How can the effects of the construction of a dam designed for improved water use be estimated in the sub-basin Yarabamba, Peru?

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Preface

This report is the final thesis of Theoclea Swiech, elaborated for the M.S.c graduation study in Water Resources Management at the Delft University of Technology. The study presented here is about the possible effects of a future dam intended for irrigation improvements. The study area is the sub-basin Yarabamba, located near the city Arequipa in south Peru. A fieldtrip was conducted in the study area from January to November 2009, in partnership with the private consultancy agency CAMP S.L.R.

The report consists of seven chapters as follows. Chapter 2 gives a description of the sub-basin while emphasizing on the climatology and hydrology. The methodology of research for both technical and social aspects is presented in further details in Chapter 3. Chapter 4 is dedicated to the description of the irrigation systems and the water management system through the water users' practices. It also presents the characteristics of the future dam Yanaorco-Paltaorco. Chapter 5 deals with the explanation of the modeling with the software WEAP, the elaboration of scenarios and the results of the model. Finally, the conclusions of the study are presented and recommendations are given in Chapter 6.

Acknowledgements

I would like to take the opportunity to thank all the people who spent their time and shared their knowledge to help me finish my thesis in the best way possible. I also wish to add that during my stay in Peru, I not only learnt about the various disciplines related to irrigation, but I also discovered a rich culture with different ways of living and thinking than ours.

First of all I wish to thank the Machicao family who welcomed me in their home and has been like an adoptive family during my stay. I am grateful to Carlos Machicao Pereyra, without whom this research would not have been possible, and to Rosa Maria, Cesar and Andrea for supporting me and making me realize that we should be thankful for what we have. I also want to thank my supervisor Maurits Ertsen, who helped me a lot in defining the subject of the thesis and elaborating the report, always providing me with advices when facing a certain issue. I am also thankful to the other members of my graduation committee, Prof.dr.ir. N.C. van de Giesen and Dr.ir. R.J. Verhaeghe for taking time to read and comment my thesis.

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I would also like to thank Deltares and Olivier Hoes for granting me a license for SOBEK, as well as *Het Lamminga Fonds* for funding my ticket to Peru. Finally, I want to thank my friends and family, especially my parents, for their support during my study.

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1. Introduction

In countries such as Peru where 44% of the population live below the poverty level (CIA, 2006) and water is a scarce resource, irrigated agriculture is not only vital for the subsistence of many but can also be a factor of economic development and by extent social improvement. To answer the global and local demand and respond to the water scarcity, governments might decide to bring modernization to the irrigation systems, for instance building irrigation dams. However, when implementing new physical structures, the actual situation and social climate are the real decisive factors for an evolution toward a new form of water management, with negative and positive aspects alike. These adjustments are hard to predict beforehand, and the appreciation of the impacts requires a good knowledge of the basin affected by the new structure.

In that perspective, the present study will be carried out in the sub-basin Yarabamba (366km², southwest of Arequipa), part of the river basin Quilca-Chili in Peru, where a dam will be built in the highest areas in order to regulate the water flow to the irrigation systems downstream. The studied area is the Yarabamba sub-basin located in the Chili river basin where the agricultural sector is the main water user. It is part of the "Chili No regulado", meaning that water is not regulated through dams contrary to the irrigation systems in the district of Arequipa. Currently the water supply fluctuates over a year, and the spatial distribution is rather uneven as the downstream valleys of Yarabamba and in a lesser extent, Sogay and Quequeña, are at the tail-end and thus receive a lesser amount of water, due to deficiencies in water management practices.

According to local institutions, the dam and its associated structures will result in an increase of the agricultural production in the sub-basin, by improving the irrigation process and bringing a transition toward more profitable types of crops. However, the study must take into account that human actions shape the systems through social factors and political decisions and in return are influenced by the behavior of the system. Thus, the investigation aims at describing the hydraulic behavior of the irrigation systems (timing and quantity) and relating it to the actual water management (technical and social levels), before studying the possible interactions between the new dam and the actual irrigation system and decide if it possible to come to conclusions and give recommendations.

1.1. Research question

This situation, though here in a specific context, illustrates a now worldwide issue in irrigated agriculture, and what are the responses of human society facing this issue: increasing water scarcity.
Water resources are being increasingly put under pressure by factors such as an increasing population and economic development, and thus a growing need for agriculture and other sectors, as well as climate change. In the case of irrigated agriculture, an often proposed solution would be to "modernize" the irrigation scheme in order to reduce the consequences of the scarcity. The definition of modernization as given by the FAO is the following:

"*A process of technical and managerial upgrading of irrigation schemes combined with institutional reforms, if required, with the objective to improve resource utilization and water delivery service to farms*" (Renault, D., 1999)

In the present case, the construction of a dam is regarded as the technical upgrading, combined with necessary changes in management related to the operation of the dam. The goal of such a structure as a dam would be to increase the yield with the same quantity of water, leaving the excess available for additional or possibly more water-demanding crops. However, the impacts of a dam on downstream uses are not accurately predictable. Though it can bring the expected benefits, it also has its social, technical and ecological drawbacks, sometimes unexpected, including the loss of flooded areas for example. Furthermore, the dam is assumed to improve the water efficiency, but the real issue might lay in the current management of the irrigation system itself, thus decreasing the potential of the dam in solving the water issues.

The objective of this study thus leads to the following research question:

How can the effects of the construction of a dam designed for improved water use be estimated in the Yarabamba sub-basin, Peru?

This problematic presupposes that an answer is given to the following sub questions:

1. What are the motives (social and technical) behind the implementation of the dam?
2. Based on what is known at the present, can recommendations on the use of the future dam be given?
3. How can the study of the behavior of an irrigation system in a micro-basin be carried out, in order to provide the necessary support to the research?
4. Is it suitable to describe the entire area by focusing on a smaller area in the sub-basin? Is the description of one or more areas representative of the micro-basin?
5. In what ways is the entire system shaped by human actions and how are they influenced by the system in return?

1.2. Study area: the sub-basin Yarabamba

The sub-basin Yarabamba is located at the foot of the old volcano Pichu Pichu, where it takes its source. Its overall area is 366 km2, and it is characterized by a dendritic drainage and scarce precipitations. It is defined by the outflow of the river Yarabamba, which is formed by the rivers Poroto and Polobaya as illustrated on Figure 1. The river goes through the sectors of Sogay, Quequeña and Yarabamba, and is formed by the convergence of the rivers Poroto and Obaya. The river Poroto runs through the sectors of Agua Buena and Susihuaya (part of the municipality of Polobaya). The river Obaya is formed by the rivers Totorani and Ospicio, in the south, and flows through the sectors of Polobaya and San Jose de Uzuña where the dam will be built.

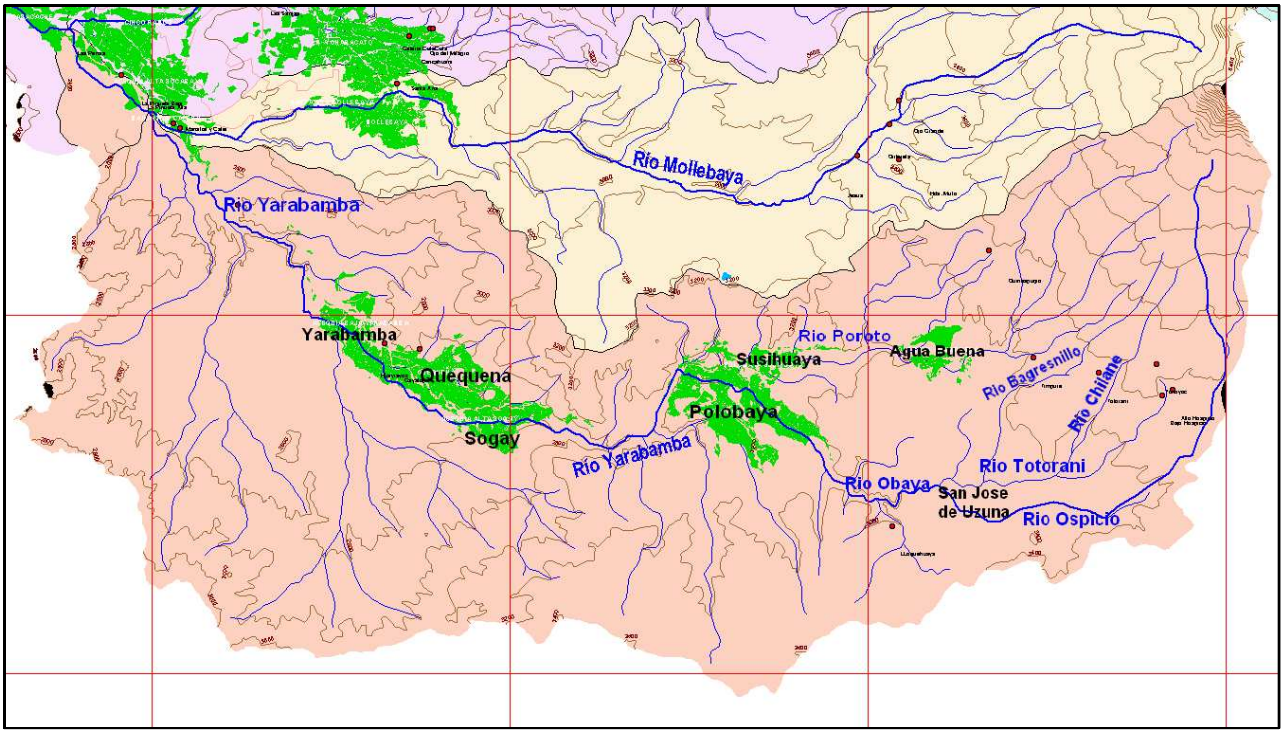


Figure 1: Illustration of the hydrography of the sub-basin

The construction site of the dam Yanaorco-Paltaorco is located in San José de Uzuña, upstream of Polobaya (Figure 2).

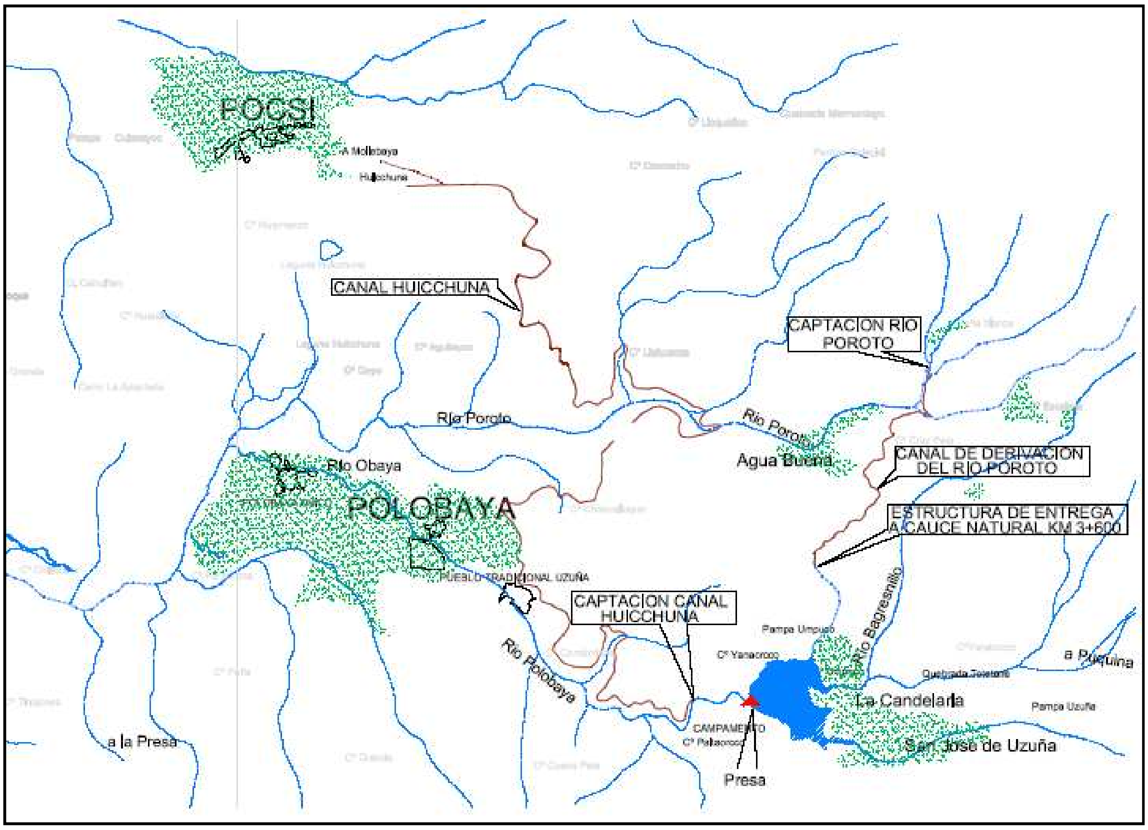


Figure 2: Location of the dam and the derivation canals

On this map appears the derivation canal of Huicchuna, supposed to bring water from the sub-basin Yarabamba to the sub-basin of Mollebaya. This canal will be mentioned further in this report.

1.3. Methodology

1.3.1 Objectives

In order to give a first answer to the research question and sub-questions, background information must be provided and processed as follows:

1. *What are the motives (social and technical) behind the implementation of the dam?*
    - Analysis of the current situation and issues
    - Realization of a social investigation to understand the needs of the stakeholders
2. *Based on what is known at the present, can recommendations on the use of the future dam be given?*
    - Results given by the models and the social investigation
3. *How can the study of the behavior of an irrigation system in a micro-basin be carried out, in order to provide the necessary support to the research?*
    - Data collection (facts, figure, maps) for a description of the study area
    - Realization of a fieldwork campaign to obtain the characteristics of the canals
    - Elaboration and evaluation of a SOBEK model of the main canals
    - Elaboration and evaluation of a WEAP model of the entire basin
    - Evaluate different scenarios and apply them to the WEAP model
4. *Is it suitable to describe the entire area by focusing on a smaller area in the sub-basin? Is the description of one or more areas representative of the micro-basin?*
    - Comparison of management practices and structures in the sectors
    - Comparison of other factors such as climatology, demography, social aspects
5. *In what ways is the entire system shaped by human actions and how are they influenced by the system in return?*
    - Description of the irrigation system through water management practices and issues
    - Investigation into the attitude of the water users toward the future dam and other projects supposed to solve the issues
    - Investigation into the legal framework around the irrigation systems

In that perspective, the study has two main aspects:

- Technical, through the hydraulic modeling of the irrigation systems and the evaluation of water needs and consumption,
- Social, through the study of the organization of the water users and the issues they are confronted with.

1.3.2 Technical aspect

The finality of the technical aspect is the study of the availability of water and behavior of the irrigation systems. To this end, the water use is evaluated with WEAP. Initially, a SOBEK model of the hydraulic behavior of the canals on primary, secondary and possibly tertiary levels was planned, but due to the complexity of gathering accurate information, only the main canals were modeled.

Modeling with WEAP aims at verifying the assertion that the dam will improve water availability. It also evaluates other solutions to see where the problem really lies, and to be in accordance with what the farmers want and think is better for them. The fieldwork allowed a better insight in the real problems faced by the farmers, seeing the conditions of the system.

As a first step the current situation is examined regarding water use specifically in terms of quantities (discharges, water delivered vs. water used) and timing (availability of water in time, crop schedules, farming strategies), before the elaboration of different WEAP scenarios including the operation of the dam and climatic changes. To this end, the technical aspect includes data collection from written sources, and the realization of a fieldwork, with the purpose of providing background information for the modeling part and to inventory the structures and their state. The maps, collected in AutoCAD, are integrated to ArcGis to provide a reliable visual source. The data for the hydraulic model are collected on the field, the missing data assumed and incoherent data corrected with the help of previous studies carried out in the area, before being used in SOBEK to model the main canals.

With the climatic and hydrologic information, the basic WEAP model is elaborated as a simplification of the situation in the sub-basin. The results are then confronted to the current situation and what is known of the hydrologic issues. The different future scenarios include the presence or not of the dam, of drier or wetter years, and parameters such as increase in cultivated area and in water-demanding crops. The scenarios are then integrated to the current situation and the validity of their outcome evaluated.

1.3.3 Social aspect

A social investigation is necessary to give meaning to the technical aspect, since the stakeholders are those whose shape the irrigation system and define its operation. The models will be confronted to the reality of irrigation and give insights into the impact on water use, on hydraulic and social levels. Their results will be related to the issues faced by the water users (equitable distribution of water, state of the structures, propositions for future improvements). A large part of this work is carried out in partnership with various institutions, such as the Junta de Usuarios (water users' organizations), the regional government, or the municipality of the sector of Yarabamba.

1.3.4 System boundaries and focus of the research

Here are presented the boundaries of the research, the physical boundary of the system (for the sake of the model), and the research boundaries, meaning what will not be investigated further during the research.

Physical boundaries

The study area being the Yarabamba sub-basin, the physical boundaries are defined by the watershed boundaries until the convergence with the river Mollebaya as illustrated on Figure 1. For simplification purposes, only the sectors Yarabamba, Quequeña, Sogay and Polobaya are modelled. The remaining sectors Susihuaya, Agua Buena and San José de Uzuña, although integrated into ArcGis, are not included due to lack of information, transportation difficulties and the fact they do not represent the majority of the water users in the sub-basin.

It has to be added that the irrigation sectors are linked by the river, which is not easily measured and where most of the water infiltrates, making it impossible to evaluate without the proper equipment. This means that each irrigation system is disconnected and evaluated separately.

The sector of Socabaya, located downstream the river Yarabamba and near Arequipa, is not part of the study as the dam is intended first for the upstream areas, and also because Socabaya is mainly supplied by springs and thus does not depend much on the river.

Research boundaries

Part of the information collected will not be used since they would be out of the scope of the thesis. Although the other sub-basins in the Oriental sub-basin are not directly linked to the Yarabamba sub-basin, the construction of the dam implies a new link between them as it is part of a project to assist each sub-basin in sharing the water. The derivation canal from the Yarabamba sub-basin to the Mollebaya sub-basin means that this sub-basin must be considered in the research.

2. Description of the sub-basin

In this chapter, the river basin Quilca-Chili, part of the region of Arequipa, is described along with the sub-basin of Yarabamba in sub-chapter 2.1. The climatology and hydrography in the sub-basin are discussed in sub-chapters 2.2 and 2.3.

Further information on the geomorphology, geology, demography and living standards of the inhabitants in the sub-basin are presented in appendix II. The legal framework for the use of irrigation water in Peru, the institutions responsible for water management at national and local scale and sources of financing are discussed in appendix III.

2.1. Description of the region of Arequipa and the river basin

The region of Arequipa is located in the Andes, in South Peru, and ranges from 0m to 4525m. The 63,345 km² area is mainly of volcanic origin, as it is surrounded by large ranges of high-altitude volcanoes that emerge above the plateaus. Deep canyons such as Majes, Colca and Sihuas contrast with this landscape. Along the coast, plateaus and dunes are characteristics of the desert of Arequipa. The region, that totalizes more than 1 million people, mainly lives on the production of wheat, cotton, rice, onion, garlic, quinoa and milk. The poverty rate in the entire region is around 45%. It could be noted that the source of the Amazon River, the longest on Earth, is located in the region of Arequipa.

The department of Arequipa is divided into 8 provinces and the province of Arequipa is itself composed of 29 districts (Arequipa - Wikipedia, 2009). In the Province of Arequipa, the climate is dry and sunny all year long, temperatures fluctuate between 10 and 24°C. The rainy season lasts from January to March but rainfall is reasonably moderate.

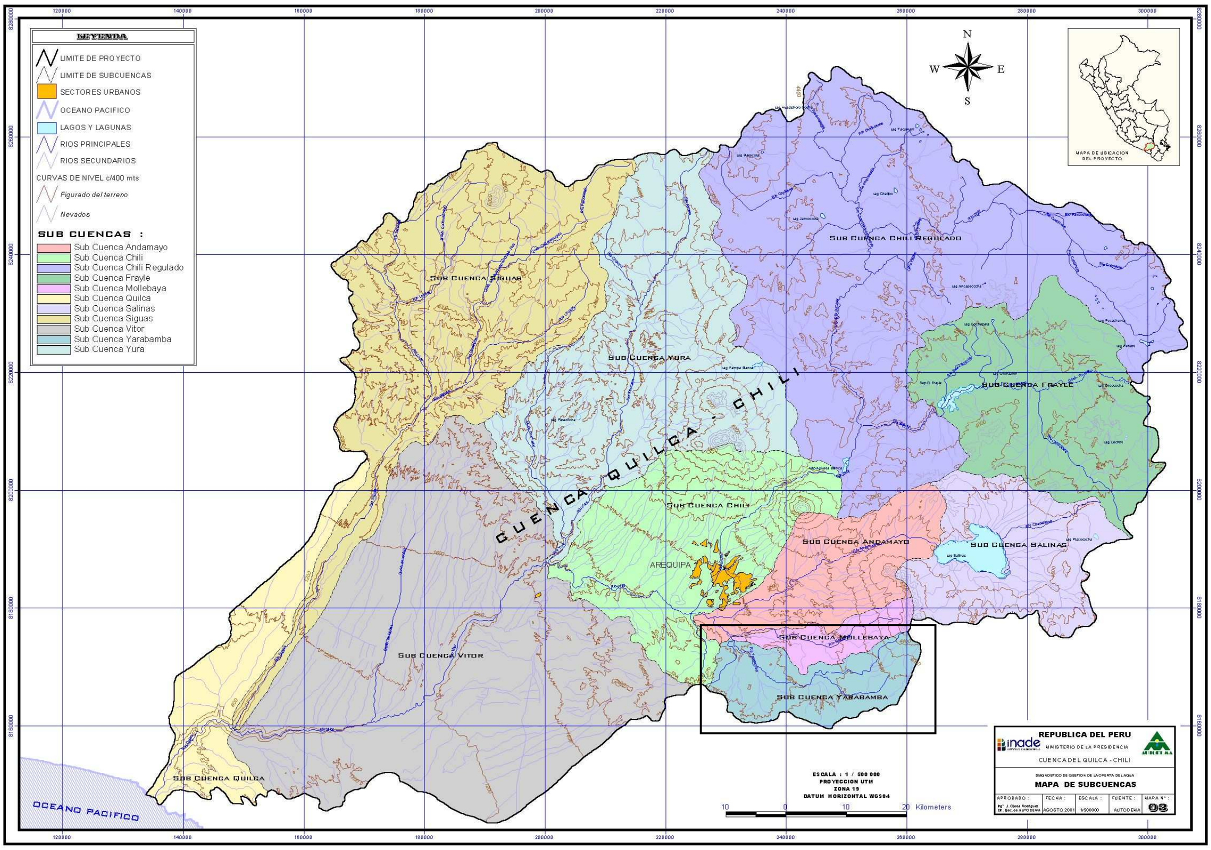


Figure 3: Map of the Quilca-Chili river basin

The river basin Quilca-Chili, where the city of Arequipa is located, belongs to the occidental side of the Andes and thus to the Pacific watershed (Vertiente del Pacífico). Its geographic coordinates are defined by 15°37' y 16°47' South Latitude and 70°49' y 72°26' West Longitude (Figure 3).

As shown on Figure 4, the river Quilca is formed by the rivers Sihuas and Vitor, respectively in the North and South of the river basin (Reformulación de Expediente Técnico, 2008). The river Vitor is formed by the rivers Yura and Chili, the latter flowing through the city of Arequipa. The river Chili receives the contribution of the river Tingo Grande, downstream of Arequipa, where the sub-basins Andamayo, Mollebaya and Yarabamba are located. Upstream of Arequipa, the river Chili is formed by the rivers Blanco and Sumbay, respectively originating in the sub-basins Chili Regulado and El Frayle. The total area of the river basin, not including the sub-basin Sihuas, is 12.542 km².

The sub basin Andamayo (509.6 km²), Mollebaya (154.5 km²) and Yarabamba (365.9 km²) are part of the oriental sub-basin, which is not regulated (Chili No Regulado), meaning that the flow is not regulated via a dam (JJUU, 2006). At this point, the river Tingo Grande is formed by the union of the river Andamayo, from the sub-basin of the same name, and the river Postrero, which is the junction of the rivers Mollebaya and Yarabamba.

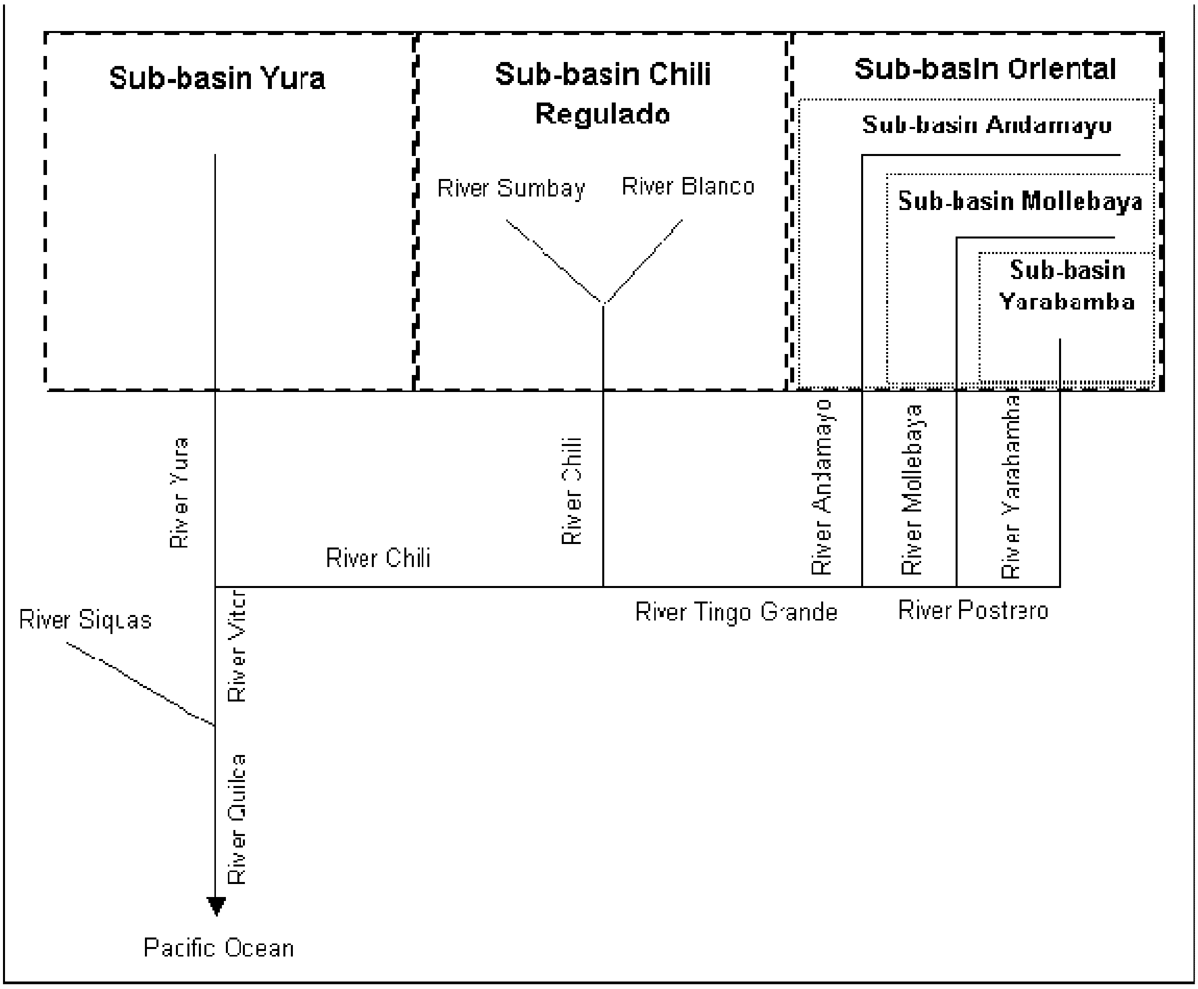


Figure 4: Scheme of the different sub-basins in the Quilca-Chili basin

The water users' organization (Junta de Usuarios) of the oriental sub-basin consists of more than 6100 users for a total irrigated area of 6127 ha, divided in 17 "Comisiones de Regantes" (see appendix III) as illustrated in Table 1.

