4,0 km long, construido de mampostería de piedra, capacidad 70 m3/s.
- Canal Taymi: 48,8 km long, with a capacity of 65 m3/s in the initial part (Until Partidor Desaguadero) and of 25 m3/s from Partidor Cachinche.
- Devilvery La Puntilla, with a capacity of 80 m3/s

Figure 1 Hydraulic Diagram: Tinajones



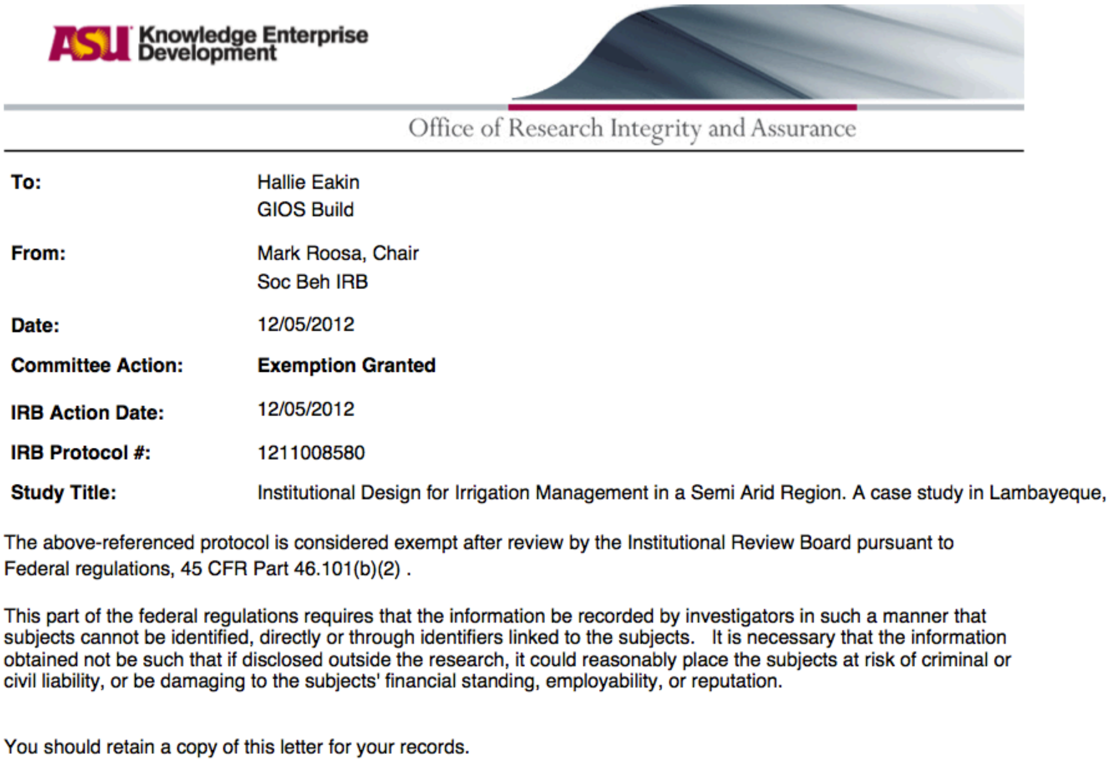
APPENDIX C

CALIBRATION DETAILS

Param.	Values	Units	Source
q_1	342.6	Thousand of national currency/MCM	q_i = crop coefficient (ha/MCM) * Yield (tn/ha) * Price (S/. / tn) Crop coefficient: Herrera and Paz Caferata (2009) Yields and Prices: BCRP (2013)
q_2	576.5	Thousand of national currency/MCM	
r_1	1.17	Thousand of national currency	Formula from Kiani and Abbasi (2012): $r_i = u_i *2 q_i$ Irrigated Water (u_i): Luna Huamán (2007)
r_2	0.97	Thousand of national currency	
c_1	12	Thousand of national currency/MCM	Own estimations
c_2	24.3	Thousand of national currency/MCM	Water Tariff (0.0243 (S/./m3)): ANA (2008)
a	0.01	1%	Regional Presidency (2010)
l_1	30	km	ANA (2008)
l_2	20	km	ANA (2008)
Θ	0.2	20%	Governmental Estimations for Laws N° 27360 y N° 27460
w	0.8	80%	Lee (1994)
E_1	0.37	37%	ANA (2008)
Q_s	800	MCM	Luna Huamán (2007)

APPENDIX D

INSTITUTIONAL REVIEW BOARD REQUIREMENTS



Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Hallie Eakin GIOS Build
From:	Mark Roosa, Chair Soc Beh IRB
Date:	12/05/2012
Committee Action:	**Exemption Granted**
IRB Action Date:	12/05/2012
IRB Protocol #:	1211008580
Study Title:	Institutional Design for Irrigation Management in a Semi Arid Region. A case study in Lambayeque,

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.