1) Acequia Alta – Socabaya	10) Mollebaya
2) **Acequia Alta - Sogay**	11) Paucarpata
3) **Acequia Baja – Yarabamba**	12) Piaca
4) Alangui	13) Pocsi
5) Cinco Ramos – Socabaya	14) **Polobaya**
6) Characato	15) **Quequeña**
7) Chiguata	16) Sabandia
8) Chilpina	17) Santa Ana – Mollebaya
9) Huasacache	

Table 1: Comissiones de regantes in the Oriental sub-basin

At the scale of the sub-basin, two main areas can be distinguished by their altitude: the "high altitude" zone, around 3000m, and the "low altitude" zone, around 2350m. The high areas in the sub-basin include the sectors Polobaya and its annexes, Totorani, San Jose de Uzuña, Susihuaya and Agua Buena. In the low areas are the sectors Sogay, Quequeña, Alto Yarabamba and Bajo Yarabamba. The irrigated area and number of users in each sector of the sub-basin Yarabamba are given in Table 2.

Irrigation sectors	Commission de Regantes	Irrigated area (ha)	Number of users
Bajo Yarabamba	Bajo Yarabamba	128.6	155
Alto Sogay	Alto Yarabamba	96.94	139
Bajo Sogay		174.6	249
Alto Quequeña	Quequeña	92.48	113
Bajo Quequeña		166.27	208
Polobaya	Polobaya	476.6	1250
San Jose de Uzuña		101.2	--
Susihuaya		94.4	112
Agua Buena		98.9	125
Totorani		61.1	--

Table 2: Total irrigated area and number of users per irrigation sector (2004 - ATDR)

The total population listed in Polobaya, Quequeña and Yarabamba reach 3691 people, meaning that the total population in the entire sub-basin is around 4000 (see appendix II).

2.2. Climatology

Contrary to the Northern hemisphere, summer occurs in the months of January to March, and winter from June to September. In the region of Arequipa, climatology is defined by two seasons: dry and rainy. The rainy season is in winter, from January to March, and begins sometimes earlier or ends later. The rest of the year, the climate is dry, with a large temperature variation between day and night.

2.2.1 Climatologic data

Since there are no meteorological station in the studied area, the climatology data were based on the nearest meteorological station of Characato (location 16°27'S 71°29'W, 2451m), with correcting factors. The data recorded include temperature, sunshine, wind speed, humidity and rainfall. This station, however, presents unusual values compared to other stations in higher areas, generally higher especially regarding evaporation, wind speed and sunshine hours. This is why it might not be appropriate for the high areas of Polobaya, among others. Since there is no other station nearby, meteorological data were simply corrected depending on the altitude of the studied area (PROFODUA, 2004, p. 124).

Temperature

In the sub-basin the temperatures are estimated to vary between 14.6 °C in August and 17.7 °C in December, with an annual average of 16.3°C. These variations are lower compared to the variations encountered in Arequipa (between 29°C and 4°C in extreme cases).

Sunshine time

The average daily sunshine time is 8.8 hours. Between January and February, this average drops to 6 hours, while from July to November it reaches 10 hours daily.

Wind velocity

The average monthly wind velocity varies between 2 and 8 m/s, with the maximum velocity recorded during the dry season.

Relative humidity

The annual average relative humidity is around 40%, with the lowest values between July and September (JJUU, 2006).

2.2.2 Evaporation

The daily evaporation was measured through a pan evaporation method, at the meteorological station of Characato (PROFODUA, 2004). The reference evapotranspiration was then deduced through the application of a pan coefficient Kp (Table 3).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual (mm)
ET0 (mm/day)	3.9	3.7	3.5	3.7	3.5	3.3	3.5	4	4.5	5	5	4.5	1,468.10

Table 3: Reference evapotranspiration for the sub-basin Yarabamba

The average evaporation rate is from 6.8mm to 8.4mm per day in the sectors of Yarabamba, Quequeña and Sogay. For the sectors of Polobaya and its annexes, which are located at an altitude of 3000m, the meteorological factors have been adjusted and give and average evaporation from 6mm to 6.8mm per day (Table 4).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Yarabamba, Quequeña, Sogay (mm/day)	5.8	5.1	5.1	6	6.6	6.8	7.1	7.7	8.2	8.4	8.2	7.1	6.8
Polobaya (mm/day)	5.1	4.4	4.4	5.2	5.8	6	6.2	6.7	7.2	7.4	7.2	6.2	6

Table 4: Daily evaporation in the Yarabamba sub-basin per month (PROFODUA, 2004)

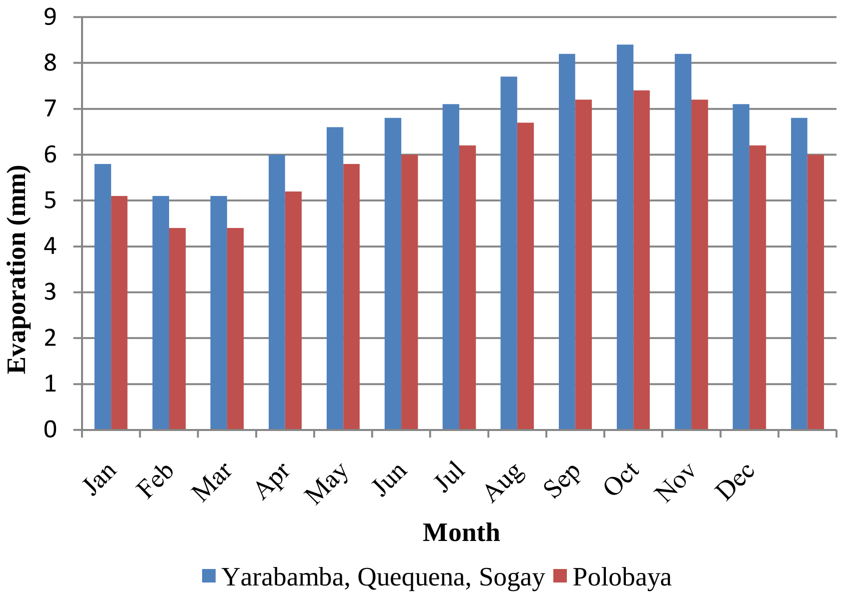


Figure 5: Daily evaporation in the Yarabamba sub-basin

2.2.3 Precipitation

Due to the Humboldt Current, which runs from the southern tip of Chile to the northern part of Peru, precipitations in the studied area are scarce. Between the altitudes of 1500 and 3000 m, the annual superior limit for precipitations is 200mm. The rainy period is concentrated between December and April, and almost no precipitation occurs between June and August (Table 5).

Most of the precipitation records were obtained between 1964 and 1995 in the entire basin. Since a large amount of data was missing, the normal ratio method of Van Te Chow was applied, with the data of neighboring stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual (mm)
All sectors (mm/month)	54.6	67.6	38.1	1.7	0.2	1	0	2	0.7	0.3	2	13.1	181.3

Table 5: Monthly precipitation in the Yarabamba sub-basin

Table 6 illustrates the effective precipitation per month (PROFODUA, 2004). It can be seen that only during the months of January, February and March, precipitation can be used by the crops.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual (mm)
Effective precipitation (mm/month)	23	31	13	0	0	0	0	0	0	0	0	0	67

Table 6: Monthly effective precipitation in the sub-basin Yarabamba

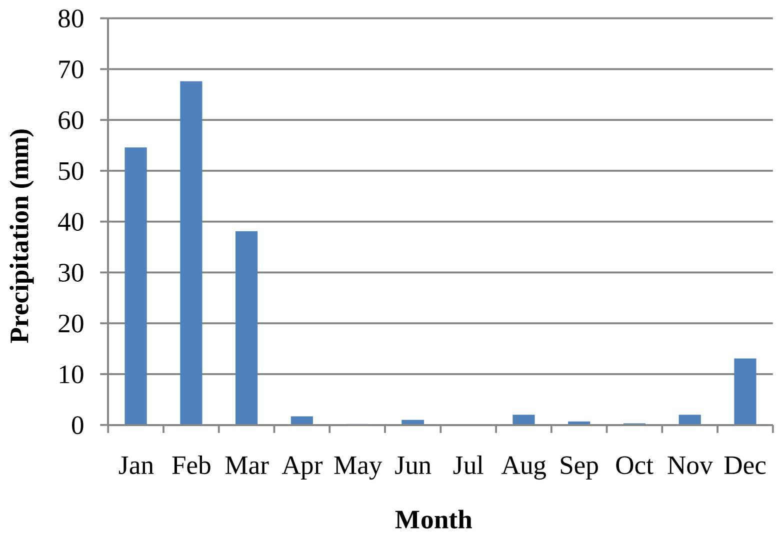


Figure 6: Monthly precipitation in the Yarabamba sub-basin

2.3. Hydrology

In the entire basin of the river Chili, the runoff water originates from precipitation in the highest parts, from snow melting, and from lakes distributed along the Altiplano zone. In the study area water resources are scarcely available, especially since the geomorphology makes it difficult to use groundwater. Most of the water that comes with a regular discharge along the year is composed of filtrations from the Lagunas Salinas. Due to the impervious rock base found at a shallow depth, water that was not used in the irrigation system can be retrieved as it runs along that layer back to the river and streams, to be used again by the farmers (*Estudio de factibilidad - Volume I*, 1980, chap. VI).

2.3.1 Hydrography

The river Yarabamba is formed by the convergence of the rivers Poroto in the North and Obaya in the South, at 2925m. The river Poroto is formed in Agua Buena, as the union of the brooks Quinsapuquio and Pena Blanca. The river Polobaya starts in San Jose de Uzuña, and is formed by the brook Totorani and the river Uzuña. On Figure 7, small arrows represent the various streams that feed the main rivers (bold arrows), and dotted squares stand for the different irrigation sectors (PROFODUA, 2004).

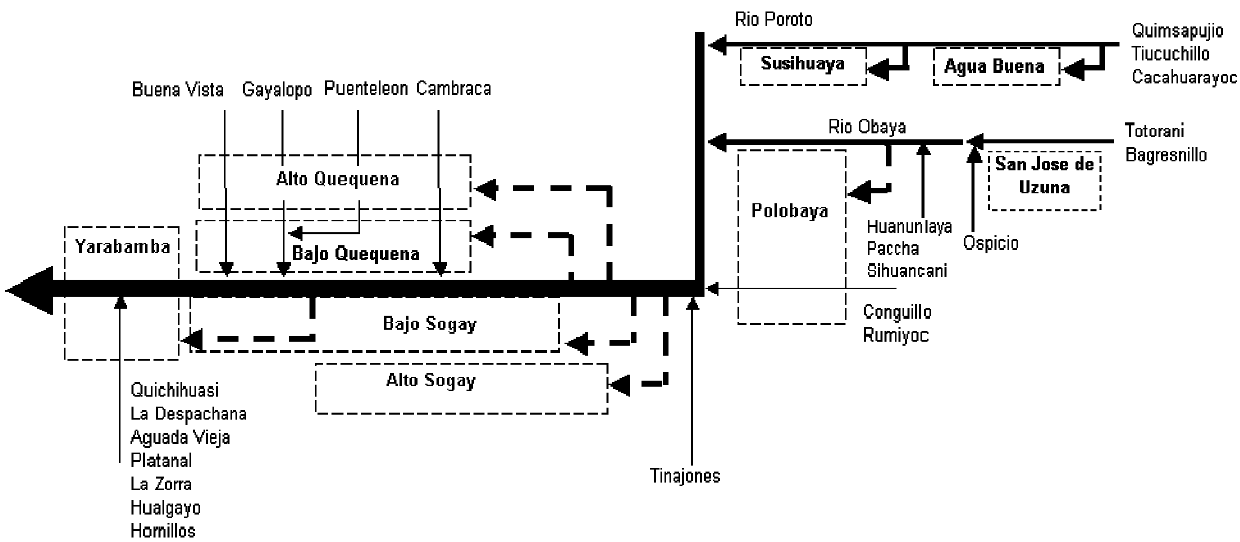


Figure 7: Hydrographic scheme of the sub-basin

Historical discharges

Table 7 illustrates the evolution between 1980 and 2000 of the average discharge in the rivers Totorani, Polobaya and Yarabamba (*Estudio de factibilidad - Volume III*, 1980; JJUU, 2000). It can be noted that the average discharge has decreased in Polobaya and Yarabamba, the highest drop being in Yarabamba. Since Totorani, which is located upstream of all the sectors, has the same discharge, this decrease could be explained by the increase in cultivated land in the upstream sectors, or maybe by a lack of water due to changes in the precipitation pattern.

	Average discharge 1977-80 (m3/s)	Average discharge 1990 - 2000 (m3/s)
Totorani	0.26	0.27
Polobaya	0.46	0.31
Yarabamba	0.55	0.26

Table 7: Evolution of river discharge between 1980 and 2000

Table 8 also illustrates the difference in canal head flow between 1980 and 2007 (*Estudio de factibilidad - Volume III*, 1980; CAMP S.R.L., 2008). Again we can observe a decrease of discharge in time, which means that the river discharge is effectively lower, due to a lack of water upstream. In any case, these measurements, if correct, illustrate the critical need to improve water management in the basin.

	Discharge (m3/s)					
Date	Polobaya	Alto Sogay	Bajo Sogay	Bajo Yarabamba	Alto Quequeña	Bajo Quequeña
June 1980	0.315	0.037	0.182	0.069	0.061	0.174
July 1980		0.115		0.028	0.127	0.08
2007	0.276	0.022	0.040	0.029	0.029	0.053

Table 8: Evolution of discharges in the main canals between 1980 and 2007

Water quality

Analyses show that the river's salinity is moderate with a low content in sodium, which means that salinization of the land is not problematic, at least in the downstream sectors. Polobaya however is more affected, due to a bad drainage in the fields (*Estudio de factibilidad - Volume I*, 1980, chap. IV).

2.3.2 Groundwater sources

Groundwater flows play a major role in the hydrology of the basin, although the processes related to them are not well know. It is the only almost permanent source of supply for the streams and rivers. Discharges value range from 0.01 l/s to 1.5 l/s for the metamorphic, plutonic and sedimentary rocks, and from 30 l/s to 600 l/s for volcanic rocks.

Shallow aquifers

Shallow aquifers are defined by aquifers of variable magnitude, existing at superficial depths, where water flows under the impulse of gravity to the hill slope or other depressions where they form springs. According to observations in the sub-basin, the water in these aquifers is continually renewed by precipitations and emerges as springs that are used directly for irrigation. Waters moves through a system of combination of fractures and fissures meaning that the water is stored in the gaps left by intrusive rocks. Infiltrated water flows down before being stopped by impervious layers common in the area. The water then follows the layer, through cracks and openings (horizontal movement) before flowing as springs. On the same principle, water that was not consumed by the crops infiltrates and returns to the river bed through the same path.

Deep aquifers

There are some deep aquifers in the Pampas of San Jose de Uzuña, Lagunas Salinas and Arequipa, but their characteristics are not well known. It would seem that the Lagunas Salinas play an important role in the origin of springs downhill. Recently a drop in the lagoon's water level has been observed, meaning that the aquifer might not be recharged as usual, and that the sub-basin of Yarabamba will lack this water in the coming years (PROFODUA, 2004).

Name	Number of springs	Flow (l/s)	Annual volume (m3)
Polobaya	44	404	12,743,698
Quequeña	12	10	315,360
Sogay	6	1.1	34,690
Yarabamba	4	2.36	74,425
Total	66	417.5	13,168,172

Table 9: Inventory of available springs

3. Information collection and data analysis

Chapter 3 presents step by step the collection and processing of the data, from the fieldwork, the different sources of information and the interviews. Sources of information are presented in appendix IV.

3.1. Fieldwork

3.1.1 Goals of the fieldwork

Studies and reports are available concerning the characteristics of the canals in the sub-basin, but the majority of this information is either old or seems inaccurate as different sources present different information of the same canal. Thus a fieldwork was needed to complete and verify these data. The fieldwork revealed itself more complex than in theory, since the sections of the canals are not only variable, but the canals are not well maintained, the structures damaged or water leaking out. This aspect will be discussed further in the report.

Since the fieldwork requires three persons to optimally collect data, two students from the National University (UNSA) participated in the fieldwork. The fieldwork started in April and ended in May, outside of the rainy season when it would have been difficult to conduct a fieldwork, due to high discharges and a considerable load of sediments. Furthermore, the discharges would not have been constant from day to day.

3.1.2 Data collected

In Table 10 are exposed the elements considered during the fieldwork. What should be known is the location and characteristics of the water inlet from the river, the number of structures, the type of structure (derivation structure to laterals), the presence of reservoirs and other structures along the canal. More specifically, the data that have to be collected from the fieldwork are presented in Table 11 along with the device or methodology used to obtain it. The dimensions of the structure and of the cross section are measured separately for clarity purposes. Other data are obtained from reports and studies, or deduced from the fieldwork measurements.

Element	To know
Water inlet	Characteristics
Number of structures	Inventory
Type of structures along the derivation canal (to laterals)	Observations (water loss, condition of the structures, side on the canal)
Reservoir, tanks	Characteristics of water tanks
Other structures (water measurement devices, sifons, proportional divisor, alcantarillas, disipadores de energía,..	

Table 10: Elements to study during the fieldwork

Characteristic or measurement		**Methodology or device**
Location of the measurement point		GPS
Structure	Type	Visual
	Width	Measurement with tape measure
	Material	Visual
	Side (on the canal)	Visual
	Status (open, closed, leak)	Visual
Cross-section	Width at the top	Measurement with tape measure
	Width of water surface	Measurement with tape measure
	Width at the bottom	Measurement with tape measure
	Height	Measurement with tape measure
	Water level	Measurement with ruler
	Height of sediments layer	Measurement with ruler
	Shape	Visual
	Material	Visual
	Manning coefficient	Estimation
Water velocity		Float method
Discharge		Float method

Table 11: Data collected and methodology

The approach used to carry out the fieldwork consists in starting at the beginning of the derivation canal and taking measurements along the length of the canal, at every evident change of section or presence of a lateral gate, all the while recording the number of other structures. At each of these points, the location was recorded with the GPS, the structure photographed and the dimensions measured. The water velocity, obtained with the float method, was determined where the canal was sufficiently strait, without vegetation and with a laminar flow, according to the guidelines. However it was difficult to comply all these restrictions, and the measurements had to be made in places where the situation was the best possible.

Before the beginning of the fieldwork, data have been obtained from studies and inventories and compiled as a support to the investigation. In particular, the length of the canal and the location of structures helped in the canal recognition. After the first days, the investigation method was modified as it was not entirely possible to detect a change of section or slope. Furthermore additional columns were introduced in the data sheet.

Measurement methods and devices that were used during the fieldwork, such as the float method and estimation of the roughness coefficient, are presented in appendix IV.

3.1.3 Processing of fieldwork data

At the end of the fieldwork, the data were analysed and processed in order to be used further in the models, in particular the discharge and slope of the canal.

Discharge calculation

The discharge, measured at different points along the canal, is used to define the boundary condition in the models and to estimate the loss of water through leakage and outflow from the lateral gates. Once the results have been obtained, a correction coefficient is applied. This coefficient depends on the apparent validity of the discharges, for example, if there is no water inflow along the canal, and on the contrary leakage is present, a discharge downstream can not be higher than the discharge upstream. In the final tables, a discharge is defined for each point by interpolating the discharge values where it is known and according to the state of the gate at theses points (open, closed or leaking).

Slope and elevation

Although the GPS gives the elevation of the points ("GPS elevation" in Figure 8), the error is so large that it is very difficult to settle on a correct value. This slope thus has to be estimated in the cases of Quequeña, Sogay and Yarabamba. In the case of Polobaya, the slope data was taken from a report.

To find the slope, the Manning equation is used through the software Manning.exe developed by Adrian Laycock (Laycock, A., 2007). First, the elevation for the initial point is determined, either with Google Earth or with the data of the feasibility study of 1980. Then the length between points is measured in ArcGis, where the GPS locations have been uploaded. The roughness coefficient is estimated with the help of photos and description of the cross sections. With these parameters the slope gradient is obtained, and finally the elevation of each point.

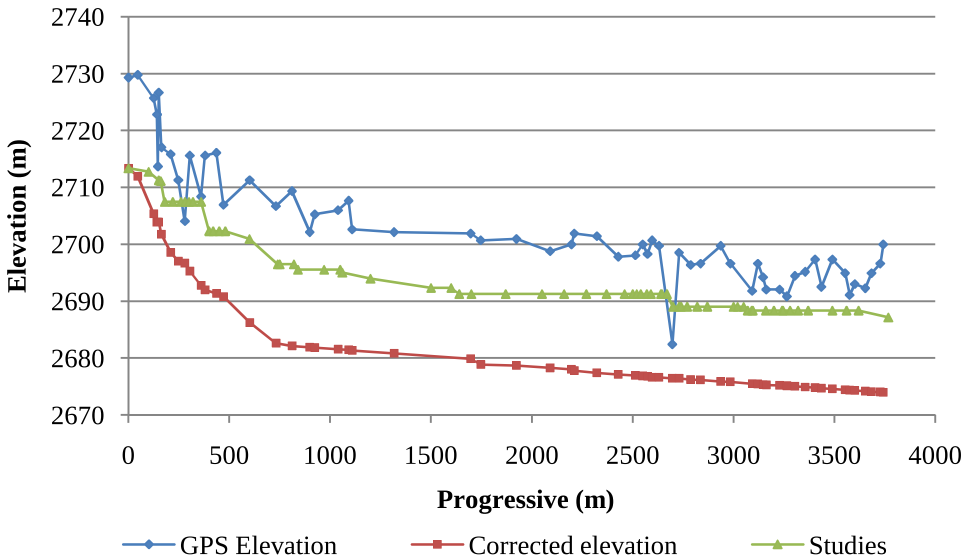


Figure 8: Comparison of the points elevation in Alto Sogay

Figure 8 shows a comparison between the elevation of the points that were inventoried and will be used in the models. In the case of Alto Sogay, the comparison can also be made with the results of the 1980 study, along with the data given by the GPS. In this case, although the corrected elevations appear to be lower than the elevation from the study or the GPS, the slope is still very similar to the slope from the study, which means that this correction is acceptable. Furthermore, the altitude in itself is not vital for the model, since the slope is the factor really taken into account.

3.1.4 Results of the fieldwork

The processing of the data into tables is mentioned in appendix IV. During the fieldwork, many issues concerning the infrastructure have been observed, and are described further in the report. Most of the data gathered were supposed to be used for the modelling of the hydraulic behaviour of the canals. However, due to the large irregularities in the dimensions of the main canals, the errors given by the devices (the GPS in particular) and the fact that very few secondary and even less tertiary canals are lined, it was not possible to obtain accurate data. Taking dimensions of the secondary canals to include them in a model would not have proven relevant, since their cross sections vary too much (Figure 15), without taking into account the considerable losses of water, thus making the discharges measurement complicated. Eventually, only the main canals were modelled (see appendix X).

3.2. Social investigation

3.2.1 Goals of the investigation

Interviews were carried out with the people involved in the system's management. This was done with several objectives:

- To compare the situation changes between 1980 and now and try to estimate them in the future
- To understand better the relation between the farmers and their irrigation system
- To get a real vision of the actual issues faced by the farmers, which are sometimes overlooked in technical studies

3.2.2 Investigation method

The interviews were mostly possible thanks to the help of the municipality of Yarabamba, although others were carried out separately.
The people interviewed include:

- The president of the Junta de Usuarios
- The manager of the Junta de Usuarios
- The agronomic engineer of the municipality of Yarabamba
- The manager of the municipality of Yarabamba
- The mayor of Yarabamba
- The president and farmers of the Comision de Regantes Bajo Yarabamba
- The vice-president and farmers of the Comision de Regantes Sogay
- An engineer who has been part of the study and design of the dam

The question form that was used for the interviews is in appendix IV. It has to be said that the answers to these are subjective since each person has its own opinion on the same matter, and therefore they might not reflect reality. However, it was instructive to compare answers and realize that only such interviews can highlight the real problems of the farmers, and what solutions they think best for themselves.

4. The irrigation system

In chapter 4, the irrigation system is first described for each sector, followed by an explanation of the “mini-fundio” issue through plot statistics in sub-paragraph 4.1. The operation of the system is detailed in sub-paragraph 4.2, along with a description of the infrastructure and the implications on management. In sub-paragraph 4.3, water use in irrigation is presented, more specifically concerning the water rights of each sector, the main irrigation methods used on the fields, and the irrigation efficiency. Finally, issues mentioned during the social investigation are discussed in sub-paragraph 4.4 and the future dam is presented in sub-paragraph 4.5.

4.1. General description

4.1.1 Irrigation sectors

Polobaya

The sector of Polobaya is located in Polobaya, at the confluence of the rivers Poroto and Obaya, and includes the annexes Susihuaya, Agua Buena and Tasata (Figure 9). The main canals are represented by the green lines and secondary canals by the red lines, while blue stands for rivers.

The sector is divided into 5 irrigation systems, each with its own water source:

- Sector Polobaya
- Small irrigation systems
- Susihuaya (river Poroto)
- Agua Buena
- Tasata and Segache

The sector Polobaya consists of the sub-sectors Uzuña, La Rinconada, La Capilla, El Chorro, Buena Vista, Polobaya Chico, Las Haciendas y Las Mercedes. The small irrigation systems use filtrations from Polobaya and water from isolated springs. Susihuaya irrigates with water from the river Poroto, Agua Buena mainly with spring water as well as Tasata and Segache (PROFODUA, 2004).

All these systems have their own reservoirs to store water during the night. The whole sector is affected by an excessive parcelling as well as uncontrolled creation of new cultivable areas. The last point is one of the reasons for the unequal distribution of water between Polobaya and the downstream areas of Yarabamba, Quequeña and Sogay, since the technical plans and maps for the distribution of water do not concord with the reality of the sector. It has to be noted that there is no map of the parcels elaborated by the Junta de Usuarios, and that the irrigated area had to be roughly estimated.

Sogay (Acequia Alta de Yarabamba)

The sector is part of the sector of Yarabamba, located on the left side of the river. It has two main derivation canals, Alto Sogay and Bajo Sogay, with their head gates located respectively at 2700 and 2625 m of altitude. These canals derive water from the river Yarabamba by means of dikes, and receive filtrations from the upper sector of Polobaya. At the level of the reservoir Quichinihuaya, the canal Bajo Sogay becomes the canal Alto Yarabamba which goes through the sector of Yarabamba.

Although the entire sector suffers from a lack of water, the lower area of the canal Bajo Sogay is more subject to water shortages than the higher area.

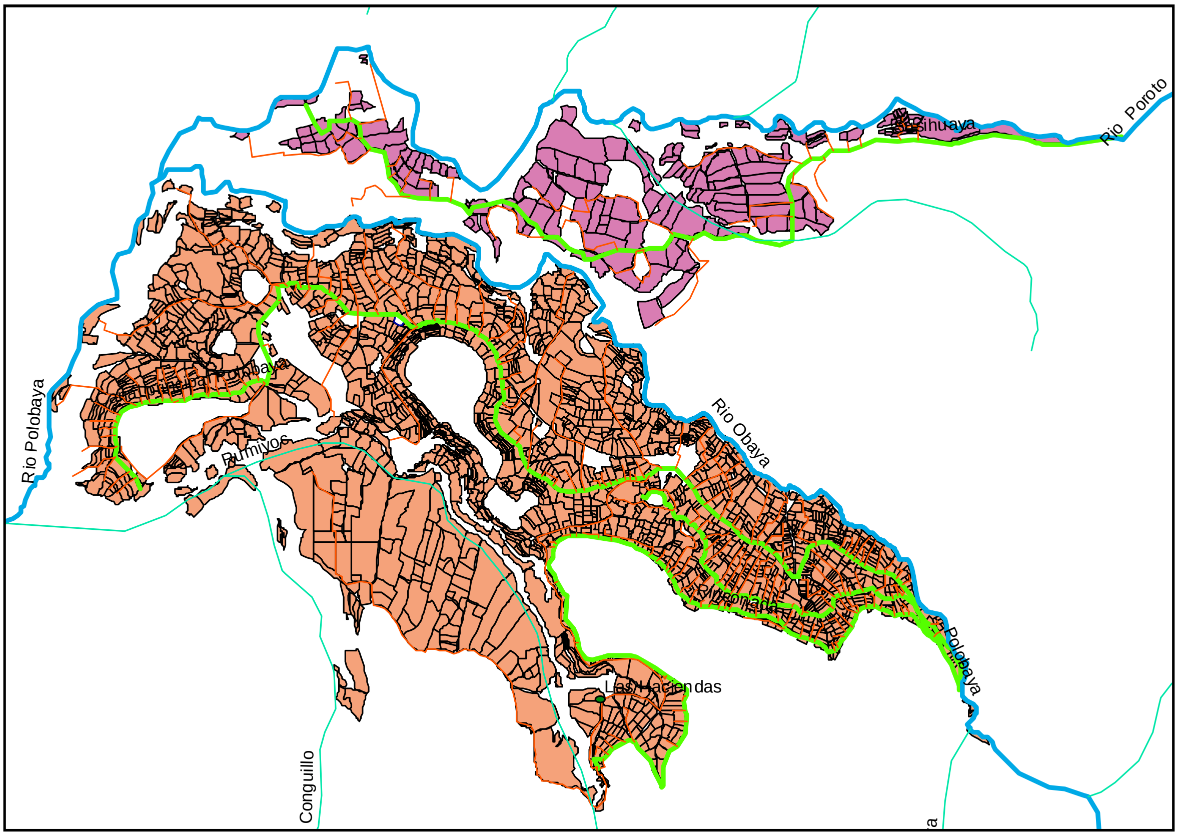


Figure 9: The sectors of Polobaya (bottom, light red) and Susihuaya (top, purple) sectors

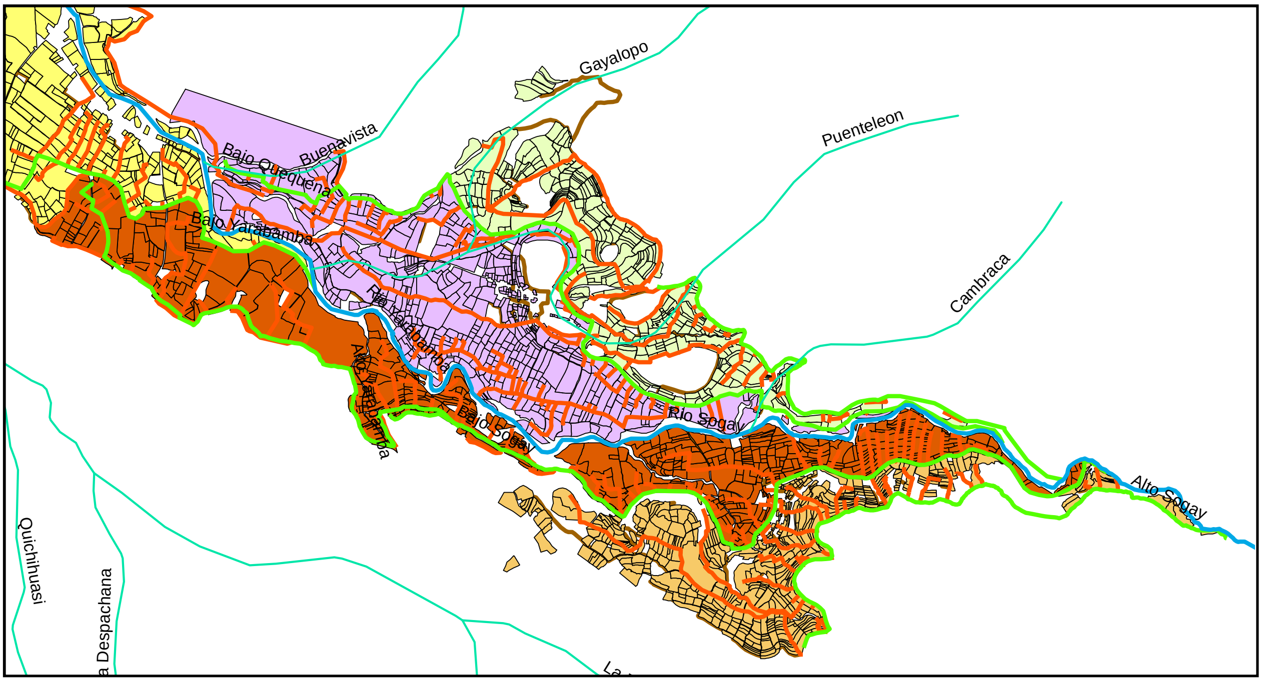


Figure 10: The sectors of Alto Sogay (bottom, light orange), Bajo Sogay (dark orange), Alto Quequeña (top, light green) and Bajo Quequeña (purple)

Sector Quequeña

This sector is located in the municipality of Yarabamba, on the right part of the river of the same name (Figure 10). The sector of Quequeña takes its water from the river Yarabamba and from the filtrations La Isla and Buena Vista. It is divided into 4 irrigation systems, among which the main canals Alto Quequeña and Bajo Quequeña. The others two are small irrigation systems (around 5% of the total irrigated area). The canals are rustic and winding due to the irregular topography. The main canals have their own concrete reservoirs, each located midway, to provide water for the lower areas (PROFODUA, 2004).

Sector de Acequia Baja de Yarabamba

The sector is located in the downstream area of Yarabamba, on the left and right sides of the river (Figure 11). The sector has two main canals, Alto and Bajo Yarabamba, although the canal Alto Yarabamba is the extension of the canal Bajo Sogay and thus does not take its source in this sector. As for the other canals, the canal Bajo Yarabamba takes its source in the river Yarabamba, at 2740m of altitude, the rest of the water coming from filtrations from Bajo Sogay.

Two other irrigation systems are located on the opposite side (right) of the river, each of them being provided by a canal, Alto Chulumpaya and Bajo Chulumpaya. The area of these systems represents around 25% of the total area in the sector. Their water comes from the stream Gallalopo (right side of Yarabamba) in the case of Alto Chulumpaya, and from the river and the springs Buena Vista and Huanaqueros in the case of Bajo Chulumpaya.

In this sector more than in others, many parcels are not irrigated due to the lack of water. Along the canal Bajo Yarabamba, a reservoir stores water during the night.

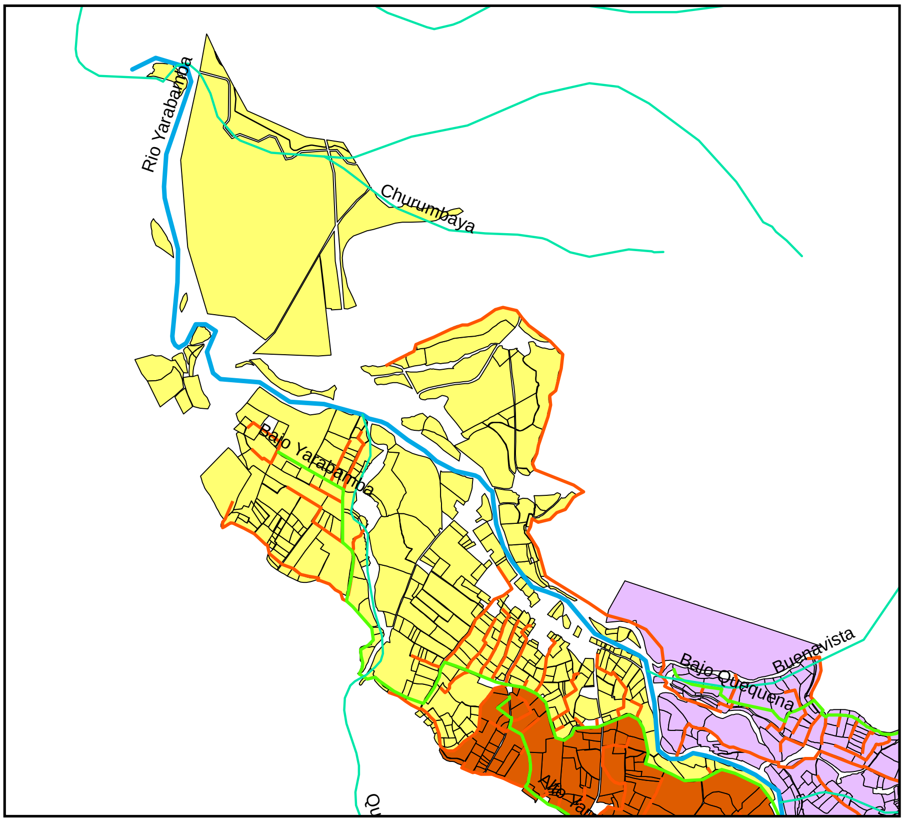


Figure 11: The sector of Bajo Yarabamba (yellow)

4.1.2 Plots statistics and "mini-fundio"

The "minifundio" effect is a problem that has existed for years, not only in the area of research but also in the entire country. "Mini-fundio" stands for "small parcel", where the cultivated area per user is very small. This has several consequences on production. First, global productivity is very low, as each one makes the choice of its own crop, without associating with other farmers. Due to the small size of each parcel, machines are not used since they would not be profitable. For those who have a very small parcel, production is barely enough for self-subsistence. Then, some land owners do not live in the villages and come to their fields occasionally, thus neglecting them while they could be put to better use. Finally, the excessive parceling and number of users make it difficult to set up a cooperative, which would organize the production and sales.

It can be said that the parceling of the land is relatively high, which can be explained by two main reasons: land configuration, and parceling due to inheritance. The first reason can be illustrated by the case of Alto Sogay for example, where the relief is steep, hence the use of andenes which reduces consequently the size of the parcels. In Bajo Yarabamba, the relief is smoother, hence the favorable environment for larger parcels. The second reason is more significant since it can be prevented but still occurs. Every time that a land owner gives the land to his children as heritage, the plot is split in equal parts, rapidly reducing the size of each plot. To remediate to this, some have suggested the creation of a law to, at least, stop the division.

Table 12 summarizes the plot size, the area and number of parcels per user, and the minimum and maximum plot size. The average plot size varies between 0.17 and 0.64 ha, which is rather small and justifies the designation of "mini-fundio". The smallest parcels even amount to 60m².

	Total area (ha)	Number of users	Total number of parcels	Average plot size (ha)	Average number of parcel per user	Area per user (ha/user)	Maximum plot size (ha)	Minimum plot size (ha)
Bajo Yarabamba	128.6	155	285	0.44	1.8	0.83	6.3	0.01
Alto Sogay	96.94	139	401	0.17	2.9	0.70	2.46	0.038
Bajo Sogay	174.6	249	487	0.29	2.0	0.70	11	0.01
Alto Quequeña	92.48	113	305	0.25	2.7	0.82	2.8	0.01
Bajo Quequeña	166.3	208	514	0.29	2.5	0.80	3.55	0.009
Polobaya	476.6	1250	1700	0.21	1.4	0.38	5.5	0.0078
San José de Uzuña	101.2	_	134	0.64	_	_	2.53	0.0061
Totorani	61.1	_	_	_	_	_	_	_
Susihuaya	94.4	112	174	0.54	1.6	0.84	4.15	0.02
Agua Buena	98.9	125	131	0.29	1.0	0.79	1.07	0.021

Table 12: Plots statistics (Ministerio de agricultura)

Table 13 indicates that between 1980 and 2005, the number of plots has increased dramatically in all the sectors. Since the total cultivable area has decreased in Quequeña and Yarabamba, due to abandonment of lands, this can be explained by the figures in Table 14, where it can be seen that the average plot area has decreased by more than two thirds. In Polobaya the total cultivable area has increased but at the same time the average plot size has also decreased.

	Quequeña		Yarabamba		Polobaya	
	1980	2005	1980	2005	1980	2005
Less than 3.5	266	818	450	1168	543	2133
3.6 to 5	5	1	8	2	7	5
5 to 10	5	_	7	2	6	1
10.1 to 20	_	_	2	1	1	_
20.1 to 50	_	_	_	_	1	_

Table 13: Number of plots in 1980 and 2005

	Quequeña	Yarabamba	Polobaya
Ha/plot 1980	1.1	1	0.9
Ha/plot 2005	0.27	0.3	0.42
Total area 1980 (ha)	310	470	520
Total area 2005 (ha)	258	400	832

Table 14: Average plot size and total cultivable area in 1980 and 2005 (Ministerio de agricultura)

4.2. Water distribution

4.2.1 System operation

The water distribution is generally based on water availability and crops requirements. In this case, since there is no defined schedule for the irrigation turns. Farmers use water when it is available, based on routine and habit. The farmers along a same canal know each other well and there are usually no conflicts concerning the water distribution pattern.

Types of crops

In all the sectors, the main crop that is cultivated is alfalfa (around 60%), especially in Polobaya where the climate is harsher. The main reason for this choice is the lack of water: the alfalfa, which is a flowering plant used as forage, is resistant to water stress such as encountered in the sub-basin. It grows year round, but is a low-value crop as the main products farmers can obtain are indirect: milk and meat. Other plants are grown, such as onion, when water availability allows it. It has to be noted that most of these crops are used for self-consumption. Details on the type of crops and the crops schedules can be found in appendix V.

Distribution

The water is derived from the main river by way of stone dikes, or sometimes a concrete dike (see appendix XII).

Figure 12: Head gate in Bajo Sogay

Figure 13: Dike of concrete in Bajo Yarabamba

The water is then derived to secondary canals by means of gates. Along this canal, water is then distributed to tertiary canals or directly to parcels. When it is the turn of a farmer, the main or secondary canal is closed and all the water is derived for a certain amount of time (water turn).

Figure 14: Lateral gates

These gates can be made of steel, or of stone and loam in most of the cases. During a water turn, the time during which the gate is open is based on the surface of land. In most of the sectors, farmers are granted 1 hour per topo (1/3 of hectare), although this amount varies depending on the location of the farmer along the canal. To take losses into account, the farmers near the head of the canal are allowed around 50 min, while those downstream might have up to 1h30 (Table 15).

Water turns

Table 15 gives the irrigation frequency and the time allocated per "topo" in each sector. Frequency of irrigation varies between 20 and 32 days, which is low and restricts the possibilities to grow water-demanding crops. It has been heard from the farmers that a minimum frequency should be around every 15 days, with an optimal frequency of 8 days.

	Frequency (days)	Time per "topo"
Bajo Yarabamba	20	55 min - 1h25
Alto Sogay	23	55min - 1h30
Bajo Sogay	23	1h
Alto Quequeña	24	1h20
Bajo Quequeña	32	1h20
Polobaya	20	_

Table 15: Irrigation frequency per sector

The discharge available is typically between 70l/s downstream and 300 l/s upstream, as Table 16 shows.

District	Measured discharge April 2009 (m3/s)
Polobaya	0.27
Alto Sogay	0.07
Bajo Sogay	0.076
Alto Quequeña	0.044
Bajo Quequeña	0.085
Bajo Yarabamba	0.065

Table 16: Measured discharge in each sector

4.2.2 Sector infrastructure

Table 17 summarizes the characteristics of the main canals, as well as the total length of the canals found in the system. The difference between the design discharge and the current discharge is substantial, which means that the canal might be overdesigned. However, it has been seen on the field that during the rainy season, most of the main canals are nearing overflow in some places, due to the accumulation of rocks and sediments.

Sector	Length derivation canal (m)	Design discharge (m3/s)	Current discharge (m3/s)	Total canal length (m)
Alto Sogay	3,767	0.157	0.05	20,310
Bajo Sogay	5,116	0.19	0.15	29,519
Alto Quequeña	3,432	0.18	0.06	20,370
Bajo Quequeña	6,344	0.18	0.06	29,497
Bajo Yarabamba	4,202	_	0.085	22,212
Polobaya	6,500	_	_	149,000

Table 17: Summary of the characteristics of the derivation canals in each sector (JJUU)

Each sector has its own concrete reservoir, Polobaya having three since it has the largest irrigated area (Table 18). Most of the time these reservoirs are located midway of the main canal, and are filled during the night, from 6 PM to 6 AM, to allow an extra discharge during the day.

Sector	Number of reservoirs	Capacity (m3)
Alto Sogay	1	2100
Bajo Sogay	1	2600
Alto Quequeña	1	2500
Bajo Quequeña	1	2500
Bajo Yarabamba	1	3000
Polobaya	3	5000, 5000 and 2500 m^3

Table 18: Number of reservoirs per sector

4.2.3 Condition of water structures and implications on water management

This part focuses on the condition of the infrastructure and its impact on water management and operational flexibility.

State of the canals

First of all, it has to be noted that a very small fraction of all the canals are actually lined, most of the time the main canals and some first orders canals. While the main canals are usually in concrete, most of the other canals are simply dug in the soil, covered by grass or small rocks, occasioning high water losses by infiltration. In Bajo Quequeña, the main canal even consists of the bed of a natural stream at one point.

During some periods of the year, the canals are full of weeds, plants, soil and small stones or even rocks, especially after the rainy season. During that same season, the water overflows the top of the canal in some places, flooding the area around it.

Figure 15: Main and secondary canals in Bajo Yarabamba

State of the structures

The lateral gates are mostly in a bad shape, as they are simply consist of sand or soil, and a large stone. Some gate are steel gates, generally rather old, but they are in very small numbers. Some lateral off takes were made for steel gates, but they have been stolen and replaced by stone and loam. These "gates" allow for a low flexibility and high water losses.

There is at least one large concrete reservoir in each sector, but in general use of small reservoirs on field has not been observed. It seems that only the wealthiest farmers have one. The capacity of the large reservoir is limited, especially during the rainy season, when water could be stored and used even after the beginning of the dry season.

Finally, there are measuring structures, but mainly at the head of the canal, in order to monitor the head flow. However, the rest of the canal is not equipped with any structure, which could have given a more accurate idea of the real discharge, taking losses into account. The measures given by these structures are rather inaccurate, since they are usually covered with pebbles, or algae, changing the roughness coefficient.

Figure 16: Reservoir in Alto Sogay

Operational flexibility

Due to the previously mentioned facts (poor flow measurement, deficiency of operation structures, lack of reservoirs and on-field storage), the flexibility in scheduling water turns is low. Flow-rate control and measurement are essential for a fair water delivery, as the operator can adjust the quantities delivered to each farmer. This illustrates the fact that reality never matches theory, as structures get worn, can be damaged, and scheduling itself can be affected by the stakeholders' behavior, by lack of maintenance, funds, or appropriation of water by upstream users (Goussard, J., 1996).

4.3. Water use in irrigation

4.3.1 Water rights

Water rights in the different sectors are presented in Table 19, which summarizes the annual volume assigned to each sector, based on the required volume per hectare and the licensed area, although this does not represent accurately the actual cultivated area. The tables from which these data were extracted are in appendix VI.

Sector	Licensed area (ha)	Assigned volume per ha (m3/ha)	Total annual assigned volume (m3)	Real water allocation (m3/ha)
Bajo Yarabamba	128.61	10,053	1,292,916	7,253
Alto Sogay	96.94	12,891	1,249,654	7,253
Bajo Sogay	174.6	12,891	2,250,769	7,253
Alto Quequeña	92.48	11,700	1,082,016	10,092
Bajo Quequeña	166.27	11,700	1,945,359	10,092
Polobaya	476.63	12,000	5,719,560	18,291
San José de Uzuña	101.21	12,000	1,214,520	9,145
Susihuaya	94.42	11,000	1,038,620	12,930
Agua Buena	98.98	12,000	1,187,760	12,930
Totorani	61.18	12,000	734,160	9,145

Table 19: Assigned annual volumes (m3) in each irrigation system - Source (PROFODUA, 2004)

It can be seen from the real water allocation, measured during a fieldwork, that the distribution is far from fair. While Polobaya is assigned only 12,000 m3/ha, it actually takes more than 18,000 m3/ha, depriving most of all the sectors Bajo Yarabamba, Alto Sogay and Bajo Sogay.This can be explained by the way water distribution is done at the diversion structure of Susihuaya, in the river Polobaya (Figure 17), which derives water for the main irrigation system of Polobaya. The off take to the main canal of Polobaya is on the left side, leaving the water filtrating from the right side to the downstream sectors. The available discharge in the river amounts to 342 l/s at the divider, and this amount is distributed as 75% for Polobaya and 25% for the downstream sectors, via a derivation structure consisting in a dike made of stones (*Estudio definitivo de la presa San José de Uzuna*, 2000). However, downstream sectors benefit from filtrations coming from unused water in Polobaya which accounts for the low discharge available. This return water would amount to 10% of the derived water in Polobaya according to an old study (*Estudio de factibilidad - Volume I*, 1980), but the exact quantity has not been investigated.

Figure 17: The divider in Polobaya

4.3.2 Irrigation methods

Land preparation

A typical system of land preparation in Peru is the structure called “andenes”(Figure 18). These consist in terraces built on the mountain side, typically coming with a stone wall, and filled with fertile soil. This is a logic adaptation to the landscape, which, over 500m of altitude in the Andes, is made of deep and narrow valleys. To expand the cultivable areas, ancient Peruvian civilizations had to adapt to the side of the mountains and thus these “suspended gardens” follow the natural curve of the landscape, at the same time delaying erosion. (Andén (agricultura) - Wikipedia). Furthermore, the production is improved thanks to the creation of a micro-climate, and the implementation of an efficient irrigation system is possible. Terraces are very similar to andenes, although they do not require the use of a stone wall to retain the soil (Gonzales de Olarte, E. and Trivelli, C., p. 18).

Andenes in Alto Sogay

Andenes in the Sacred Valley

Figure 18: Typical andenes landscapes

Application methods

Two main types of application methods are used in the entire Oriental sub-basin, and thus in the Yarabamba sub-basin: furrow and border irrigation. Furrow irrigation is the most common method, and is applied to maize, garlic, potato, etc., but some crops require a different type of application method, such as alfalfa, barley and oats (pasture crops).

Furrow irrigation:

Furrows consist of small parallel channels separated by ridges, on top of which crops are grown (Figure 19). Most of all this method is adapted for crops that would be damaged if their stem was under water. (FAO Irrigation methods, chap. 3) Furthermore, water runs more quickly through the furrow than another method.

Figure 19: Furrow irrigation

Border irrigation:

This consists in long, separated strips of land (Figure 20). The water flows down the field, and is drained at the lower part, at the end of the plot. This method is more adapted to crops that grown closely, since it is easier to harvest them. In general borders require more precision than furrows (FAO Irrigation methods, chap. 4). This technique is well adapted to crops such as alfalfa, maize, etc.

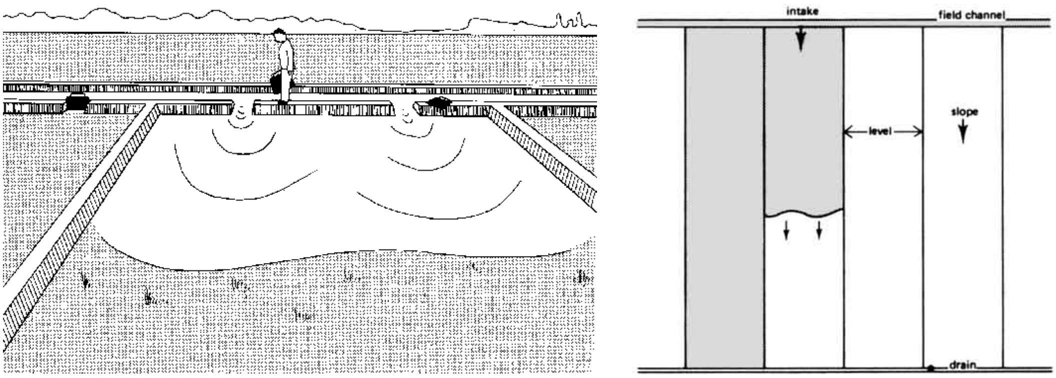


Figure 20: Border irrigation (source: FAO)

4.3.3 Irrigation efficiency

Irrigation efficiency is dependent on factors such as the methods and systems of irrigation, hydraulic characteristics, type of water delivery at the field level, soil type and the farmers themselves. Although various definitions exist, in our case the efficiency is based on three partial efficiencies:

- conveyance efficiency (main system conveyance)
- distribution efficiency (related to the distribution structures and tertiary level canals)
- Field application efficiency (water delivered to field used by the crop).

In the report from PROFODUA, each efficiency coefficient was estimated on representative parts of the system in the Oriental basin, to finally be multiplied, which gives the final irrigation efficiency coefficient. It is given as:

[Irrigation efficiency] = [conveyance efficiency] x [distribution efficiency] x [application efficiency]

The results are summarized below:

Conveyance efficiency:

- Unlined canals: between 73 and 78%
- Lined canals: between 88 and 97%

The average is thus 85%.

Distribution efficiency:

This efficiency coefficient was estimated at 88%, being given the rudimentary aspect of the lower levels canals and distribution structures.

Application efficiency:

Crops such as maize, garlic, potato are cultivated using furrow irrigation, while border irrigation is used for alfalfa, barley and oats. Taking into account the small size of the plots, the good gradient of the ground, the frequency of maintenance and irrigation and the good drainage conditions, the application efficiency is estimated at 60%.

The irrigation coefficient is therefore around 45%, which means that for a given volume of water 45% will be effectively used by the plant for its growth. The required water volume for each sector has to be estimated according to that coefficient. It has to be noted that the efficiency coefficient in the Oriental sub-basin (and thus in the Yarabamba sub-basin) is among the highest as the other coefficients in the basin vary between 37 and 48% (PROFODUA, 2004, p. 142).

4.4. Known social and technical issues

The issues encountered by each sector as well as their organization are generally alike, although they differ in, for example, relationships to the municipality, availability of funds, etc. Table 20 summarizes most of the issues that have been discussed during the interviews with the different parties. The mini-fundio effect, the lack of water and the deficient infrastructure have been mentioned most of the time, although deeper issues such as the lack of interest for the basin from the government and the lack of communication between the different organizations have been brought up. The results of this interview are presented in more details in appendix VII.

Stakeholders	Issues	Reasons	Possible solutions
Downstream sectors	The dam might not be sufficient to remediate the lack of water	Climate change and illegal water intakes in Polobaya	Build a canal directly from the dam
Junta de Usuarios	Absence of a defined "plan de cultivo" in most of the sectors		
Junta de Usuarios	Farmers do not pay the water tax	Some farmers cannot pay, others refuse to pay in protest against the government	
Farmers	Mini fundio effect	Division of the land at inheritance	Pass a law to prevent the division, or even regroup the parcels
Farmers	Farmers have to abandon lands to be able to grow other crops than alfalfa	Lack of water, low irrigation frequency	
Farmers	Some people live in the city and don't cultivate their land	Lack of interest to the small size of parcels	Sell these lands to other farmers or create cooperatives
Farmers	Polobaya illegally takes most of the water for land extension	Authorities are weak and do not have interests in the sub-basin	
Farmers	Water taxes are high but no investments are made to improve irrigation	Weak and corrupt authorities	
Farmers	Deficient irrigation infrastructure	Absence of help from the government	Some farmers want to ask for credits
Farmers	Funds (canon minero) are badly used by the municipality	Lack of transparency, the municipality ignores the needs of the farmers	
Farmers	Lack of information on dam and new water law	Lack of communication between the Junta, Comisiones de Regantes, ATDR and the government	

Table 20: Main concerns of the stakeholders

A study of the evolution of the situation between the year 1980s and nowadays is also presented in appendix VIII.

4.5. The "Yanaorco – Paltaorco" dam

The project of Yanaorco-Paltaorco dates back to 1978, when the first studies were made. At the time, most of the present issues already existed:

- Lack of water during the months of April to November leading to low yields and abandon of cultivable land
- Lack of storage and regulation structures
- Deficient infrastructure

The aim of the project is eventually to increase the agricultural production and by extent the living standards in Polobaya, Yarabamba and Quequeña, through the improvement of irrigation. Initially, it was thought that the project would not only help to stabilize the current water offer compared to demand, but also to retrieve abandoned land (around 200 ha). However, it has been show later that it can only allow for the improvement of the currently irrigated lands, with a stable flow of at least 0.62 l/s/ha (see appendix IX). For comparison, the current allocated water flows are shown in Table 21.

	Water flow allocated per hectare (l/s/ha)
Polobaya	0.58
San José	0.29
Susihuaya	0.41
Alto Sogay	0.23
Alto Quequeña	0.32
Bajo Sogay	0.23
Bajo Quequeña	0.32
Bajo Yarabamba	0.23

Table 21: Water flow allocated per unit of area

For that purpose the dam, which would have a capacity of 10 million m3 and a height of 26m, would store the water collected during the rainy season to be used during the dry season (see appendix IX). Instead of a peak flow during the rains and a low during the dry season, the flow would be regulated over the year, with a more regular discharge. The storage area would be filled by water from the melted snows of the Pichu Pichu, the various streams and springs upstream of San José de Uzuña (Figure 2).

The total cost of the project was estimated at 18 million of Nuevo Soles (around 4 million Euros), financed by various organizations (see appendix IX). The profitability of the project is sustained by the reconversion of the traditional agriculture into a more modern one, with high-value crops and low water consumption, which will eventually require efficient irrigation systems (CAMP S.R.L., 2008).

The operation of the dam will be at the charge of the Junta de Usuarios of the Zona No Regulada, with the supervision of ATDR. With the changes due to the water law, it is probable that the organizations in charge will be the Autoridad de Agua (Water authority). The personnel in charge at the dam will include a chef engineer, an operation technician and three guards. The Regional government and ministry of Agriculture will supervise and check the proper operation by the Junta.

To this date, it seems that the distribution of water to the sectors has not been determined yet. During the last visit, the construction was just at its beginning, although the derivation canal to the sub-basin Mollebaya had been built, but it is not yet known whether or not it will be in service.

5. Modeling with WEAP

Chapter 5 deals with the modeling in WEAP. It has to be noted that the modeling with SOBEK is discussed in appendix X. The modeling strategy is explained in paragraph 5.1, followed by an explanation of the data of the current situation in paragraph 5.2. The scenarios are then described in paragraph 5.3 and evaluated, with the results commented in paragraph 5.4. The table of necessary data for WEAP is presented in Appendix XI.

5.1. Modeling strategy and assumptions

The aim of the model is to understand how the current situation can be improved through the construction of the dam, as well as assessing the impact of land extension and increase in crops with a higher water consumption. Improvement of the irrigation efficiency is also considered, combined with the previous factors, before water availability for each sector is evaluated in terms of allocated water volumes.

First the water basin is simplified down to the basic schematics, featuring only the main rivers, for which data are available:

- Poroto
- Totorani
- Ospicio
- Polobaya
- Yarabamba

The river Ospicio is included in this model since the dam will be built at its convergence with the river Totorani. Upstream rivers flow into each other at the convergence point, which means that the discharges are set only at the heads of the river branches, in Totorani, Ospicio and Poroto.

Irrigation sectors are modeled as demand sites along the rivers (Figure 21) and feature only the main sectors, with Susihuaya and Agua Buena, and San José de Uzuña and Totorani, respectively grouped. The annual and monthly water demand is known for these sectors, but in order to allow varying parameters in the scenarios, the demand of water is calculated in terms of cultivable area and water demand per unit of cultivated area. It is supposed that water demand for other uses (domestic or industrial) is inexistent, which is relevant since there are no industries in the sub-basin and the domestic water consumption is minimal.

In the case of the scenario which includes the dam, a reservoir and a diversion are added to the previous model.

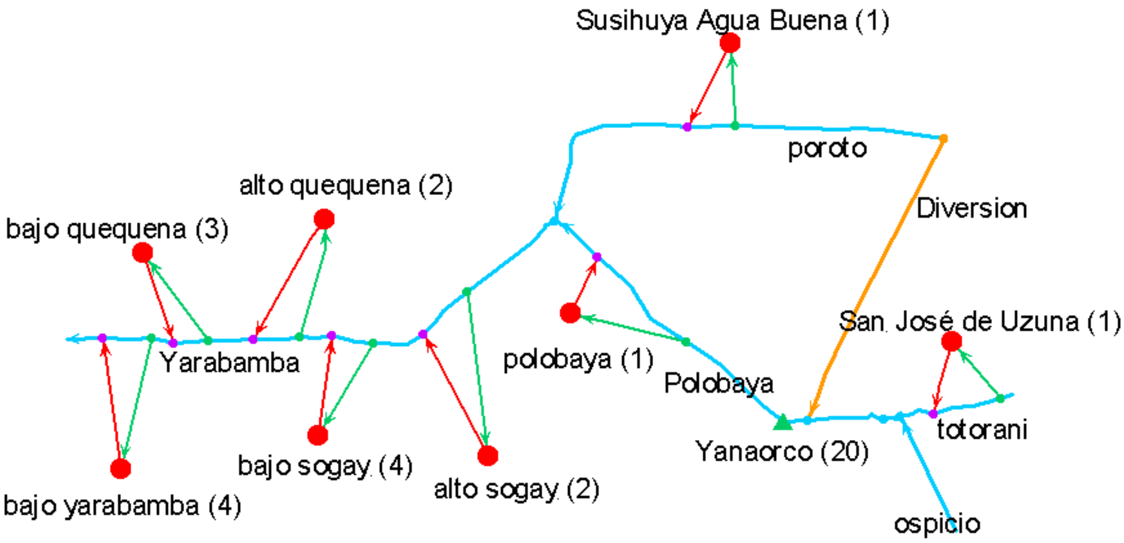


Figure 21: WEAP model of the current situation

5.2. Modeling of the current situation

Rivers

The discharges available are included in appendix XI. Since there are monthly discharges for only three rivers (Totorani, Polobaya and Yarabamba), the discharges for the other two, Ospicio and Poroto, had to be deduced.

Assuming that no water flows in or out of the river apart from the demand sites, we can make a balance in order to find the discharges of the rivers Ospicio and Poroto. Based on Figure 21, we have:

Poroto Upstream= Yarabamba upstream – Polobaya upstream + Demand Polobaya + Demand Susihuaya

Ospicio upstream = Polobaya upstream + Demand San José Uzuña – Totorani upstream

The water demand is based on the required irrigation allocation, show in Table 23. Table 22 gives the monthly river discharges, known or estimated. Only the discharges corresponding to Poroto upstream, Ospicio upstream and Totorani upstream are added to the model, since they are considered as springs. The discharges in the confluents, the rivers Polobaya and Yarabamba, are deduced by the software based on the calculated discharges of the influent.

In the case of the scenarios with dam, the diversion from the river Poroto to the dam is calculated as the difference between the discharge of the river Poroto and the demand in Susihuaya, only during the rainy season (as “excess” water).

	River discharge (m3/s)											
River	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand San José	0.071	0.060	0.062	0.073	0.073	0.067	0.067	0.078	0.080	0.106	0.113	0.106
Demand Susihuaya	0.075	0.063	0.065	0.078	0.075	0.071	0.071	0.08	0.085	0.108	0.118	0.114
Demand Polobaya	0.209	0.173	0.184	0.218	0.211	0.198	0.2	0.222	0.236	0.307	0.329	0.313
Polobaya upstream	0.41	0.44	0.41	0.28	0.22	0.24	0.28	0.28	0.26	0.26	0.3	0.31
Yarabamba upstream	0.31	0.35	0.31	0.23	0.19	0.19	0.25	0.23	0.24	0.24	0.24	0.28
Totorani upstream	0.36	0.39	0.37	0.25	0.2	0.21	0.25	0.25	0.23	0.22	0.26	0.27
Poroto upstream	0.184	0.146	0.149	0.246	0.256	0.219	0.241	0.252	0.301	0.395	0.387	0.397
Ospicio upstream	0.12	0.11	0.10	0.10	0.09	0.10	0.10	0.11	0.11	0.15	0.15	0.15
Diversion Poroto	0.11	0.08	0.08	0.17	0	0	0	0	0	0	0	0

Table 22: WEAP model – rivers discharges

Demand sites

The water demand per site is calculated with the total area (in hectares) and the annual water demand per unit of area (m3/ha) as well as the together with the monthly variations (Table 23). This information is given in appendix XI. It has to be noted that the total area is taken instead of the actual cultivated area, since we wish to evaluate the current situation and illustrate the fact that lands are abandoned for lack of water.

Sites were given a priority according to their position in the scheme (higher priority for upstream sites). It is also supposed that 10% of the flow derived for each sector returns to the river, as filtrations (*Estudio de factibilidad - Volume I*, 1980).

	Required water allocation	Total area	Required water allocation	Priority
	l/s/ha	ha	m3/ha	
Bajo Yarabamba	0.482	129	15,203	4
Alto Sogay	0.485	97	15,290	2
Bajo Sogay	0.481	175	15,172	4
Alto Quequeña	0.476	92	15,004	2
Bajo Quequeña	0.475	166	14,984	3
Polobaya	0.491	477	15,483	1
San José de Uzuña - Totorani	0.4985	162	15,726	1
Susihuaya - Agua Buena	0.433	193	13,651	1

Table 23: WEAP model – total area and water demand per unit of area

5.3. Scenarios

Scenarios description

Scenarios are representative of how a system might evolve in the future in a particular setting, for an assessment of this situation. The information associated to the Current Accounts is the starting point of all the scenarios.

Several parameters are evaluated, among them:

- The presence of the dam and the diversion from the river Poroto
- Drier years, due to climate change (Water year method)
- Increase in cultivated area
- Increase in water demanding crops (higher water demand per ha)
- Increase in irrigation efficiency (more cultivated land with the same amount of water)

	Parameter				
Scenario	Presence of the dam	Climate change - drier years	Increase in cultivated area	Increase in water demanding crops	Increase in irrigation efficiency
1		X			
2		X			X
3		X	X		X
4	X	X			
5	X	X	X	X	
6	X	X		X	
7	X	X	X	X	X
8	X	X			X

Table 24: WEAP model – Scenarios and their parameters

Table 24 summarizes the parameters that are included in each scenario. Scenario 1 illustrates the current situation in a context of climate change, where rainfall is scarcer and river discharges lower. In scenario 2 the irrigation efficiency is increased, as well as in scenario 3 where the cultivated area is also increased. Scenario 4 introduces the dam in the same context of climate change, to observe the potential improvements. In scenario 5 there is an increase in cultivated area as well as in water demanding crops. Scenario 6 only includes an increase in water demanding crops. Finally, in scenario 7 the dam is integrated along with an increase in cultivated area, water demanding crops and irrigation efficiency, while scenario 8 is a test scenario to study the influence of the increase in irrigation efficiency.

The choice to keep the climate change parameter in all the scenarios is due to the fact that this would be the worst case scenario, and in the opposite situation, the situation can only be better. Furthermore, it has been observed on location that glaciers are melting and rivers have been running drier these past years.

The scenarios are run over 15 years, from 2010 to 2025, with 2009 the year of the current account.

Dam

The evaporation for the surface of the storage area is taken from the climatic data of Polobaya. The structure has a maximum height of 26m and a storage capacity of 10 million cubic meters.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net Evaporation (mm) Polobaya	98	64	93.9	154	174	179	186	199	215	222	214	173

Table 25: WEAP model – Net evaporation of the reservoir's surface

Climate change

Climate change in our case is characterized by drier years. The current account is defined as "normal", and the other years in the scenario assigned a random pattern (Table 26). The definition varies during the year, taking into account the dry and rainy seasons.

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Dry	normal	wet	dry	dry	normal	dry	very dry	normal	wet	normal	very wet	dry	very dry	dry	normal

Table 26: WEAP model – Water year method pattern

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Very dry	0.6	0.6	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7
Dry	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8
Normal	1	1	1	1	1	1	1	1	1	1	1	1
Wet	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2
Very wet	1.6	1.6	1.6	1.3	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.3

Table 27: WEAP model – Water year method definition

Increase in cultivated area

The total physical area is taken as the maximum area usable for agriculture, meaning the sum of the currently cultivated and abandoned lands. In this scenario we will assume that the cultivable area increases by 10% in each sector, and 20% in Polobaya, as this sector already has a tendency in extending its cultivable area. This increase is linear, which means that the total area is reached in 2025.

	Total area	Increase	New total area
	ha	%	ha
Bajo Yarabamba	129	10	141
Alto Sogay	97	10	107
Bajo Sogay	175	10	192
Alto Quequeña	92	10	102
Bajo Quequeña	166	10	183
Polobaya	477	20	572
San José de Uzuña - Totorani	162	10	179
Susihuaya - Agua Buena	193	10	213
Total	1298	_	1475

Table 28: WEAP model – Increase in cultivated area

Increase in water demanding crops

The increase in water demanding crop is based on the coefficient of 1.03. This coefficient was found for the sector of Bajo Yarabamba, for a land increase in alfalfa of 30 ha.

	Required water allocation	Coefficient - water demanding crops	Water allocation - water demanding crops
	m3/ha		m3/ha
Bajo Yarabamba	15,200	1.03	15,656
Alto Sogay	15,295	1.03	15,754
Bajo Sogay	15,169	1.03	15,624
Alto Quequeña	15,011	1.03	15,461
Bajo Quequeña	14,980	1.03	15,429
Polobaya	15,484	1.03	15,949
San José de Uzuña - Totorani	15,721	1.03	16,192
Susihuaya - Agua Buena	13,655	1.03	14,065

Table 29: WEAP model – Increase in water demanding crops

Increase in irrigation efficiency

Irrigation efficiency is based on conveyance efficiency, distribution efficiency and application efficiency, which for the current system, is respectively 0.85, 0.88 and 0.6, giving a global efficiency of 0.45.

Assuming improvements in conveyance, achieved for example by lining the main canals, its efficiency changes from 0.85 to 0.9. Similarly, the distribution is improved through repair and upgrading of the canals of lower levels and their hydraulic structures. The distribution efficiency thus is adjusted from 0.88 to 0.9. Finally, the application efficiency improves from 0.6 to 0.75 through modification in water management at field level, such as irrigation timing, more frequent water turns according to the crops' needs. The new irrigation coefficient is thus 0.6, which is applied in all the sectors.

	Required water allocation	Current irrigation efficiency	Improved irrigation efficiency	New water requirement	New water demand
	l/s/ha	_	_	l/s/ha	m3/ha
Bajo Yarabamba	0.482	0.45	0.6	0.362	11,400
Alto Sogay	0.485	0.45	0.6	0.364	11,471
Bajo Sogay	0.481	0.45	0.6	0.361	11,377
Alto Quequeña	0.476	0.45	0.6	0.357	11,258
Bajo Quequeña	0.475	0.45	0.6	0.356	11,235
Polobaya	0.491	0.45	0.6	0.368	11,613
San José de Uzuña - Totorani	0.4985	0.45	0.6	0.374	11,791
Susihuaya - Agua Buena	0.433	0.45	0.6	0.325	10,241

Table 30: WEAP scenario – Increase in irrigation efficiency

5.4. Results

Calibration of the first model

The results of the first model were compared to the data entered in the model and the effective supplied volume according to the tables in appendix VI. Priorities were tested this way and, since the results were coherent, scenarios were then implemented.

Comparison of the unmet demand in each sector

The unmet demand is defined as:

Required water volume – received water volume

From the current situation, it can be seen that during some months, there is an unmet demand in some sectors, while in others, when water is more abundant, the water required is supplied but water goes out of the system, hence the justification of the dam. Table 31 presents the annual volumes of water unused by any of the sectors in the sub-basin. It has to be noted that the amount of annual unused water is higher in scenarios 2 and 3 since both scenarios introduce an improvement in the irrigation efficiency, thus a lower water consumption rate per sector.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Sum
Scenario 1	1	0.1	1	3.3	0.1	0.1	1	0.1	0	1	3.3	1	5.7	0.1	0	0.1	1	19.1
Scenario 2	1	2.3	5.2	8.2	2.3	2.3	5.2	2.3	0.4	5.2	8.2	5.2	10.5	2.3	0.4	2.3	5.2	68.5
Scenario 3	1	2.2	5	7.8	1.8	1.7	4.5	1.6	0	4.1	6.9	3.8	9	1.1	0	0.9	3.2	54.6

Table 31: Streamflow (million m3) downstream Bajo Yarabamba for scenarios 1 to 3

Figure 22 to Figure 24 represent the annual unmet demand for the sectors which do not get the required amount of water. The variation from year to year is similar for the sectors of Bajo Yarabamba, and Bajo Sogay, and equal to zero in the sectors of Alto Sogay and Alto Quequeña, thus the graphs are not all represented here. The sectors San José de Uzuña and Susihuaya are not included since they are not affected by water shortage. Scenarios 4 and 7 do not appear since there is no unmet demand in any of the sectors.

The variations from year to year are due to the variations in the water year method: the unmet demand is naturally higher when the year is drier (Table 26). In the case of scenario 5, the unmet demand increases steadily over the years: this is due to the annual increase in cultivated area (see Table 24).

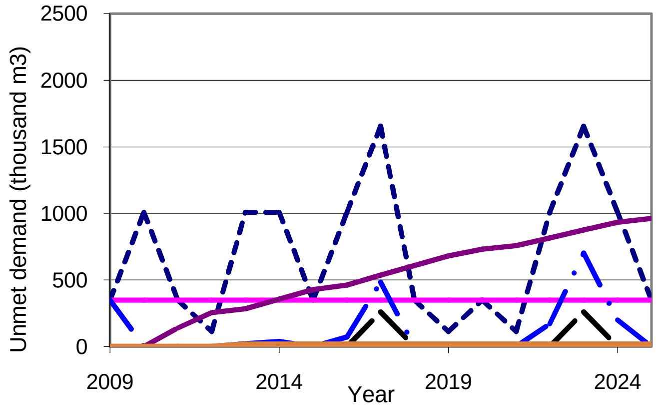


Figure 22: WEAP – unmet demand for Bajo Yarabamba

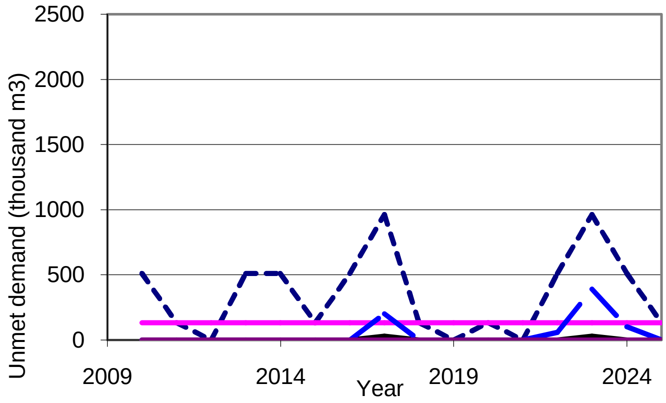


Figure 23: WEAP – unmet demand for Polobaya

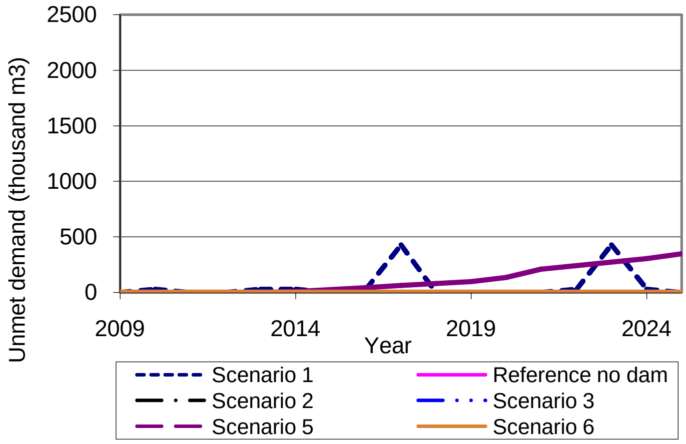


Figure 24: WEAP – unmet demand for Bajo Quequeña

It is clear that the case for which the unmet demand is the highest is scenario 1, which is logical since there are no improvements yet. In this case, it has been seen from Table 31 that between 0.1 and 5.7 million of cubic meters of water are lost annually during the rainy season, while this water could be used to meet the demand during dry seasons.

Unmet demand during dry season

Figure 25 illustrates water shortages that occur during the year in the case of scenario 1. It is clear that during the rainy season (January to March), water shortages are low. Peaks are observed during the dry season (April to December) and especially from September to December. This is due to the water demand parameter which is higher at the end of the year, as a result of the calculation method for crops requirements (see appendix VI). Practically, this illustrates the fact that some water-demanding crops such as onions, potatoes (see appendix V) are grown during that period.

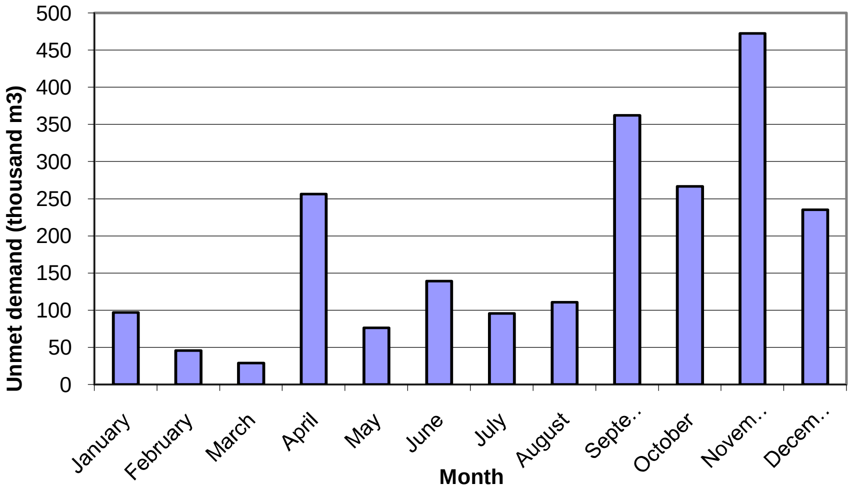


Figure 25: WEAP - Monthly average of unmet demand (scenario 1)

Storage volume

Figure 26 compares the water volume in the reservoir per year, for the different scenarios. The volume in scenario 4, 5 and 6 presents a saw tooth variation: the reservoir is filled during the rainy season, with the excess water that is not used by the sectors, reaching a peak at the end of the season. The water is then used during the dry season, thus draining the reservoir until the next rainy season.

In the case of scenario 4, the volume rises constantly during the totality of the simulation: the water in the reservoir is not totally used year after year, and the spare water is stored up for the following years, thus increasing the total volume. Although this situation is theoretical, it makes sense regarding the model, as scenario 4 has the same parameters as the current situation with only the addition of the dam. In the case of scenario 6 (increase in water-demanding crops), there is no excess water from year to year, but the dam provides enough water for the current year. Scenario 5 (increase in water-demanding crops and in cultivated area) not only does not leave excess water but also shows a decrease in the water volume available each year. This is due to the steady increase in the cultivated area over the simulation time which leads to a higher water consumption.

Scenarios 7 and 8 illustrate situations where the irrigation efficiency is improved, although scenario 7 includes the increase in water-demanding crops and cultivated lands. In both cases, the reservoir fills up rapidly the first years, and remains full during the entire time of the simulation.

As can be seen, in the current setting of the water year method, the most efficient scenarios would be scenarios 7 and 8, followed by scenario 4. From this graph we can conclude that to ensure a suitable use of the dam, at least in the current situation, improvement in irrigation efficiency is highly recommended.

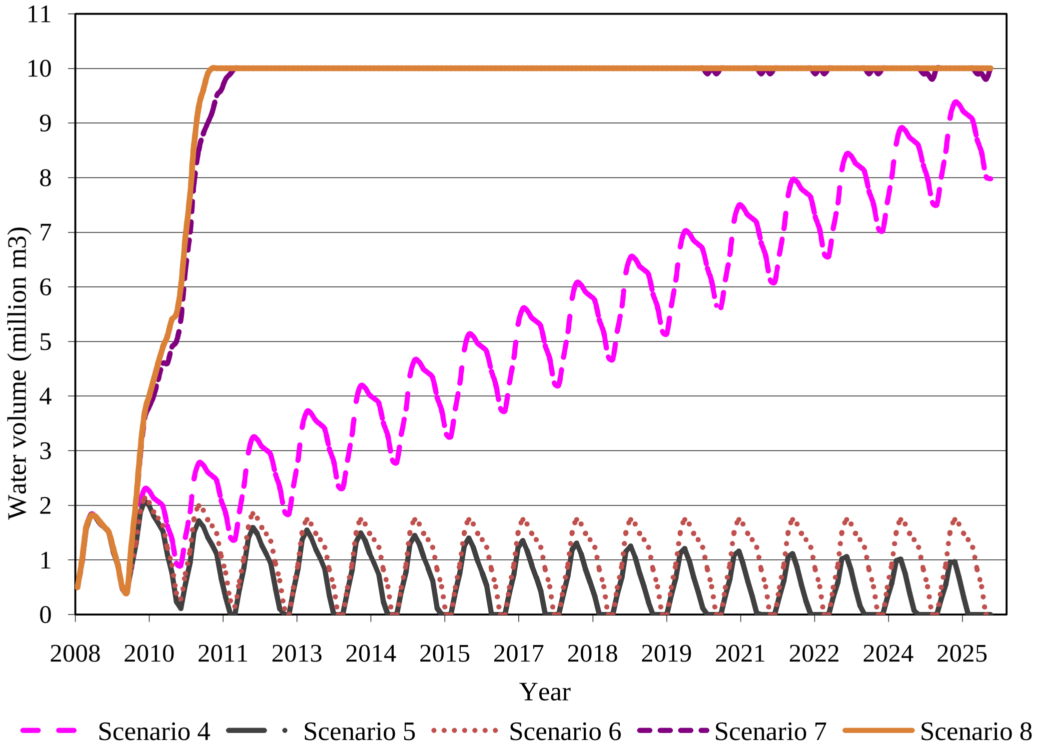


Figure 26: WEAP – storage volume comparison

Summary and conclusions

Table 32 summarizes the results of the comparison, regarding unmet water demand per sector and per scenario, as well as the water level in the reservoir. It can be seen that in the cases of scenarios 1, 2, 3, 5 and 6, most of the sectors present a deficiency of water. However, the unmet demand varies widely from scenario to scenario.

In the case of scenario 5 the storage volume of the dam is very low, which explains why there is such a lack of water, and we know that this scenario includes a high water consumption. Scenario 5 is the case which has the higher unmet demand, with scenario 6 the lowest. Scenario 1, the current situation, also presents a very high deficit.

		1	2	3	4	5	6	7
Unmet demand	Bajo Yarabamba	X	X	X	–	X	X	–
	Alto Sogay	–	–	–	–	–	–	–
	Bajo Sogay	X	X	X	–	X	X	–
	Alto Quequeña	–	–	–	–	–	–	–
	Bajo Quequeña	X	–	–	–	X	X	–
	Polobaya	X	X	X	–	–	–	–
	San José de Uzuña - Totorani	X	X	X	–	–	–	–
	Susihuaya - Agua Buena	–	–	–	–	–	–	–
	Total (thousand m3)	37,189	2,313	6,033	–	46,491	533	–
Water volume in the reservoir		–	–	–	Average	Low	Low	High

Table 32: WEAP – scenarios comparison

It follows that, in the cases where there is no dam, the best solution to palliate for the lack of water would be to increase the irrigation efficiency. With the dam, we can see that increasing both the cultivated area and the percentage of water demanding crops would not be sustainable. To resolve this, the irrigation system would have to be improved regarding its efficiency, as in scenario 7. In the case that only the percentage of water-demanding crop increases (scenario 6), the situation would be sustainable and the reservoir kept full. If the dam is built but there is no change to the current desired cropping pattern, the demand would be met as well, as in scenario 4.

6. Conclusions

In this chapter, answers to the research question and sub-questions are proposed, before recommendations concerning the general management are given, and issues for further research are considered.

6.1. Discussion and conclusions

For information, the questions are re-addressed.

How can the impacts of the construction of a dam designed for improved water use be estimated in the Yarabamba sub-basin, Peru?

This problematic presupposes that an answer is given to the following sub questions:

1. *What are the motives (social and technical) behind the implementation of the dam?*
2. *Based on what is known at the present, can recommendations on the use of the future dam be given?*
3. *How can the study of the behavior of an irrigation system in a micro-basin be carried out, in order to provide the necessary support to the research?*
4. *Is it suitable to describe the entire area by focusing on a smaller area in the sub-basin? Is the description of one or more areas representative of the micro-basin?*
5. *In what ways is the entire system shaped by human actions and how are they influenced by the system in return?*

The main focus of the research was the dam which was supposed to improve the water distribution and availability in the sub-basin. From the results of the study, it can be concluded that other factors, related to the irrigation system itself, are involved in the efficiency of the new structure. The farmers, the main stakeholders, believe that more could be done to improve the system and their standard of living.

What are the mechanisms (social and technical) behind the implementation of the dam?

The objective of the project is, through the improvement of water efficiency, the development of the area. Water scarcity is the main issue in the basin, leading to poor yields and the inability of growing crops with a high commercial value. Rainfall is available only from November to April, the rest of the year being very dry. Furthermore, the lowest areas of Yarabamba, Sogay and Quequeña are disadvantaged compared to the highest area of Polobaya. By creating a large storage area to regulate the variations of water availability through the year, the dam would allow to at least palliate the lack of water in existing lands, and at best to extend agricultural lands. Farmers would then be able to shift toward higher value crops more easily than without this extra storage.

This dam had been planned for year, dating back to the end of the 70s. Based on the studies that have been carried out since then, it is supposed to hold 10 million cubic meters, with a height of 26m. Derivation structures from another river in the same basin will be built, but it has to be mentioned that another derivation canal has been built downstream of the dam, this time to provide water to the northern sub-basin of Mollebaya. However, the issues over this structure have not been resolved yet, as water shortages might still happen in Yarabamba even after the dam's completion.

Meteorological stations in the area have provided the data to design the dam, but since there was no historical rainfall or discharge data in the sub-basin itself, a model was used to determine discharges and rainfall but has not been calibrated with data from the sub-basin.

Since the funds for the construction have been obtained mainly from loans, farmers will pay a fixed water tax per volume of water delivered, which was not the case before. Farmers used to pay an annual water tax based on the number of hectares, not the volume of water. The dam will be operated by the Junta de Usuarios Zona no Regulada, and the ex-ATDR, which is now the Local Water Authority (ALA). It has to be noted that the distribution to the different sectors has not been determined yet.

Based on what is known at the present, can recommendations on the use of the future dam be given?

Most of all, the main issue that should be resolved is the fair distribution of water. However, this is not possible without a strong cooperation between sectors, and a potential change in diversion structures. The upstream sector of Polobaya has built a new derivation canal in order to change entirely its current irrigation system, seemingly without authorization, and the downstream sectors are afraid they will keep on taking most of the water. Some people said that a canal should be built all the way from the dam to Yarabamba, Sogay and Quequeña, to curb the activities of Polobaya. The competition between the sectors should be reduced, otherwise the benefits of the dam would not give the expected results. This example shows that the use of the dam is so closely linked to the irrigations systems of the downstream sectors, both on a technical and socio-political plans, that it is hard to give recommendations without considering the system itself. It also has to be mentioned that the situation in the sub-basin is particular and might not be representative of similar projects, since the construction of the dam arrived at the same moment as the implementation of the new water law, both with unknown factors.

How can the study of the behavior of an irrigation system in a micro-basin be carried out, in order to provide the necessary support to the study?

A good framework should include the assessment of the irrigation system through the physical infrastructure, the operators and the water users (Vos, J., 2002). Physical infrastructure can be studied through the layout of the canals and the water control structures. Operators include all the regulating and operating bodies, assessed through the methods used to induce good performance and the ability of the operator to perform well, regarding both the users and the authorities. Finally water users are those who shape the system and are thus considered through their participation in management, accountability of organization, and mutual social control.

The research has been carried out in accordance with this framework, as it considered all three aspects. The study process has been supported by written data as well as interviews. While reports and digital documents such as maps were useful to understand the basic issues of the sub-basin, the study would not have been complete without the fieldwork and the interviews, which allowed to gain insight on the infrastructure but also the needs and opinions of the water users. A hydraulic calculation tool such as SOBEK helps evaluating the physical infrastructure, as the behavior of the irrigation system and especially the canals can be understood at the scale of the system. It is then possible to point out defects and take measures to rectify them, such as overtopping during the rainy season. In the case of this research, the specificity of the topic made it necessary to use tools such as WEAP, in order to evaluate water volumes on the basin scale. Scenarios are introduced that help complete the scope of available information.

It has to be noted that each source of information comes with inconsistencies and errors. The data from the fieldwork that is used for modeling is dependent on the integrated error of the devices (GPS) and the measurement errors made by the operators (cross section, etc…). The characteristics of the canals vary a lot along its length, meaning that it is very hard to obtain accurate values. It was interesting to see during this fieldwork, that the reality of canal infrastructure is far from the theory, where a "perfect" canal is always considered. There are differences noted between the different reports, which means that at least one source includes errors. Sometimes information in the report is lacking, hence the need for the social investigation and the fieldwork. These facts can be simply overlooked for lack of funds or motivation from the authors, or deliberately hidden in order to manipulate the opinion of the reader. Another difficulty was the reluctance of some people to give information, as it seems information is valuable and there is competition between various institutions. Finally, the social investigation might be biased as everyone sees his own interest.

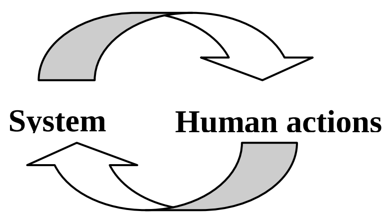
Is it suitable to describe the entire area by focusing on a smaller area in the sub-basin? Is the description of one or more areas representative of the micro-basin?

To answer this issue, information from the different sectors were compared. The areas are rather similar, since they are close enough, but the issues and situation of the downstream sectors differ from the upstream sectors. The infrastructure and its state is rather similar, as they all have lined main canals, unlined secondary and tertiary canals, rudimentary water control structures. However Polobaya differs from Yarabamba, Quequeña and Sogay on a climatic, topographic and even social point of view. The community of Polobaya has a more traditional and rural type of community, where people help each other more than in the other sectors. Being located higher, Polobaya is exposed to harsher climates, which makes efficient agriculture more difficult, although the topography is smoother and more suitable. There is also the issue of Polobaya taking a large amount of water, which is resented in the downstream sectors. This illustrates the fact that without regulation, those closer to the water source usually tend to take advantage of their location. This could have happened to any sector, and is not necessarily dependent on the characteristics of the sector. The downstream sectors of Yarabamba, Sogay and Quequeña are quite similar although they differ in topography (smoother in Yarabamba, steeper in Sogay) and in regulation authorities (in this case, Comisiones de Regantes), as they seem more efficient in some sectors than others.

Thus, in this study, it is reasonable to consider that one area is representative of other areas, as long as they are nearby. They still differ in details but their infrastructure, operation and issues are similar. In Polobaya, more distant, issues differ although the infrastructure and mode of operation is alike to the other sectors.

In what ways is the entire system shaped by human actions and how are they influenced by the system in return?

The relation between the water users and the system works both ways as farmers adapt to the conditions set by the system, while the system depends on the decisions and actions of the water users. Most of the factors described below have an influence either way, much like a circle effect.



The first case is mainly illustrated by the lack of water and the low efficiency of the infrastructure (water losses, low irrigation frequency, low flexibility), which forces the farmers to grow crops resistant to water scarcity but with low profits, such as alfalfa. Storage exists, in the form of rather large reservoirs for each canal, but is still lacking and on-field reservoirs are almost inexistent. Funds are however lacking for this type of infrastructure, and thus the farmers have to adapt to the current system. Irrigation techniques, which should be a factor determined by the farmers, can hardly be improved since the lack of flexibility of the system does not allow it. The “mini fundio” effect, which consists in farmers owning very small parcels, prevents good production as only low-level technologies can be applied.

The water users influence the system in many ways, including of course the construction of new infrastructure (canals, reservoirs, etc…), and the good maintenance and operation of the system. Sometimes the users themselves damage the infrastructure, stealing steel gates for example, which however does not benefit the entire system. The lack of water in the downstream sectors is not only induced by water scarcity in the sub-basin, but also by the actions of the water users upstream where the water intake is higher than the intake established by the authorities. The mini fundio is produced by farmers and authorities who do not prevent land division, although it has been existing for decades.

6.2. Recommendations

6.2.1 On water management

It has been shown in this study that although the dam can alleviate the water deficit in the current situation, if the data entered in the model are close enough to reality, land extension cannot be envisioned without a change in the irrigation system itself.

From the interviews, it is evident that a change in the crop type is necessary if the area is to develop economically. Due to the scarcity of water, the only crop that can resist is alfalfa, which does not have a high value, as it is used for cattle and eventually the production of milk and meat. According to the results from WEAP, if the farmers wish to change to higher value and more water demanding crops, the situation would be sustainable, but we have seen that the data entered in the model is not entirely accurate and may not reflect the real situation, as many fear that the reservoir will not be filled in any case.

The system thus has to be more efficient, especially concerning the frequency of the water turns. Different solutions have been proposed to increase the efficiency:

- Increase irrigation frequency
- Line the main canals and lower order canals
- Change to drip or sprinkler irrigation

The first solution would be feasible with the presence of the dam, since water availability would not vary so much along the year. However it also requires a more efficient irrigation system, which means that lining the main canals and at least, the first order canals, is necessary, as well as replacing most of the off take structures by steel gates. Another solution would be to install small reservoirs at field level, but the lack of water per farmer would not make the solution very efficient.

Of course, the farmers feel that changing the entire system would be the best solution, and drip irrigation has been mentioned quite a lot. A study had been done in the adjacent sub-basin of Mollebaya, where it had been found that drip irrigation would cost around 2000$ per hectare. Although this system is efficient, it is also very costly and has to be maintained sufficiently.

Considering the current situation, these changes might not be possible, as it is not even known if the dam will satisfy the planned use. Among the unknowns are climate change, which might affect rainfall patterns and diminish the quantity of water available in the entire basin; the effective distribution of water which is still not clear, as water might be deviated toward another basin, or most of it taken by Polobaya for its land extension; the influence of the new water law and the change in institutions, not well known yet; and the future help from the government, whether or not it will be decided to support other improvements in order to support the use of the dam.

The FAO gives recommendations concerning what steps have to be taken to improve irrigation (Pundarikanthan, N. and Santhi, C., 1996).

First a good knowledge of the system is necessary. In the sub-basin of Yarabamba, there are no meteorological stations, which means that data must be derived from stations further away and might not be representative. Groundwater flows are not well known or measured, and should be investigated to evaluate the possibility of exploiting them. It also seems that the different organizations, such as the Junta, the ATDR, and the Comisiones de Regantes, scarcely communicate their information to each other, and often are not in digital format, making them easier to loose and more difficult to transfer. At the level of the canals, measuring structures are present but mainly at the head, which means that the discharge downstream is roughly estimated.

Secondly, farmers and officials should be trained and informed, which is not always the case in the sub-basin. For example, although there is a center for cattle artificial insemination, it is barely used and dairy cattle’s production capacities are not improved. The municipality does not give much transparency concerning its actions, especially concerning irrigation projects. Farmers should also associate, in order to change their crop type, set up a cooperative to sell at a higher price, lower the transportation costs to the city, and even ask for a credit. The idea of a “mancomunidad” proposed by an NGO would help promote solidarity between the sub-basins, for example for water transfer. This however has to be explained, otherwise water users might see it as an infringement on their water rights.

Finally, a feedback is necessary, as changes in the system must be monitored and their consequences evaluated, through interactions with the stakeholders and understanding of their needs. For example, an impact that has to be monitored is the effect of the new water tax aimed at recovering the costs of the dam, which might be too high for small farmers who will thus sell their lands and leave.

6.2.2 Further research

Further research could be carried out in the future, to understand better the processes working behind irrigation systems in the oriental sub-basin and to study the links between the conclusions of this study and what has really happened. In particular, the actual effects of the dam once it is in operation could be considered, as well as the implementation of the new water law which might put the farmers at a disadvantage. In that point of view, the possibility of an improved irrigation system (through lining, improvement of structures, construction of reservoirs) or of a different irrigation system (drip or sprinkler irrigation) could be explored. Another interesting point is the relationship between the different micro-basins in the oriental sub-basin, the way water can be shared between them and the notion of mancomunidad that has been evoked. The mini-fundio issue and how further land division could be prevented, can also be investigated.

The modeling part was at first supposed to include a modeling with SOBEK, but due to the complexity of taking accurate fieldwork measurements of the secondary and tertiary canals, only the main canals were modeled. A more accurate model could be made, based on another fieldwork where measurements of these canals could be carried out. With this model, canals could be tested with a uniform lining, new discharges and these variations observed to make conclusions on possible future improvements.

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Appendices

Appendix I: Peru

Peru, or Piruw in Quechua and Aymara, is located in South America, with a surface of 1,285,216 square kilometers adjoining the Pacific Ocean. The country is bordered by Ecuador and Columbia in the North, Brazil in the east, Bolivia and Chile in the south and the Pacific Ocean in the West. The Republic of Peru has a total population of 29 million inhabitants, with a population growth rate of 1.264%. The main spoke language is Spanish, but Quechua is also an official language. Other native languages such as Aymara are also spoken.

Geography

The country is divided into 25 regions and 1 province (Lima Province), as shown on the map.

Figure I- a: Regions of Peru - (Peru Info)

There are three major geographic regions in Peru: the coast in the West, a narrow and arid plain; the sierra in the region of the Andes, along with the Altiplano plateau; and the jungle (selva), a wide plain covered by the Amazon rainforest that accounts to 60% of the country's surface.

The Andes and Humboldt Current are the cause for a wide range of climates. On the coast temperatures are moderate with low precipitation and high humidity. In the sierra, rains are frequent during summer but temperature and humidity decreases with the altitude. Between the rainforest (selva) and sierra in the east, semi-tropical cloud forests lie between 800 and 3800m. Heavy rain falls and high temperatures are characteristic of the "selva", which hold a remarkable number of species of plants and animals (Country profile - Peru, 1992). It has to be noted that the Pacific zone is characterized by the presence of the Southern Oscillation phenomenon called El Niño, occurring every three to eight years, defined by warmer surface waters in the eastern side of the Pacific Ocean. In Peru, El Niño is the cause of warm and very wet summers (December-February), sometimes provoking major floods.

Resources

Peru has numerous resources such as minerals sources but also halieutic resources. Industrial activities include mining and refining of minerals, metal fabrication, petroleum and natural gas extraction and refining, fishing and fish processing, textiles fabrication and food processing. Among the main resources exported are copper, silver, gold, petroleum, timber, fish, iron ore, coal, phosphate, potash, hydropower and natural gas. The main post of economical revenue is services (66%), followed by industry at 25% and finally by agriculture (8.4%).

The place of agriculture

2.88% of the land is arable, and 0.47% is permanently cultivated. The total irrigated area is 12,000 km^2, with the main products being asparagus, coffee, cotton, sugarcane, rice, potatoes, corn, plantains, grapes, oranges and coca. Livestock industry provides poultry, beef, dairy products and guinea pigs. The total renewable water resource is around 1,900 km3, with an annual water withdrawal of 20 km3. 80% of this amount is used for irrigated agriculture.

Appendix II: Morphology, geology and demographics of the study area

Morphology of the sub-basin

The morphology in the area is marked by the mounts Misti and Pichu Picchu (respectively at the top and on the right of Figure II- a).

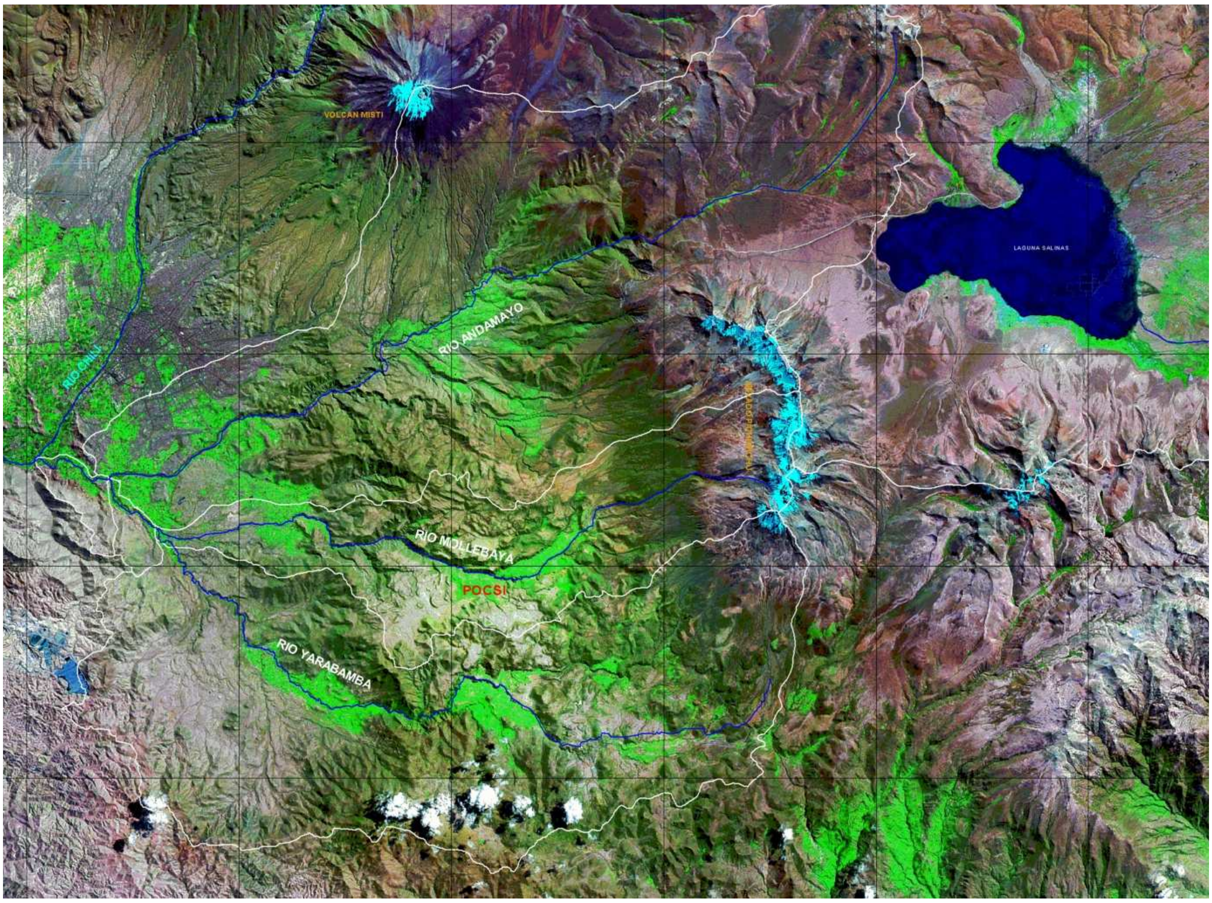

Figure II- a: Map of the area of Arequipa – Google Earth

Mounts Misti and Pichu Pichu are old volcanoes that present an advanced state of erosion. They behave as a groundwater storage unit, and springs form at the foot of the mountain range. The "Lagunas Salinas" is another significant feature, located behind the Picchu Picchu with a total area of 33km². This lagoon is a large salt water reservoir, covered with wetland vegetation. The "pampas", zones with a low relief and variable area, are common in the Altiplano. More specifically, the pampas in Yarabamba and Polobaya are depressions were filled with mud and other alluvial materials. The valleys are rather recent, characterized by powerful superficial flows during the rainy season while subterranean flows are fed by filtrations from the irrigated area (PROFODUA, 2004, p. 64).

The topography of the areas of Yarabamba, Quequeña and Sogay varies from flat to steep, and from flat to hilly in Polobaya. Wherever the slope is important, the presence of terraces or andenes can be noticed as a logical adaptation to the environment (*Estudio de factibilidad - Volume I*, 1980, chap. IV).

Valley of Sogay

Valley of Polobaya

Figure II- b: Valleys of Sogay and Polobaya

Geology

Geological aspects

The study area is defined by the presence of sedimentary rocks: Yura group (sandstones and shale), Pleistocenic and alluvial conglomerates; volcanic rocks: Tacaza and Sencca (rhyolite tuff, like the Arequipenian “sillar”); and plutonic rocks: coastal batholith (granitic rocks).

The coastal batholith layer, which is a typical formation of the Andes, reaches hundred of meters depth; it is overtopped by volcanic rocks, issued from volcanic activity, and sediments, such as alluvial, that are found mainly in the river and stream areas. Erosion is a defining morphologic process which shaped the landscape by acting on the base of plutonic and volcanic rocks since the tertiary period. At the scale of the sub-basin, the rock layer on top of the batholithic layer was first eroded, uncovering it. The depression created was later filled with lava rocks of the Sencca group (consolidated volcanic ash), before being subjected to erosion processes again. Nowadays the impact of erosion is rather limited and kept to the areas of the sub-basin where the precipitations are the most intensive. On a seismic point of view, there are no major faults in the area, and although joints are present in the coastal batholith they do not represent a major risk.

The two zones of Polobaya and Yarabamba differ in their geology since the zone of Polobaya is covered by volcanic Sencca rocks, easily eroded, while the zone of Yarabamba is characterized by granites, which are more difficult to erode. (*Estudio de factibilidad - Volume I*, 1980, chap. VI)

Types of soil

The soil is mainly alluvial, created by the accumulation of material that was eroded and carried away by the water from higher areas. The surface soil presents a dark color which characterizes most of the time loam or sandy loams, with a rather fine consistency. In Yarabamba, Sogay and Quequeña, fertility of the soils is rather good, with a moderate permeability, a good drainage and no salinization problems. In Polobaya, the use of andenes is less common since the topography is rather flat, with very smooth slopes. However the consistency of the soil is rather thick, with a low permeability, and poor drainage that leads to salinity problems increased by the presence of impervious layers. For comparison, the infiltration rate is higher in Yarabamba-Quequeña-Sogay (12.7 cm /h) than in Polobaya (9.6 cm/h) (*Estudio de factibilidad - Volume I*, 1980, chap. IV).

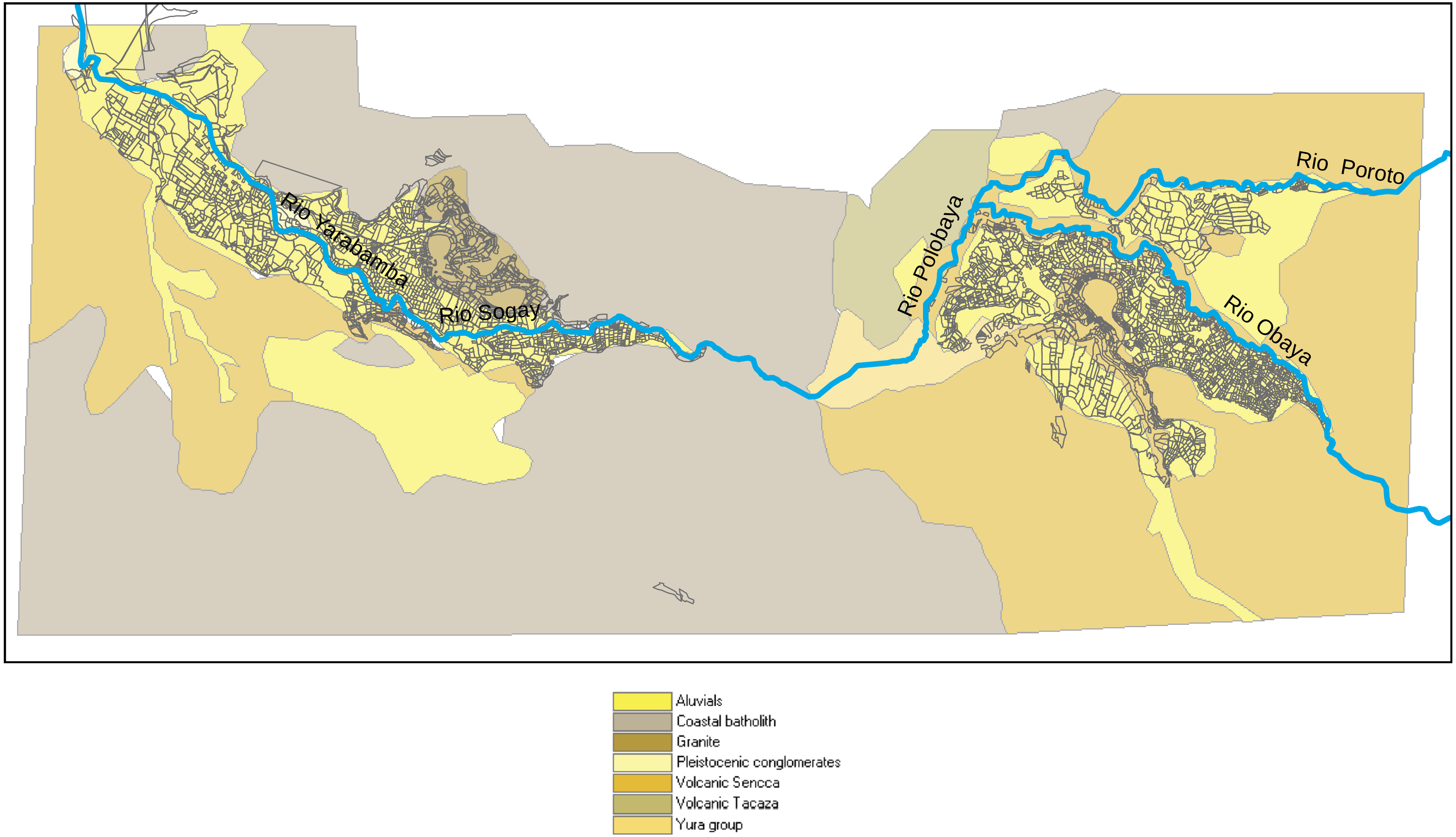

Figure II- c: Geologic map of the sub-basin Yarabamba

Demography, economics and society

A social and cultural difference has been observed between the upper zone of Polobaya and the lower zones of Sogay, Quequeña and Yarabamba. Most of all the population's behavior differs, in that the lower zones are nearer to Arequipa and thus are influenced by the way of thinking of the people from the city. People are more individualistic and disorganized, while in Polobaya the population is more mindful of the entire community (*Estudio de factibilidad* - *Volume I*, 1980, chap. II).

Demography

There are around 600 families in the area, with most of them living in Polobaya. In this area, families count with more members, especially children who usually participate to the manual labor in the field. Each family counts with between 4 and 5 members. **Error! Reference source not found.** gives population statistics in each sector.

Polobaya	Men	Women	Total
0 - 14	185	148	333
15 - 64	606	373	979
65 +	60	73	133
Total	851	594	**1,445**

Quequeña	Men	Women	Total
0 - 14	136	129	265
15 - 64	382	413	795
65 +	79	80	159
Total	597	622	**1,219**

Yarabamba	Men	Women	Total
0 - 14	133	85	218
15 - 64	323	340	663
65 +	76	70	146
Total	532	495	**1,027**

Table II- a: Population by age category in Polobaya, Quequeña and Yarabamba – (INEI, 2007)

The number of inhabitants has been decreasing steadily, due to the low living conditions and lack of appropriate working conditions. Apart from the milk production, most of the crops are destined to auto-consumption and thus are not a stable source of revenues, which is why, when they have the possibility, the inhabitants of the sub-basin tend to go working in the city.

Living standards

The middle class represents only 3% of the population, with a majority owning around 5 hectares. They earn between 6 and 15 times the national minimum wage a year. This class has a better access to services, technologies, and more chances to occupy a political charge. They are also able to give their children a better education and usually employ workers on their field.

On the contrary, the lower class represents 97% of the population, characterized by the ownership of very small parcels. Land parceling is very high and results in high production costs, with a high necessity of the family workforce. They earn 1.4 times the minimum wage, which is not sufficient to satisfy the needs of their families.

Education levels

Around 40% of the population does not have any education. However, 40% of the children have at least secondary education or higher. Although the area benefits from learning centers and secondary schools, people with enough resources have a tendency to send their children to Arequipa for a better education.

Housing

Houses in Yarabamba, Quequeña and Polobaya benefit from the basic services. In Quequeña a majority of the houses have access to drinking water, electricity and sewerage. In Sogay and Yarabamba, it seems that suitable drinking water is lacking, as well as sewerage. Polobaya still lack all these services. Most of the houses are privately owned and rudimentary, made of stone or concrete, with roofs of metal sheets (*Estudio de factibilidad - Volume I*, 1980, chap. II).

Activities

85% of the population is in working age (6 to 70 years old), but around 20% of this active population is not working. Their main activity is agriculture, although mines (Cerro Verde) and quarries exploitation fill in for many jobs. Cattle raising is the main economic activity, especially since the main crop cultivated in the sub-basin is alfalfa, as forage crop, followed by the cultivation of products for human consumption. However, these activities are not well paid, especially since agriculture in the sub-basin does not benefit from new agricultural techniques.

Due to the low salaries, many go to the city of Arequipa to work, leaving their field poorly attended, and others go seasonally, when agriculture is harder due to the lack of water (May to December) (*Expediente canal Sogay*).

Appendix III: Legal framework and institutions

Legislative aspect

Chronological summary

Agriculture in Peru dates back to 5000 years ago, when the Chavin culture built simple irrigation systems near Lima. The Incas followed by building an extensive and complex irrigation system, which provided water to 700 000 hectares. The arrival of the Spanish people, who focused on mines exploitation, reduced considerably the extent and importance of agriculture in Peru.

In 1899 was drafted the first Codigo de Aguas, followed by a new Codigo de Aguas in 1902, which was in use until 1969. This code was based on the privatization of water, although it already divided the different uses of water (public use, fishing, navigation). With this code, the water users nearer to the sources of water were advantaged compared to those farther.

The 20th century started with an important institutional development in the irrigation sector with the creation of the Cuerpo de Ingenieros de Minas y Aguas (1904) and the Servicio Hidrológico (1911). The first large-scale public irrigation projects were launched in the 1920s, with every year increasing investment rates. From 1945 to 1948, the government approved the National Plan for irrigation improvement, and until 1956 public investments in irrigation reached a maximum, with 50% of the total public investments.

Under the presidency of Juan Francisco Velasco Alvarado (1968-1975), the agrarian reform was initiated along with the creation of a new law (Law n°17752) in 1969. Water resources were considered in a very different way in this decree, where they are declared a scarce resource which must be protected and regulated. Thus all the water resources, without exception, are owned by the government. This decree also recognizes the levels of importance in water protection, such as the adequate distribution of water or its quality. From then on, the Peruvian government has invested around 5 billion US$ to improve the irrigation infrastructure. This agrarian reform had for consequences the expropriation of all the large properties more than 100 ha in surface, and the division of the land among the farmers. Many of them were already “minifundists”, and went on cultivating their parcels independently (Bethel). This led to low agricultural yields, since the organization of production systems had been disrupted.

During the following years, several modifications were brought to the law, which led to the decree of 1981, and further in 1991 with the decree 653, promoting investments in the agricultural sector. This latter modified the administrative organization as well as the water users’ organizations. However, the new decree leans toward a more economical approach of water ownership, which endangers the principles of the original water law, that is to say the collective aspect of water use and ownership (Las leyes de agua en el Perú. Planes hidrológicos de cuencas - Monografias.com).

In 1989, the government approved the decree 037-89-AG transferring irrigation related responsibilities to the Junta de Usuarios. However, while they were supposed to increase their financial independency, and stimulated private investments, low water taxes and efficiency led to insufficient resources for the Junta to expand and maintain their irrigation systems.

In 1996, the government created the Subsector Irrigation Program (Programa Subsectorial de Irrigaciones – PSI) to improve the status of the Junta and their economical sustainability, and increase investment in the irrigation systems; this program is now considered a big success.

In the past years, a deep change has been introduced in the legal framework with the approval of the decentralization law, the Organic law of Regional Governments (2003), which initiated the transfer of power toward the departments, and the Organic law of Municipalities.

In March 2009 was introduced a new water law (Water resources law n°29338) to remediate the problems posed by the previous law.

National Law n°17752

As mentioned before, this law brought essential modifications in the way water is managed. Apart from what has already been said, it can be mentioned that this law defines priorities in the use of water: first necessities / domestic use, cattle raising, agriculture, energetic, industrial, mining uses, other uses. To the end of planning the water management policy, the government has the obligation to inventory the use of water resources, preserve them, and provide information about hydrology, hydrogeology, meteorology etc., in all the rivers basins.

The same law defines the roles of the Water Authority (Autoridad de Agua), which is in charge of the conservation and preservation of water resources, the Junta de Usuarios and the Comisiones de Regantes, which must elaborate the Planes de Cultivo y Riego. A special ruling was made for these organizations (DS 005- 79-AA). This law was however considered obsolete and contrary to the principles of integrated water management, as it does not recognize the multisectorial aspect of water, management at basin level, or water as an economic good.

The problem with the previous water law was that it was more advantageous to the coastal areas, to the detriment of other regions, the sierra in particular. Furthermore, different norms were superposed, producing the existence of different policies per sectors, as well as confusion in applying the norms (Alegria, J., 2009). Conflicts appeared when water resources owners were required to give away their right for the public good (villages, communities). They are usually resolved but the owners obtain compensations or the right to play a role in the project. This shows even now the consequences of the old water code. Other issues include the absence of the hydrological river basin plan (Historia de España - Monografias.com).

New water law

The new water law was created to palliate to the issues raised by the old water law. Formalized in March 2009, it has not been entirely implemented yet. Its main difference with the previous law is the integration of the concept of integrated water management. Water is also recognized as a vital resources and a human right. According to this law, citizens can have a more active participation in decision making, with the reorganization and change in the status of the current institutions and groups of stakeholders. Comisiones de Regantes are viewed as an extra cost for the Junta de Usuarios and bound to be absorbed by other organizations. A different system of settlement will be established, with possibly higher taxes (Ministerio de agricultura, 2009).

Many fears surround this new water law, especially among the farmers. Most of all, the population thinks that priority for access to water will be given to those with major resources, in this case, mining companies. Mines would have unlimited and free access to water sources, contrarily to other water users who have to pay for their share (Junta de Usuarios, ect….). The creation of the ANA (Autoridad Nacional del Agua) is illustrated as a progress, but this organization being based in Lima, is subject to all sorts of pressures especially from mining companies. This has already been proved, as lobbies have already succeeded in eliminating from the law, the article concerning water protection at the source. Without this protection, mines can contaminate and dry up the water sources and affect the entire area downstream, including agriculture (Peru: Ley de aguas anticampesinas y prominero, 2009).

Overall the extent and consequences of the law is not yet known, as institutions are just changing. But from the interview of the water users, agriculture will probably suffer as it is not considered sufficiently profitable. Taxes will be higher but the benefits from the new organization to the farmers, hardly seen. Comisiones de Regantes will disappear and be replaced by a manager, although it is not well known what will be his role and who will choose him.

Institutional aspect

Hierarchy

At the user's level in Arequipa, three main organizations are responsible for irrigation water management: the Administración Technica del Distrito Riego (ATDR), the Junta de Usuarios and the Comisión de Regantes. The role of each of these organizations will be detailed further in the chapter. (Gestión de recursos hídricos en el Perú - Wikipedia, la enciclopedia libre) (Riego en el Perú - Wikipedia, la enciclopedia libre).

illustrates the hierarchy of the institutions previously responsible for water management from national to local levels. Each of them is described in the following paragraphs, along with the new institutions (CEPES, 2003a).

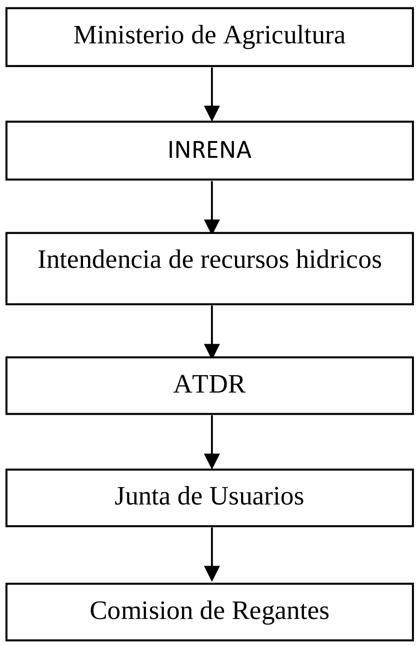

Figure III- a: Former diagram of institutions

Due to the new law, the Intendencia de recursos hidricos has been absorbed by the ANA (Autoridad Nacional del Agua), and ATDR by the ALA (Autoridad Local del Agua), while it seems that the Junta de Usuarios will not change. However it is not yet known what will happen with the Comisiones de Regantes.

Ministerio de agricultura (MINAG)

The national authority in terms of water management is the Ministry of Agriculture (MINAG), although other ministries play a part, such as the Ministry of Heath, Trade and Tourism, Energy and Mining and the Council of ministers. Its main aim is to promote the development of agriculture, through its work with other public organisms such as the INRENA.

INRENA

The National Insitute for Natural Resources (Instituto Nacional de Recursos Naturales – INRENA) is a decentralized public organism part of the Ministry of Agriculture. Its objective is to manage natural resources, water, forests, fauna and soils, in order to support the goal of the ministry, to develop agriculture. It is mainly in charge of collecting data and redacting technical reports concerning the evaluation and monitoring of the existing natural resources (Instituto nacional de recursos naturales (INRENA)).

Intendencia de recursos hídricos

The Intendancy of Water resources is an organism responsible for the proposition, supervision, and control of policies and execution of projects concerning the sustainable use of water resources. It is constituted of the Direction for basin management, and the Direction of water resources. The ATDR depend technically and functionally on the Intendancy (CEPES, 2003a).

Junta de usuarios

The water users boards (Junta de Usuarios) regroup all the Comisiones de Regantes in an Irrigation district (Distrito de riego). They are private association, with public financing, responsible for the operation, maintenance and improvement of the irrigation infrastructure, and the good organization and active participation of the water users regarding their irrigation system. There must be one representative of each sector among the junta, role usually held by the presidents. The president of the Junta is himself a president of one of the sectors.

The junta is in charge of collecting the water tax, through the Comisiones de Regantes, destined to carry out the annual operation and maintenance of the irrigation system, when approved by the ATDR. When conflicts arise, or when farmers do not pay their tax, the Junta is allowed to intervene. It is also, technically, responsible for the elaboration of the Plan de Cultivo by every Comision de Regantes, destined to control the fair distribution of water to the sectors. Finally, the Junta has a role in the training and information of users concerning the management of the system (*Informe Tecnico Proyecto Huayrondo*, chap. 2).

Comision de regantes

A Commission de Regantes is an association of farmers from a sector or sub-sector of irrigation. In general, these commissions include a president, a vice-president, a secretary, a treasurer, a water guard and other assistants. The main mission of the Commission is to maintain the canals and other structures and be in charge of the water allocation. They are also responsible for conflict management when it occurs.

ATDR (Administración Técnica de Distrito de Riego)

The Technical Administration of Irrigation District (Administración Técnica de Distrito de Riego - ATDR), is the authority in charge of managing the water, guarantee the rights to its access and distribute water between sectors, in the agricultural and non-agricultural domains alike. The ATDR controls the entire Chili basin, regulating the water from the rivers in the basin. Most of all, it acts as a control entity, regarding the operation of the organization it is in charge for, such as the Junta and the Comisiones de Regantes (*Informe Tecnico Proyecto Huayrondo*, chap. 2).

Gobierno regional and Gobierno local

The regional governments are not directly responsible for the water management, but have the responsibility to develop the region, allow the execution of projects with public investments, and promote economic activities. They are formed by the regional president, and the Regional council, which generally approves the budgets proposed by the president, as well as the budget assigned to the "canon de agua" (collected water taxes). In that sense, their role in water management mainly has to do with the investments granted to the Comissiones de Regantes, in order to maintain their canals.

The local government assumes the same function, but at a local scale, due to the decentralization law that requires more local governance (Gobierno regional en el Perú - Wikipedia, la enciclopedia libre).

Municipalities

Municipalities can be at both district and province levels. The structure is the same in both cases, with the Council composed by the mayor and the manager (regidor), with the mayor being the executive organism. Their range of influence is wide, as they must deal with issues of all type in their districts, water management being only one of them (Gobierno regional en el Perú - Wikipedia, la enciclopedia libre).

ANA

In 2008, the Peruvian government created the National Water Authority (Autoridad nacional del Agua – ANA), subject to the Ministry of Agriculture, suppressing the Intendancy for water resources. The ANA is in charge of designing and implementing the national policies concerning water management. Its specific objectives are to take into account the legal framework and needs of all the stakeholders, in partnership with local and regional governments, to formalize the rights to water, its distribution and quality, and manage conflicts. This new entity regulates the actions of the private actors, such as users or mining companies, in water management. The ANA is supposed to be more democratic, as it intends to include representatives from the farming community in particular. It also aims at giving more autonomy to users' organizations (Autoridad Nacional del Agua - ANA).

The National Water Authority was put into operation to simplify the institutions in place, as the ATDR and the Intendancy are now part of the same organization. Below is the new diagram.

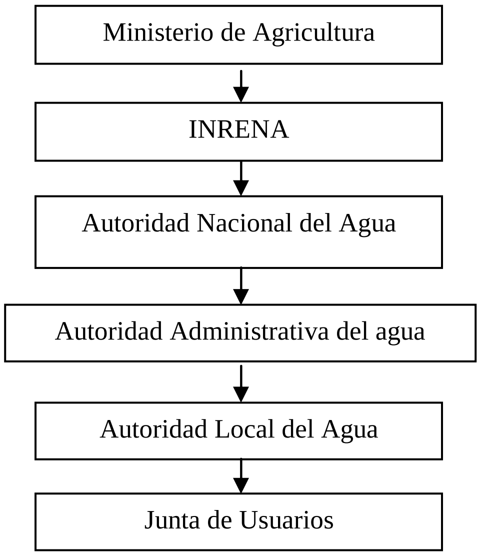

Figure III- b: new diagram of institutions (Semana Económica, 2009)

Sources of financing

Water tax

The Junta de Usuarios are in charge of collecting the water tax. Only 50% of the Junta is technically and financially independent. The rest needs help to maintain it financial sustainability. In practice, the Juntas establish their own water tax, approved by the ATDR (Riego en el Perú - Wikipedia, la enciclopedia libre).

Since most of the time water volumes are not measured, the water tax is based on the area and the type of crops and not the water volume. Generally, they vary between 2.2 and 25$ per ha. The water tax has three components: a part for the Junta de Usuarios, one for the Canon de Agua (used by the Comisiones de Regantes) and one for "Amortization". In the sub-basin Yarabamba, only the first two are applied. A large part of the tax is destined to finance the activities of the Junta (around 80%). The rest is used for the ATDR and the costs of operation and maintenance (corresponding to the Canon de Agua) (CEPES, 2003b).

Canon Minero

The "canon minero" is a fund given by the mining companies to different entities, based on their benefits from their mining activity. In theory, this fund is distributed as follows: 10% for the local governments or districts where the mine is located, 25% for the local or provincial governments of the same zone, 40% for the local governments of the department of the same zone, and 25% is destined to the Regional government. This fund can only be used for projects and works of general interest. In particular, the management of these funds must be transparent, with a large implication of the population in the decision concerning the projects in which to invest.

For information, the department of Arequipa received and used the amount of 76 millions of Nuevos soles in 2006 (*Canon minero - posibilidad de inversion en turismo*, 2008).

Plan de cultivo y de Riego

The “plan de Cultivo y Riego” is a document that aims at planning the water resources available for irrigation, associated with agricultural information of a specific area. ATDR and the Junta de Usuarios are in theory responsible for the plan management, and approve it before the harvesting season starts. To be part of the plan, users must be registered in the census of water users (Padrón de Uso de Agua), have formalized their intention to sow (Declaración Jurada de Intención de Siembra), have paid their water tax, and that the hydraulic infrastructure around and in their field is in good state (COMISION DE REGANTES BOZA - AUCALLAMA - PLAN DE CULTIVO Y RIEGO (P.C.R)).

However, at the moment, the sectors of the Yarabamba sub-basin do not have any “plan de cultivo”, as they say they are not in a regulated zone and thus this is not necessary. When the dam will be in service, they will nevertheless have to present one.

Appendix IV: Methodology

Sources of information

Apart from the interviews, the main sources of information consisted in reports and digital maps collected from various organizations, listed in Table IV- a.

Sources	**Type of information**
ATDR	GIS and AUTOCAD maps of districts and canals
Junta de Usuarios	Inventories of in irrigation infrastructure in Quequeña, Sogay, Yarabamba
Other studies	Report PROFODUA Report EVAP Feasibility study 1980 Report AUTODEMA

Table IV- a: Sources of information

Measurements methods and devices

Devices

The dimensions of the cross sections were measured with a tape measure, and a ruler in the case of low water levels. To measure longer distances as required in the case of the float method, a tape measure was used. The GPS, a Garmin eTrex Legend, was used to take measurements of the location in UTM coordinates as well as the elevation. The GPS comes with a maximum inaccuracy of 15m, but usually showed an inaccuracy between 4 and 8m.

Float method

To measure the discharge, the float method was used. This approach is based on the following relation:

$$Q=AV$$

With Q the discharge (m3/s), A the cross sectional area and V the flow velocity(US Forest Service).
Likewise, the velocity of the water at the surface is defined by:

$$V = L/t$$

With L the travel distance and t the travel time.
Since surface velocities are higher than the average velocity, a correction coefficient is introduced, such as $V_{average} = k V_{surface}$. This coefficient varies from 0.8 for rough beds to 0.9 for smooth beds.

Practically, the velocity is found with the help of a stop watch and a buoyant object, in this case, small branches. In most cases the wind velocity was almost negligible and thus the velocity of the branches was not influenced. The locations were chosen in places where the canal was straight, with as little vegetation and turbulences as possible. The travel distance was 10m, as usually parts of the canals where these conditions were reunited did not exceed that distance. Each time measurement was done 3 times and the final travel time averaged. Finally, the cross section was measured at the point where it was the most representative of the canal segment’s characteristics.

Roughness coefficient

The roughness coefficient was not directly calculated on the field, but estimated during the processing of the data. This estimation was performed with the help of the photos and the observations made concerning the condition of the canal, and the following approach based on the Van Te Chow method.

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$$

Where:

n_o is a base value of n for a straight, uniform, smooth channel in natural materials

n_1 is a correction factor for the effect of surface irregularities,

n_2 is a value for variations in shape and size of the channel cross section,

n_3 is a value for obstructions,

n_4 is a value for vegetation and flow conditions,

m is a correction factor for meandering of the channel .

The data figuring in Table IV- b are taken from the table of the Van Te Chow method.

Basic material	n0	Concrete	0.013
		Cut into rock	0.025
		Masonry	0.025
		Earth	0.02
Irregularity	n1	Smooth	0
		Minor (1)	0.005
Cross section	n2	Gradual change	0
		Occasionally irregular (2)	0.005
Obstruction	n3	Negligible	0
		Minor	0.01 - 0.015
		Appreciable	0.02 - 0.03
Vegetation	n4	Low (3)	0.005 - 0.01
		Medium (4)	0.01 - 0.025
Meandering	m	Minor	1
		Appreciable	1.15

Table IV- b: Values for the parameters of the Van Te Chow method

(1) Good dredged channels, slightly eroded or scoured side slopes of canals or drainage channels

(2) Large and small sections alternating occasionally or shape changes causing occasional shifting of main flow from side to side

(3) Dense growth of flexible turf grasses or weeds; supple seedling tree switches, average depth of flow three or more times the height of vegetation

(4) Turf grasses, two times the height of the vegetation; stemmy grasses; bushy growths, moderately dense

Creation of tables for modeling

New tables were created with the fieldwork table, in which data were completed. For example, when the top width and the width of the water surface of a trapezoidal canal was known but not the bottom width, it was calculated, as well as the side slope of the canal.

A table was created for ArcGis to serve as a database. Another table, which was used for the modeling part, is supposed to hold less information, with points in double and without section (in the case of a structure where no dimensions has been taken) removed. The bank elevation was obtained from the bed elevation and canal height. The reach lengths were measured directly in ArcGis where the canal and the GPS points are plotted. From this table, another table was obtained to be imported directly into Hec-Ras. In the case where a SOBEK model is created directly, without using Hec-Ras, a specific table is made.

Questions form used in the interviews

Personal information
What is your occupation? Do you have another job?
How much land do you have? Where is it located? Are you satisfied with its location?
What is your role with the Comision de Regantes?

Crops
What type of crops do you grow?
What are the determining factors for growing these crops (price, lack of water, …)?
What type of technology do you use for these crops (fertilizers, machines…)?
How is the division of the parcels produced? Is the division rate increasing?

Water management
What is the irrigation frequency? And the available discharge per "topo"?
How is the water quantity granted to each "topo" determined?
Is there a defined "plan de cultivo"?
What is the cost of water? What is it used for?
Do you know if there are farmers who do not respect their turn and take water without authorization?
Do the farmers use wells or springs water, apart from water from the canal?
What are the methods to apply the water on the fields (furrows, etc…)? Why?
Who maintain the canals and reservoirs? What is the frequency of the maintenance? How is the maintenance done?
Would it be better to increase the irrigation frequency?
How do you think the system could be improved (new reservoirs, better canals, gates, other type of irrigation)? Are there any investments planned for the canals renovation?

Conflict management
How are the relationships with the sectors upstream?
Between farmers of the same sector?
How are conflicts handled?
How will the organization change with the new water law?
What is the history of the sector (creation, age, etc…)?
How are the water turns organized along the main canal? Is the distribution always fair (water losses, ect.)?
Are you involved in the operation of the Junta de Usuarios, ATDR, etc.? How?
What do you think is the role of the government in water management?

Concerning the construction of the dam
What do you expect from the construction of this dam?
Are there going to be any necessary changes in the infrastructure and water management?
How is the water cost going to change?
Do you think there are other solutions?

Appendix V: Crop types and schedules

In the high areas (Polobaya and its annexes), the main crops are alfalfa as permanent culture and soft corn (maiz amilaceo), cereals, onions, garlic, potatoes and beans as transitional crops (PROFODUA, 2004, p. 135).

Crop	% cultivated	Period of cultivation
Alfalfa	68	Whole year
Soft corn	10	September- October
Cereals	7	January-February
Onions	5	Whole year (August and February)
Potatoes	5	From October
Beans	3	December-January
Garlic	2	February-March

Table V- a: Type of crops and crop schedule in the high areas

	J	F	M	A	M	J	J	A	S	O	N	D
Alfalfa	■	■	■	■	■	■	■	■	■	■	■	■
Soft corn									■	■		
Cereals	■	■										
Onions	■	■	■	■	■	■	■	■	■	■	■	■
Potatoes										■	■	■
Beans	■											■
Garlic		■	■									

Table V- b: Crop schedule in the high areas

In the low areas (Sogay, Quequeña, Yarabamba), the main crops are alfalfa, onions, corn, potatoes, beans, cereals, vegetables and pumpkins.

Crop	% cultivated	Period of cultivation
Alfalfa	55	Whole year
Onions	15	Whole year
Corn	9	August
Vegetables	8	Whole year
Potatoes	3	August-September and February-March
Beans	3	February-July and July-November
Cereals	2	April-September
Pumpkins	2	August-September

Table V- c: Crop schedule in the low areas

<table>
<tr><th></th><th>J</th><th>F</th><th>M</th><th>A</th><th>M</th><th>J</th><th>J</th><th>A</th><th>S</th><th>O</th><th>N</th><th>D</th></tr>
<tr><td>Alfalfa</td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td></tr>
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<tr><td>Corn</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#c0c0c0"></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Cereals</td><td></td><td></td><td></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td></td><td></td><td></td></tr>
<tr><td>Pumpkins</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#c0c0c0"></td><td style="background:#c0c0c0"></td><td></td><td></td><td></td></tr>
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Table V- d: Crop schedule in the low areas

Table V- e shows the production costs and periods for the main crops in Sogay. It can be seen that alfalfa is one of the most advantageous considering the lack of water, as its production costs remain low, and can be produced all year long.

Crops	**Period of seeding/harvest**	**Yield Tons/ha/season**	**Production cost (S/. / ha)**
Alfalfa	Perennial	22.00	1000
Potato	August/December	8.00	2500
Maize	August/April	1.80	1000
Barley	January/June	1.20	2000
Wheat	January/June	1.30	2000
Beans	August/April	1.40	1200

Table V- e: Crops and production costs in Sogay (*Expediente canal Sogay*)

There are two types of culture, permanent and transitory. The large seeding campaign is from July to August, and the second, smaller, starts in January and February. The combination of crops for the elaboration of a cropping schedule takes into account the time of seeding, the growth period and the type of crops. Normally the type of crop in the second round is not the same as the first. According to the reports, the market influences greatly the choice of crop by the farmers, as they try to cultivate the crop with the highest expected revenue. However, it has been observed that the main factor for the choice of the crop is the water availability. They need crops that can resist to the high irrigation frequency, such as alfalfa. Very few farmers try to cultivate higher value crops, due to their sensitivity to prolonged drought and the fact they have to abandon part of their land, and most of them complain that they do not obtain a fair price when selling the production. It has been observed that the diversity is higher in the low valleys contrary to higher areas (like Polobaya), due to lower temperatures (PROFODUA, 2004, p. 128).

Although the determination of water requirements is done with CROPWAT, reality in the sub-basin shows that this is not necessary, as the lack of water imposes the cultivation of alfalfa. Farmers simply try to make the most of the water they obtain.

Appendix VI: Water requirement per sector

Calculation method

The water requirements were derived with the software CROPWAT (FAO) which uses the Penman Monteith method. First, the reference evapotranspiration was defined based on the available meteorological parameters. The evapotranspiration of the crops were then computed based on their type and soil parameters, which take into account the crop coefficient, the roots depth, the level of exhaustion of the plants, the yield, and the different growth stages. Finally, unitary crop schedules were defined month by month representing the percentage of cultivated area for each type of crop. The evapotranspiration is applied, to obtain the unitary net water requirement for the irrigated areas. With the irrigation efficiency it is then possible to obtain the brut water requirements.

Requerimientos de Agua Brutos de Acequia Alta de Sogay

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.019	0.016	0.016	0.021	0.019	0.018	0.019	0.019	0.023	0.026	0.029	0.026
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.042	0.036	0.036	0.047	0.042	0.040	0.042	0.042	0.051	0.058	0.064	0.058
Area Total	ha	65.8	65.8	62.0	65.8	62.0	62.0	62.7	60.6	62.7	62.7	65.8	65.1
Modulo de Riego	l/s/ha	0.638	0.547	0.581	0.714	0.677	0.645	0.670	0.693	0.813	0.925	0.973	0.891

Caudal Medio Anual	m3/s	0.047	Demanda Bruta por Area	m3/ha	15,290	Area Fisica Agricola	ha	96.94
Modulo de Riego Anual	l/s/ha	0.485	Demanda de Agua Total	MMC	1.48	Area de Cosecha	ha	75.90
						Intensidad de Uso de la Tierra		0.78

Cuadro 4-110
Requerimientos de Agua Brutos de Acequia Baja de Sogay

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.034	0.028	0.028	0.038	0.034	0.032	0.035	0.035	0.042	0.046	0.052	0.047
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.076	0.062	0.062	0.084	0.076	0.071	0.078	0.078	0.093	0.102	0.116	0.104
Area Total	ha	118.7	118.7	111.8	118.7	111.8	111.8	113.1	109.3	113.1	113.1	118.7	117.4
Modulo de Riego	l/s/ha	0.640	0.522	0.555	0.708	0.680	0.635	0.690	0.714	0.822	0.902	0.977	0.886

Caudal Medio Anual	m3/s	0.084	Demanda Bruta por Area	m3/ha	15,172	Area Fisica Agricola	ha	174.60
Modulo de Riego Anual	l/s/ha	0.481	Demanda de Agua Total	MMC	2.65	Area de Cosecha	ha	137.00
						Intensidad de Uso de la Tierra		0.78

Cuadro 4-111
Requerimientos de Agua Brutos de Quequeña – Toma Alta

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.018	0.015	0.015	0.020	0.018	0.017	0.019	0.019	0.022	0.024	0.027	0.025
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.040	0.033	0.033	0.044	0.040	0.038	0.042	0.042	0.049	0.053	0.060	0.056
Area Total	ha	62.9	62.9	59.2	62.9	59.2	59.2	59.9	57.9	59.9	59.9	62.9	62.2
Modulo de Riego	l/s/ha	0.636	0.525	0.557	0.700	0.676	0.642	0.701	0.725	0.818	0.885	0.954	0.900

Caudal Medio Anual	m3/s	0.044	Demanda Bruta por Area	m3/ha	15,004	Area Fisica Agricola	ha	92.48
Modulo de Riego Anual	l/s/ha	0.476	Demanda de Agua Total	MMC	1.39	Area de Cosecha	ha	72.60
						Intensidad de Uso de la Tierra		0.79

Requerimientos de Agua Brutos de Acequia Baja de Yarabamba

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.025	0.021	0.021	0.028	0.025	0.024	0.026	0.026	0.031	0.034	0.038	0.034
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.056	0.047	0.047	0.062	0.056	0.053	0.058	0.058	0.069	0.076	0.084	0.076
Area Total	ha	87.2	87.2	82.1	87.2	82.1	82.1	83.0	80.3	83.0	83.0	87.2	86.3
Modulo de Riego	l/s/ha	0.642	0.539	0.572	0.711	0.682	0.646	0.699	0.722	0.831	0.916	0.963	0.881

Caudal Medio Anual	m3/s	0.062	Demanda Bruta por Area	m3/ha	15,203	Area Fisica Agricola	ha	128.61
Modulo de Riego Anual	l/s/ha	0.482	Demanda de Agua Total	MMC	1.96	Area de Cosecha	ha	100.40
						Intensidad de Uso de la Tierra		0.78

Cuadro 4-112
Requerimientos de Agua Brutos de Quequeña – Toma Baja

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.032	0.027	0.027	0.036	0.032	0.031	0.033	0.033	0.040	0.044	0.049	0.045
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.071	0.060	0.060	0.080	0.071	0.069	0.073	0.073	0.089	0.098	0.109	0.100
Area Total	ha	113.1	113.1	106.5	113.1	106.5	106.5	107.7	104.1	107.7	107.7	113.1	111.9
Modulo de Riego	l/s/ha	0.628	0.531	0.563	0.707	0.667	0.648	0.678	0.701	0.826	0.910	0.964	0.894

Caudal Medio Anual	m3/s	0.079	Demanda Bruta por Area	m3/ha	14,984	Area Fisica Agricola	ha	166.27
Modulo de Riego Anual	l/s/ha	0.475	Demanda de Agua Total	MMC	2.49	Area de Cosecha	ha	130.50
						Intensidad de Uso de la Tierra		0.78

Cuadro 4-113
Requerimientos de Agua Brutos de Polobaya

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.094	0.078	0.083	0.098	0.095	0.089	0.090	0.100	0.106	0.138	0.148	0.141
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.209	0.173	0.184	0.218	0.211	0.198	0.200	0.222	0.236	0.307	0.329	0.313
Area Total	ha	329.3	333.1	325.5	320.9	317.1	313.3	305.7	317.1	305.7	336.9	340.7	340.7
Modulo de Riego	l/s/ha	0.635	0.519	0.565	0.679	0.665	0.632	0.654	0.700	0.772	0.911	0.966	0.919
Caudal Medio Anual	m3/s	0.234		Demanda Bruta por Area			m3/ha	15,483	Area Fisica Agricola			ha	476.63
Modulo de Riego Anual	l/s/ha	0.491		Demanda de Agua Total			MMC	7.38	Area de Cosecha			ha	390.10
									Intensidad de Uso de la Tierra				0.82

Cuadro 4-114
Requerimientos de Agua Brutos de San José de Uzuña

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.019	0.016	0.017	0.020	0.020	0.018	0.018	0.021	0.022	0.029	0.031	0.029
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.042	0.036	0.038	0.044	0.044	0.040	0.040	0.047	0.049	0.064	0.069	0.064
Area Total	ha	68.0	69.0	68.0	66.0	66.0	65.0	63.0	66.0	64.0	71.0	71.0	71.0
Modulo de Riego	l/s/ha	0.618	0.522	0.559	0.667	0.667	0.615	0.635	0.712	0.766	0.901	0.972	0.901
Caudal Medio Anual	m3/s	0.048		Demanda Bruta por Area			m3/ha	14,956	Area Fisica Agricola			ha	101.21
Modulo de Riego Anual	l/s/ha	0.474		Demanda de Agua Total			MMC	1.51	Area de Cosecha			ha	82.00
									Intensidad de Uso de la Tierra				0.81

Cuadro 4-115
Requerimientos de Agua Brutos de Susihuaya

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.014	0.012	0.012	0.014	0.014	0.013	0.013	0.015	0.016	0.020	0.022	0.021
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.031	0.027	0.027	0.031	0.031	0.029	0.029	0.033	0.036	0.044	0.049	0.047
Area Total	ha	48.2	49.0	47.4	46.6	46.6	45.8	45.0	46.6	45.0	49.8	49.8	49.8
Modulo de Riego	l/s/ha	0.643	0.551	0.570	0.665	0.665	0.633	0.644	0.708	0.800	0.884	0.984	0.944
Caudal Medio Anual	m3/s	0.035		Demanda Bruta por Area			m3/ha	11,690	Area Fisica Agricola			ha	94.42
Modulo de Riego Anual	l/s/ha	0.371		Demanda de Agua Total			MMC	1.10	Area de Cosecha			ha	57.00
									Intensidad de Uso de la Tierra				0.60

Cuadro 4-116
Requerimientos de Agua Brutos de Agua Buena

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.020	0.016	0.017	0.021	0.020	0.019	0.019	0.021	0.022	0.029	0.031	0.030
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.044	0.036	0.038	0.047	0.044	0.042	0.042	0.047	0.049	0.064	0.069	0.067
Area Total	ha	69.2	70.0	68.4	67.4	66.6	65.8	64.2	66.6	64.2	70.8	71.6	71.6
Modulo de Riego	l/s/ha	0.636	0.514	0.556	0.697	0.661	0.638	0.654	0.706	0.763	0.904	0.964	0.936
Caudal Medio Anual	m3/s	0.049		Demanda Bruta por Area			m3/ha	15,612	Area Fisica Agricola			ha	98.98
Modulo de Riego Anual	l/s/ha	0.495		Demanda de Agua Total			MMC	1.55	Area de Cosecha			ha	82.00
									Intensidad de Uso de la Tierra				0.83

Cuadro 4-117
Requerimientos de Agua Brutos de Totorani

Concepto	Unid	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Demanda Neta Total	m3/s	0.013	0.011	0.011	0.013	0.013	0.012	0.012	0.014	0.014	0.019	0.020	0.019
Eficiencia de Riego		0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Demanda de Agua Total	m3/s	0.029	0.024	0.024	0.029	0.029	0.027	0.027	0.031	0.031	0.042	0.044	0.042
Area Total	ha	44.6	45.5	43.8	42.9	42.9	42.0	41.1	42.9	41.2	46.4	46.4	46.4
Modulo de Riego	l/s/ha	0.650	0.527	0.548	0.676	0.676	0.643	0.657	0.723	0.752	0.905	0.948	0.905
Caudal Medio Anual	m3/s	0.032		Demanda Bruta por Area			m3/ha	16,495	Area Fisica Agricola			ha	61.18
Modulo de Riego Anual	l/s/ha	0.523		Demanda de Agua Total			MMC	1.01	Area de Cosecha			ha	54.30
									Intensidad de Uso de la Tierra				0.89

Table VI- a: Water requirement per sector - (PROFODUA, 2004) Volume 2

District	Licensed area (ha)	Water volume (m3)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Bajo Yarabamba	128.61	109,809	94,223	104,319	100,954	98,828	95,640	98,828	115,300	116,894	120,790	116,894	120,437	1,292,916
Alto Sogay	96.94	106,135	91,071	100,828	97,576	95,521	92,440	95,521	111,442	112,982	116,748	112,982	116,408	1,249,654
Bajo Sogay	174.6	191,161	164,029	181,603	175,745	172,045	166,495	172,045	200,719	203,494	210,277	203,494	209,662	2,250,769
Alto Quequeña	92.48	91,897	78,854	87,302	84,486	82,708	80,040	82,708	96,492	97,826	101,087	97,826	100,790	1,082,016
Bajo Quequeña	166.27	165,222	141,771	156,961	151,898	148,700	143,903	148,700	173,483	175,882	181,744	175,882	181,213	1,945,359
Polobaya	476.63	485,771	416,823	461,482	446,596	437,194	423,091	437,194	510,059	517,111	534,348	517,111	532,780	5,719,560
San José de Uzuña	101.21	103,151	88,510	97,993	94,832	92,836	89,841	92,836	108,309	109,806	113,466	109,806	113,134	1,214,520
Totorani	61.18	62,353	53,503	59,236	57,325	56,118	54,308	56,118	65,471	66,376	68,589	66,376	68,387	734,160
Susihuaya	94.42	88,212	75,691	83,801	81,098	79,390	76,829	79,390	92,622	93,903	97,033	93,903	96,748	1,038,620
Agua Buena	98.98	100,878	86,560	95,834	92,743	90,790	87,862	90,790	105,922	107,387	110,966	107,387	110,641	1,187,760

Table VI- b: Water volume monthly assigned to each sector (m3) (PROFODUA, 2004)

Appendix VII: Results of the social investigation

At the scale of the sub-basin

After interview of staff member at the municipality of Yarabamba, which regroups the sectors of Yarabamba, Sogay and Quequeña, it appears that the main concern is the future availability of water.

Although the dam was proposed to solve the problem of the water availability, the downstream sectors fear that with the absence of rain and the influence of Polobaya, the dam might not be as beneficial as is presented. Most of the water from the river Polobaya is directed at Polobaya, leaving only filtrations to the downstream sectors. Thus it has been proposed to build a canal that would bring water directly from the dam to Yarabamba, to avoid the manipulation of the gates by Polobaya. The manager also spoke about a reservoir in the sector of Yarabamba, to derive subterranean waters which emerge there as springs. It also appeared that the mayor is not well aware of the problems faced by the farmers.

The president of the Junta de Usuarios, who is also president of the Comision de Regantes in Socabaya, has been interviewed as well. It appears that little information from the sectors of the oriental sub-basin is communicated to the Junta. For example, no “plan de cultivo” had been transmitted, nor irrigation schedules. According to the president, farmers in the sub-basin do not pay their tax: from January to July 2009, only 9% have paid in Quequeña, 3% in Bajo Yarabamba, 2% in Sogay and 1.5% in Polobaya. On the contrary, 28% of the farmers in Socabaya have paid. According to him, there is no organization in the sub-basin, and no law enforcement is possible due to the lack of appropriate structures and help from the government.

A common feature is the absence of “plan de cultivo”, required by the law, since the area is “not regulated”. Farmers simply know by habit what is going to be cultivated, and how much water they need. However, it seems that since the moment the dam will be in service, famers will have to present one and follow it.

Another common issue is the mini-fundio effect. Excessive land parceling is responsible for, among others, low yields, low revenues, and difficulties to set up farmers’ cooperatives, apart from land abandonment.

The farmers in each sector have to pay a water tax, which is collected by the Junta and used to pay for services provided by the Junta, the regional government among others. This tax depends on the location of the sector, and on the quantity of water it receives.

Bajo Yarabamba

Farmers in Bajo Yarabamba feel that their main problems are the lack of water and the minifundio issue.

Irrigation frequency is of 20 days, irrigating from 5.30 AM to 5.30 PM. Now in the dry season, the discharge is around 30l/s and will lower to 20 l/s, but during the rainy season it can reach 100 l/s. Due to the instability of water delivery, farmers have to abandon part of their land in order to be able to cultivate higher-value crops, such as onion or Chinese garlic. But most of the crops are for self-consumption, and the main forage crop is alfalfa, which covers a majority of the cultivated land. Alfalfa has the advantage of resisting to the irrigation frequency of 20 days. To take into account losses along the canals, those downstream are allowed a longer irrigation time (up to 1h25/topo) than those upstream (55min/topo). Although there is no "plan de cultivo", farmers organize themselves with an irrigation schedule. Bajo Yarabamba has a reservoir, which is filled between 5.30 PM and 5.30 AM. The gate of the reservoir is opened during the day, providing a double discharge for the downstream part of the main canal. This discharge is subdivided again. Although the president denies that there are farmers stealing water, it seems that some people come at night to pump water from the river. It was not very clear who is responsible.

The minifundio, created by inheritance and division of the land, makes it impossible to introduce machines and only provides the minimum for most of the farmers. Many land owners live in the city where they work and do not put much interest in cultivating their land properly, while those who stayed in the village struggle to obtain as much as possible from their land. According to the president, 9 persons possess 50% of the whole land in Bajo Yarabamba (120 ha), while a majority of the others own a quarter of topo (0.35 ha), and the rate keeps on increasing.
On-field, all the farmers use fertilizers and pesticides since their first goal is to produce, without thinking much of the ecology.

Concerning the water tax, in the sub-basin Yarabamba, the water tax depends on the category of the sector, thus the relative amount of water it receives. In Bajo Yarabamba, the tax is 30 S/. per ha, thus 10 S/. per topo. This tax is destined to the government, to pay for administrative services above all. Farmers can decide not to pay, but eventually they will see their water supply cut. Apart from this tax, farmers have to pay 1.5 S/. per month to the Comision de Regantes, of which 130 S/. per month will be used to clean the canals. For the maintenance of the reservoir, another 2 S/. per topo is required. This cleaning happens three times in the year, before and after the rains, and in the middle of the year. The rest of these funds are destined to the water guard. However, to do repairs to the canals and reservoirs, another source is necessary, such as support from the municipality. It has to be noted that due to its proximity to the municipality itself, the president of Bajo Yarabamba is greatly involved in the acquirement of extra resources for new projects. This is why a sum of 800 000 S/. has been granted to line the main canals in the coming years, in Bajo Yarabamba. There is also a project for a new reservoir, in order to store even more water during the rainy season.

Relationships between sectors seem to be cordial, but when pressed, the president admitted that Polobaya does not respect the water distribution, leaving only small filtrations for the lower sector. The problem is that the authorities are weak and do not manage to force Polobaya into respecting the law. It seems that between the farmers themselves rapports are not very pleasant; those who produce more envy the others, and have a selfish attitude concerning the production since they do not try to help each other. In that view laws are not really adapted to reality.

Farmers consider the dam as a possible improvement, since there would be more filtrations. In winter, fewer crops are cultivated due to the cold, allowing to increase the volume of the dam. However, they feel that the price of water will increase, due to the necessity to maintain a larger infrastructure, and to regulate the distribution.

For the moment, farmers consider that the most urgent dispositions to take concerning the irrigation system are to stop the increase of minifundio, organize the sale of the products, and reduce the irrigation frequency. In the first case, the ideal would a law forbidding the division of the land between children, and a system implying one of the children to buy the land. Of course the ideal would be to regroup the terrain, such as a group buying most of the small lands and cultivating only one crop. The problem with the production is that, due to small volumes for each farmer, intermediates are necessary. However they usually buy the raw products at a very low price to sell them at a much higher price, while the farmer loses the difference. The solution would be to set up farmers' cooperatives, to regroup the production and be able to sell it directly to the consumer in the city. The president gave an example of a NGO that helped farmers to regroup and find markets to sell their crops. In Bajo Yarabamba, help from the government would be absolutely necessary to this end. Finally, increasing the irrigation frequency from 20 to 15 days would help improve the production, and the optimal frequency would be 10 days. In the long run, farmers are considering shifting to drip irrigation as they believe water will be scarcer then. They would however need investments and support from the state.

Sogay

The farmers in Sogay are highly unsatisfied with how their problems are dealt with. In spite having many problems concerning not only irrigation but also their living conditions, it seems that no attention is given to them and thus feel "abandoned". Most of them are strictly farmers and do not have another profession, but those who left for the city have parcels which they do not take care of. The president of this commission lives in Arequipa, and furthermore is not really acquainted to the system. This is why the vice-president, a farmer who lives in San Antonio (sector of Sogay) and knows a lot more the issues of the farmers, was interviewed.

Like in all the other sectors, the main problem is the lack of water, with an average water turn of 23 days. Without water, farmers can only cultivate alfalfa and such crops for cattle, to produce milk which is sold to the company Gloria. The technology level is low, especially since the plots are very small. Some farmers use fertilizers and pesticides but it seems that a handful of them do not, as they wish to cultivate ecologically.

At the time of the interview, since there is no rain, terrains are abandoned, but during the rainy season all of them are used to cultivate temporary crops such as onion, which are higher-value crops. In Alto Sogay, there is an average discharge of 80 l/s during the rainy season, while during the dry season it can drop as low as 18 l/s. Like in the other sectors, those downstream of the main canal are allowed longer water turn than those upstream (from 55 minutes to 1h30). There is a water registry to organize the water turns in the upper part, but downstream the reservoir of Alto Sogay, farmers get water when there is water available.

Concerning the water tax, farmers have to pay an annual fee of 16 S/ per topo. It was said that some farmers are simply unable to pay this tax, due to lack of resources. Others refuse to pay since they feel that the government is not doing anything for them. The problem with the tax is that a majority (60%) goes to the Junta, but farmers never see this money invested back in projects or in the irrigation system. Before, 70% of this tax used to go to the Comision de Regantes, and 30% to the Junta, which allowed the farmers to invest in small projects. Apart from this tax, they also have to pay separately for the water guard (2 S/. per topo). Farmers do not have to pay to clean the canals and reservoirs, as they are asked to do it themselves.

When farmers steal water, which it seems, happens often, they are fined, especially since there is always someone to see it. The interesting feature is that some farmers have small reservoirs on field.

The farmers admit that their relationship with Polobaya is based on resentment, as the farmers have seen their water volume decrease a lot when Polobaya started its extension. They sometimes go to the water divider in Polobaya to protest, but the situation does not change. With the other sectors, relationships are more cordial although the farmers find unfair that 50% of the water is given to Yarabamba and 50% to Sogay, while there are only 100 ha in Yarabamba compared to 270ha in Sogay. Between farmers of the sector, relationships are said to be good, and that there is no exclusions or jealousy. Most of the famers try to coordinate their crop schedules among themselves.

The farmers know how they would like to see their system improved, with for example a minimum irrigation frequency of 12 days, and a new and larger reservoir to store water at night. Secondary canals have to be lined, since a large amount of water is lost by seepage in the earthen canals and in some places, the canal's material is sand. In the long run, they wish to switch to irrigation by aspersion or drip irrigation, as they know this would save a lot of water. However, they do not benefit from any help from the government or the municipality. If they wish to improve the system, the Comision has to pay for the study and present the project to request funds. Some farmers are thinking of asking for a credit instead. According to them, governmental institutions like the Junta organize meetings but talk a lot and do not propose any concrete improvement.

One of the farmers' complaints illustrates the inadequacy of the authorities. The funds from Cerro Verde (14 millions of Nuevo soles) are used by the municipality of Yarabamba without much transparency, for projects that are not related to irrigation. Farmers are only given bags of cement to line their canals themselves. However, during the past years, the municipality has built parks in order to attract visitors to the sub-basin, and in particular invested 275000 Nuevo soles in a dinosaurs' park. Meanwhile, inhabitants in the municipality do not have access to drinking water, since it only consists in water from the river treated with chlorine. There is no sewerage system, or even clean bathrooms, which means that wastes are contaminating the air and are responsible for diseases. Farmers feel offended, as they believe that it is agriculture that makes the villages live and that money should be invested in them, making the green fields the first source of touristic attraction and most of all improving the living conditions of the inhabitants. They would need support now more than before, since the price of life keeps on increasing (such as the price for seeds), while they are paid less (for instance, a liter of milk is bought at 0.8 S/. compared to 0.9 S/. before). When asked if they could organize manifestations in Arequipa, they replied that they are peaceful people and do not wish to cause problems, contrary to the people of Polobaya.

Farmers, in Sogay as well as other sectors, worry about the future of their irrigation system, as not only water is lacking but also no information is given. For example, the Comision de Regantes has not been informed yet about how the water from the dam will be distributed. They only recognize that with this water, a higher irrigation frequency will be possible but extending terrains will not, since they are not sure there will be enough rain to fill the dam. They fear that the water will be used for Polobaya and mining activities most of all, for which a solution would be to bring the water directly from the dam to the downstream sectors, in order to ensure their share of the water.

Finally, the new water law is going to change the institutions, such as the disappearance of the Comision de Regantes and its replacement by an administrator, but there again, almost no information is given. With this law, people fear that water will be privatized, since priority will be given to those with largest resources, like the mining industry.

Other issues

Among the worries concerning the dam, the impact of the water surface has been mentioned, as a large area will be flooded in San José de Uzuña. There are worries that the design water level will never be reached, to which engineers answered that this was the purpose of the construction of the derivation canal from the river Poroto to the dam, in order to fill the reservoir in rainy times, when the sectors in Poroto have a surplus of water.

The problem also comes from the distribution of water, since it has not been defined yet, and already Polobaya has built a canal bringing water directly from the dam to the sector, as they wish to remodel their system in the near future. The canal Huicchuna is supposed to bring water to the basin Mollebaya, northwards of Yarabamba. In that aspect, the notion of mancomunidad and solidarity between the sub-basins has been recommended by both a NGO and the Junta de Usuarios. A mancomunidad is a free association of municipalities, allowing for the implementation of projects, and gathering of funds for these projects, which is what is planned to be done in the sub-basin (Mancomunidad - Wikipedia, la enciclopedia libre).

It appeared during these interviews, that institutions are considered powerless and usually disinterested in the problems farmers face. Different organizations even blame each other for being ineffective. This is probably what the change in institutions aimed at, to clarify the processes and bring transparency to the new institutions, as well as a higher participation from unprivileged stakeholders such as farmers. However, some argue that not only nothing will change, but also that a bigger institution, such as the ANA, will be even more disinterested in the farmers' difficulties. For example, since ATDR will be absorbed, fewer field trips will be organized to evaluate the infrastructure and management problems and the farmers will be left abandoned.

Appendix VIII: Situation in 1980

Comparison with the situation in the past

In 1980, the situation presented several aspects that already had to be improved. From what has been heard during the interviews, many of these issues still exist.

A summarized account of the situation is presented in **Error! Reference source not found.** while the main aspects are detailed and compared to the actual situation and what has been deduced from the interviews below.

Situation in 1980	Recommendations	What has changed?
Defective organization of CR	Organize better	
Lack of interest of farmers		Same, “selfishness”, lack of interest in common good
Increase of minifundio	Stop the increase	Same, worst
Illegal land increase in Polobaya	Stop illegal increase	Same
Fair distribution between sectors	Stricter regulations for a fair distribution	Same
Inadequate hydraulic infrastructure	Build canals, reservoirs	Some improvements: concrete canals, in Polobaya as well, reservoirs
Irrigation techniques: high seepage rate	Change irrigation technique	Same, famers get water when it is their turn no matter how much they need, due to low irrigation frequency
Harsh climate in Polobaya	Forestation, wind breaking shields	Some trees have been planted
Salinity problems in Polobaya	Install better drainage system	Same
Low technology level		Same
Infrastructure present but not well used	Education, training	Same
Use of crops that withstand droughts (alfalfa)	Change to more valuable crops	Same
Lack of commercial structure for a higher profit	Organize the sale of the production	Same
Lack of storage for crops	Build storages	Same
No farmers cooperative	Organize farmers’ production	Same situation, no cooperative has been created

Table VIII- a: comparison between the situation in 1980 and now

Presentation of the situation in 1980

In 1980 a feasibility study was carried out to determine how to improve the situation in the Yarabamba sub-basin. At that time the project was supposed to allow the retrieval of 136 ha that had been abandoned, bringing the entire cultivated area to 1300 Ha. The report gives us interesting information concerning the conditions and existing issues in the basin at the time, and provides maps that are hardly found otherwise.

The following sub-chapters present the issues per topic, presenting the main points extracted from the report.

Organization

In 1980, there were only 3 Comisiones de Regantes: Quequeña, Yarabamba, and Polobaya. These organizations were believed defective mainly because of a lack of participation from the farmers, a flawed organization, and a prominence of personal interests.

It has to be noted that the regional direction of agriculture and food is in charge of giving advices to the farmers and helping them to sell their products; this organization put at disposition of the farmers:

- A water manager
- An agricultural technician
- An agricultural adviser

Land issues

The main issue concerning land rights was the presence already of the minifundio. Parcels could be divided in three categories:

- Minifundio: parcels smaller than 3.5 ha. It corresponds to the majority of farmers, which cultivate an average of 0.8 Ha; this leads to a low production which can only b e destined to self-consumption.
- Small property: parcels between 3.5 and 10 Ha. These farmers cultivate an average of 5.4 Ha, which are mostly used to raise cattle.
- Medium-sized property: parcels of about 16 Ha. The farming technology applied is more advanced than in the other cases.

The district of Polobaya is a rural community recognized since 1937, which was given lands by the state; however, due to lack of control, illegal irrigation has been used to transform otherwise unused lands into cultivable land.

Water issues

In 1980, there already was a conflict between Polobaya on the one hand, and Quequeña, Yarabamba and Sogay on the other hand, for the availability of water. While Polobaya had enough water due to its upstream position on the river, which some farmers used to extend their land, the lower areas had a water deficit due to the reduced filtrations.

Overall in the basin, the control of the water use was deficient, with indiscriminate retrieval in Polobaya, an inadequate hydraulic infrastructure and a lack of strict regulations for a fairer use of the water among all the districts. Furthermore, it was hard to effectively regulate the water discharge to the districts due to the lack of knowledge of the underground flows.

At field level, irrigation was done by flooding, with water turns from 8 to 15 days in Polobaya and 30 to 45 days in Yarabamba and Quequeña. With this technique most of the water is “lost” by seepage, which makes the application inefficient. Farmers wish to come back to a distribution system based on the area to be irrigated.

Finally, it has been determined that the soil quality makes the land appropriate for agriculture, but it is in fact not cultivated appropriately due to a lack of technology and water, and a harsh climate in the case of Polobaya.

Technological issues

The technology applied for agriculture in the sub-basin was low:

- there was only one tractor in use, otherwise animal traction remained the main tool
- fertilizers were used in small quantities (ammonium nitrate)
- pesticides were used without taking into account the apparition or not of diseases
- In Polobaya there is a post for artificial insemination which is not used for lack of education
- In the whole sub-basin, there was no improvement in the genetic patrimony of the animals in spite of the presence of a post of artificial insemination.

Crops

Around 25% of the land was used for transitory crops, 65% for alfalfa and the 10% remaining was not used. Alfalfa and other crops for cattle were mainly produced, since they are able to withstand a long time without irrigation.

The yield is generally higher in the lower areas than in Polobaya, probably due to the tougher and colder climate in the higher areas. Furthermore, soils in Polobaya suffer from salinization problems.

Economical issues

Another problem consists in the products management and trade. The commercial structure was lacking, with a system based on intermediaries, who decide of the price when they buy directly from the farms. The producer sold his products to wholesalers or directly to retailers, who then sell them to the consumers.

Overall the farmers lacked organization, which means they could not plan their production according to the requirements of the market. Traders prevented the farmers to obtain a fair price from their production, since they buy directly from the farm and can arrange the purchase price to obtain a major benefit for themselves. Due to the lack of storage, crops could not be stored, which prevented the farmers from obtaining a better price when selling out of season. Finally, there was no farmer association to help sell products coming from very small farms.

The exceeding production in vegetables was sold in Arequipa, while meat products, onion and garlic, were sent to Lima where prices were higher. In the case of milk, the producer sold to either the retailer or directly to the processing plant Gloria, which has the monopoly of milk products in Peru.

It has to be noted that few farmers made use of loans, since they might not obtain sufficient resources to pay it off, needed to travel to the city to obtain the loan, and required the assurance of a good harvest, especially in Polobaya.

Proposed solutions

Each district had different issues and their corresponding solutions: for Polobaya, climate improvement; for Quequeña, a better control and water distribution and for Yarabamba a better water distribution and the construction of a reservoir to store water at night.

Land-related issues

It was vital to reduce land parceling and the minifundio effect.

Water-related issues

Water issues were to be tackled at sub-basin level, by transferring water to areas with better climate, combined with the improvement of the current infrastructure. Fair distribution among the districts was also recommended.

Infrastructure improvement included the redesigning and lining of the canals, the construction of new structures such as inlets, tanks, dikes to divert the water and flow meters for discharge control. The regulations for a better distribution of water would be based on availability, soil quality, and type of cultures. Finally, the water efficiency coefficient would be increased through the improvement of the irrigation techniques. At the time, Yarabamba already disposed of canals which mainly needed to be maintained and cleaned. In Polobaya, lower orders canals (secondary, tertiary levels) had to be constructed.

Crops

In Polobaya, one of the issues concerned the salinity of the soils. To mitigate this effect, it was necessary to build an appropriate drainage system. However the high amount of rain during January-March already "washed" the salts. Another recommendation would be to install windbreak curtains to stop the winds that cause lower temperatures and a higher water demand. To that end eucalyptus trees, planted in a certain way, could improve the micro climate in the area. Organic matter should be added to the soil, crop rotation should be practiced, and fertilizers should be applied depending on the soil's fertility.

Crop schedules must be implemented and followed closely. They must take into account the following technical and social parameters:

- Soil quality
- Volume of water available for agriculture
- Profitability of the crops
- Availability of the workforce
- Behavior of the farmers

The area dedicated to rotation crops was higher in Yarabamba (312 ha) than in Polobaya (156 ha), due to the harsher climate. With the project, more land will be dedicated to basic crops, and the yield of all the crops will increase, due to a better use of fertilizers and pesticides as well as a more efficient water distribution.

Economical issues

To improve the commercial structure, a series of changes had been proposed:

- Organize the collect, storage and distribution of the products of all the farmers
- Decrease transportation prices for products
- Find the appropriate markets to sell the surplus (what has not been used for self consumption)
- Find distributors which might bring the best possible advantages regarding the sale
- Build storage structures (silos, favorable environment…)

To that end, one of the best solutions would be to create farmers' organizations or cooperatives, preferably located in Yarabamba since it is the zone with the best location.

Technological issues

In order to improve the technological level in the sub-basin, a necessary solution would be to offer training and education to the farmers, since infrastructure (insemination post) already exists but is not used. Education concerning the good use of pesticides and fertilizers is also necessary. Furthermore, a higher level of technology cannot be applied without a reorganization of the parcels (*Estudio de factibilidad* - *Volume I*, 1980).

Appendix IX: Dam characteristics

Design of the dam

Design data

Three different alternatives were considered regarding the construction of the dam. The alternative that was chosen involves an earth dam designed for a water volume of 10 million cubic meters. It will be 26.5m high, with an impervious earth material front in the upper part, a cementation layer of the same material 5m deep, and a layer of impervious earth material 1 to 2m thick and 50m long. This alternative was preferred to the others since it is more resistant to seismic risks.

Derivation structures include a derivation structure on the river Poroto and its conveyance canal 3.6km long, a 14m long outflow structure and 128m long inflow canal, a spillway with a free overflow crest and a cascade chutes canal. Initially, a derivation canal from the river Pichu Picchu was proposed but the proposition was rejected due to infringements on water rights (*Estudio definitivo de la presa San José de Uzuna*, 2000).

The design was made based on data given by nearby meteorological stations. In particular, the precipitation was estimated through the isohyets for the basin Quilca-Chili. However, these data can be discussed, since the model that was used to determine discharges based on these data has not been calibrated with measured discharges in the area. This means that the total annual volume could be lower than expected.

Dam

Type of dam	earth dam with an impervious front on the upstream slope
Height	26.50 m
Elevation of the structure	3,250 m.snm
Length of the structure	372.60 m
Width of the structure	6.00 m
Volume of the structure	238,389 m3

Reservoir

Regulated basin area	60.97 km2
Maximum level of reservoir	3,248 m.snm
Total volume	10´004,000 m3
Useful volume	9´859,000 m3
Surface of reservoir	1.17 km2

Overflow spillway

Discharge of the spillway	10.00 m3/s
Length of the outlet	11.00 m
Length of the spillway	142.95 m
Width of the spillway	8.00 m
Height of the spillway wall	1.00 m
Length of the absorbing channel	15.00 m
Width of the well	18.80 m

Minimum discharge

Length of the discharge tunnel	215.10 m
Diameter of the excavation	2.00 m
Diameter of the hydraulic tunnel	1.50 m
River derivation dike	earth dike 4m high
River derivation canal	Discharge 3 m3/s and 85 m of length

Basin transfer structures

Basin transfer area	68.77 km2
Height of the derivation dike	10.00 m
Elevation of the structure	3,500 m.snm
Elevation of derivation	3,495 m.snm
Derivation discharge	6.00 m3/s
Length of derivation canal	1,938 m

Table IX- a: Characteristics of the dam

Cost and potential impacts of the dam

Cost and investments

The total cost of the project will be 18,040,125 Nuevo Soles (around 4 million Euros). The financing of the dam would be supported by financing organisms such as the World Bank, the Inter-American Development Bank and the Andean Development Corporation (CAF), government to government loans, private organisms and loans from the Peruvian government. The cost of the dam will be recovered though a fixed water tax per cubic meter delivered for irrigation.

The operation and maintenance costs of the dam will be shared out over the farmers and included in the payment for water turns. A change in the modality of payment is necessary: from monthly payments to delivery payments (basically the advanced payment of the water turns of each user). The price of water turn will rise from 75 Soles/ha/year to 168 Soles/ha/year, which represents an increase of about 124%.

It has been said that with the extra water provided by the dam, farmers will increase their production and thus be able to pay this new water tax. However, the farmers among others believe that this new water tax will be too high for small farmers (with very small parcels), who will see their access to water cut and thus will be forced to sell their land and leave. On the contrary, the farmers with bigger parcels will be able to pay and might have priority for the access to water, thus increasing the gap between poor and lower middle class, which is not what the project aims at.

Improvement of water availability and distribution

The annual precipitation is around 325mm, with monthly precipitations around 1.8 and 96mm, according to one study. Monthly discharges indicate an annual average of 0.303 m3/s, with monthly discharges oscillating between 0.032 and 0.601 m3/s. The annual discharge with 75% of persistence is 0.213 m3/s. The annual water offer from the river is 9.6 MMC, with 6.7MMC with 75% of persistence. This value does not take the springs into account. The maximum discharge for a return period of 50 years is 3.23 m3/s, with the maximum instantaneous flow being 5.8 m3/s. However, with the influence of the springs Totorani (250 l/s), Hospicio (130 l/s), y Chilane (30 l/s), the total water offer in the basin Polobaya amounts to 19.2 MMC. In the study, it has been suggested the derivation from the river Poroto to the dam, which would bring another 4.9MMC and 3.5 with 75% of persistence.

The dam would also have as a smaller effect, to mitigate the vulnerability to flooding of the lower parts of the sub-basin, which can occur during the rainy season.

Improvement of the economic situation

The net value of the production in the basin is evaluated to increase by 27% the first year, reaching an increase rate of 840% the fourth year after the implementation of the project. This incredible jump would be due to:

- The availability and regulation of the water resource all year long, which allows for a better crop management, with higher production volumes and better prices for quality
- The reconversion from traditional products to product of high profitability, aimed at the external market; currently the percentage of products sold to external market is minimal
- Increase the production of Andean crops (Kiwicha, maca, zapallo, oregano, papa, etc.) destined to Peruvian as well as foreign markets
- Retain the migrating population, consolidating the work force in the area

Environmental impacts

The environmental impacts are supposedly small in the case measures are taken to reduce it. They are defined as follows.
During the dam construction:

- The reservoir will flood wetlands and pasture lands where cattle grazes, and which is the unique source of revenues for the locals
- The construction can generate noise and dust, which can have an impact on human health
- Probable accumulation of waste due to the construction process
- Possible accidents
- Disturbance of traffic
- Disturbance of fauna and flora species

But these impacts will be offset by the economical benefits brought by the project. Furthermore, a minimum ecological discharge is planned.

Appendix X: Modeling with SOBEK

Presentation of SOBEK

The software SOBEK, from Delft hydraulics, is an integrated software package for river, urban or rural management which has already proven to give significant results regarding the study of irrigation systems. SOBEK is based on the Saint-Venant equations, solved by a numerical scheme specially developed by Delft Hydraulics. In this study, the modeling is carried out with SOBEK Rural1D.

Modeling strategy

Modeling of the main canals in SOBEK is realized via the interface of the hydraulic modeling software Hec-Ras, which allows importing spreadsheet data or data from other software such as ArcGis. First the image of the canal is imported from ArcGis in order to draw the reach. After the importation of the spreadsheet containing the profiles definitions, data such as reach length (between two cross sections), Manning coefficient and bank stations are entered manually. Boundary conditions are determined as the water levels and discharges at each end of the canal. Lateral outflow is represented by a variation in discharge at different cross sections.

The model is then imported into SOBEK where it is checked and run. Cross sections and boundary points are converted automatically with their data which are verified (**Error! Reference source not found.**). When the basic models are made and checked, reservoirs are added to the canals that possess one as lateral flow node. The reservoirs are supposedly filled at night, between 6 PM and 6 AM, to deliver water during daytime. In the case of the canal Bajo Yarabamba, lateral canals are added with their own cross section. Each first order lateral is modeled as a lateral flow node, like an open-close structure, which is the case for steel gates, but not entirely accurate for the "stone and earth" gates. Otherwise lateral canals are modeled as lateral outflows (yellow points on Figure X- a).

In this modeling, it is assumed that there are no sediments and that the canal is clean from rocks and other obstructive objects, meaning that the canal height is its effective height. The presence of vegetation is reflected in the Manning coefficient. Another assumption is that between each cross section, the dimensions, slope and flow do not change, which is not entirely the case in the real canal.

Scenarios

Since data obtained during the fieldwork were not accurate enough to model the entire system, only the main canals were modeled. If the discharges and sections of the canals had been easier to measure and model, scenarios would have been considered and applied to the initial model. They would have aimed at estimating the impact of the dam on the hydraulic of the canals, but also to explore the possibilities of improving the system itself, as it currently is. One scenario would include a new concrete lining over the entire canal, and thus a reduction in the total water loss. This scenario could be applied in the case of irrigation efficiency improvement in WEAP, with a modification of the conveyance efficiency from 0.85 to 0.9. A second scenario would take into account new discharges, based on results given by WEAP and a fairer distribution of the water between sectors.

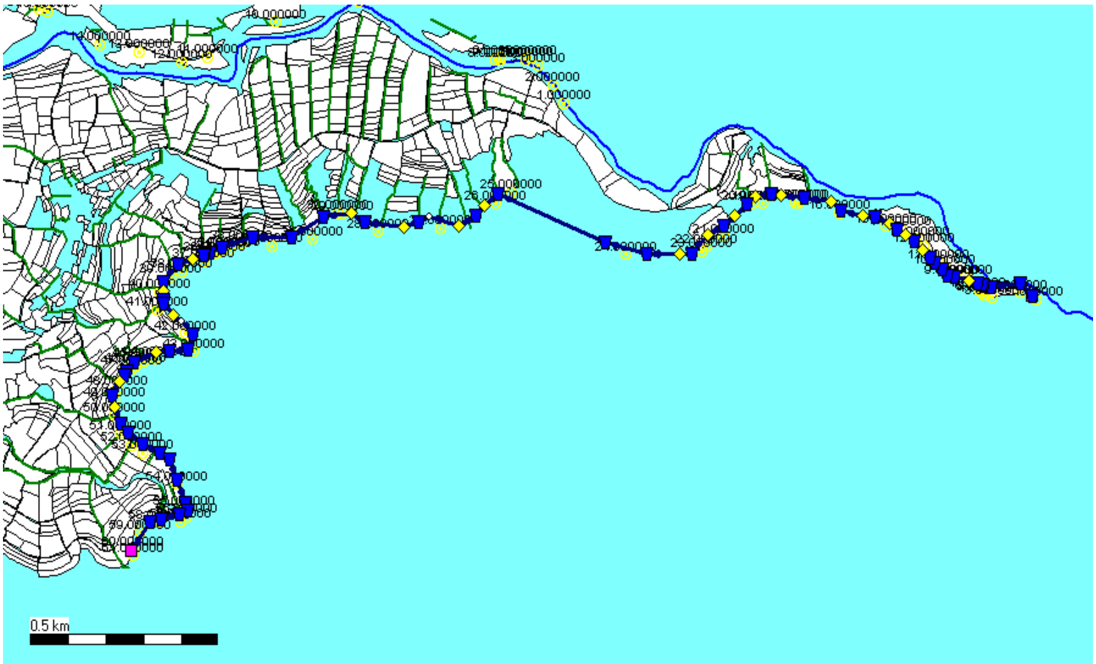

Figure X- a: SOBEK model – Schematic view of Alto Sogay

Results

The results of this study mainly intend to help understand the canal's behavior, and see that, although it is possible to model a canal based on field observations, going into detail proves rather difficult.

Figure X- b represents a side view of the downstream section of Alto Sogay, with the computed water levels. Due to the assumptions used for modeling, the computed water levels sometimes differed from the measured levels.

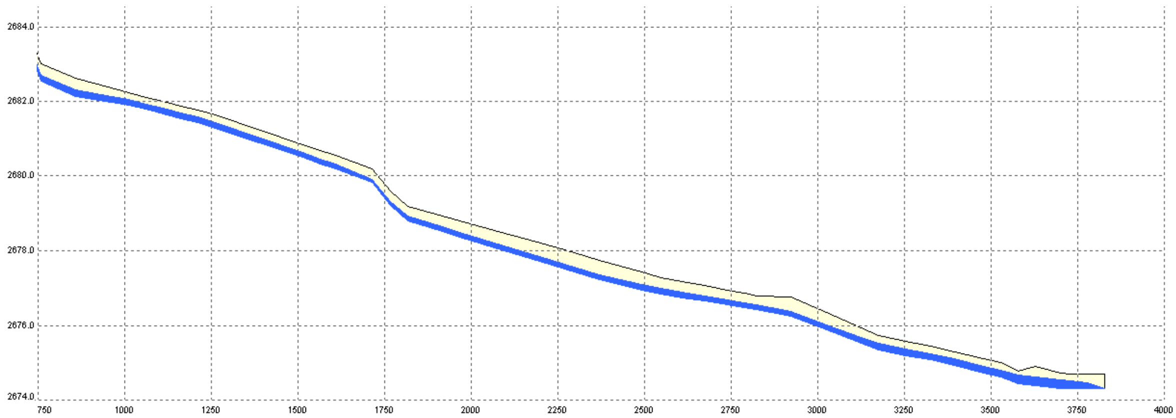

Figure X- b: Downstream section of Alto Sogay

Appendix XI: WEAP

Presentation of WEAP

WEAP (Water Evaluation And Planning System) is a software developed by the Stockholm Environment Institute which provides help for integrated water resources planning. Its operates on the principles of a water balance, representing the system in term of its supply sources, water demands, and other components such as pollution generation and ecosystem requirements through river basins systems.
WEAP operates based on the following process:

- Establishment of the time frame and space boundaries, components of the system and problem configuration
- Definition of the current accounts through a water balance database which represents the actual water demand, resources and supplies.
- Generation/ elaboration of scenarios which simulates alternatives assumptions about future impacts of parameters such as policies, climate and variations in the actual activity on water demand
- Evaluation of the scenario regarding water sufficiency among others (Stockholm Environment Institute, 2009).

Necessary data

Demand sites

Category	Sub-category	Unit	Description	
Water use	Annual activity level	ha	Annual level of activity driving demand	Surface of cultivated area, per district
	Annual water use rate	m3/ha	Total demand derived to site per unit of activity	Actual distribution of irrigation water, per district
	Monthly variation	%	Monthly share of annual demand	Monthly variation in water consumption
	Consumption	%	Percentage of inflow consumed	Consumed inflow of water for irrigation per district
Priority			Demand priority	Priority of the demand site compared to others

Table XI- a: WEAP necessary data –demand sites

Supply and reservoirs

		Sub-category	Unit	Description	
Linking demand and supply	**Losses**	Loss rate	% of flow	Evaporative and leakage loss in link	
River	**Inflows and outflows**	Head flow	CMS	Monthly flow at head of river	
	Reservoirs	Storage capacity	m3	Total capacity of dam	
		Initial storage	m3	Initial volume	
		Volume elevation curve		Relationship between volume and elevation	
		Net evaporation	mm	Monthly net evaporation	
	Diversion	Surface water inflow	CMS	Monthly water inflow to reach	

Table XI- b: WEAP necessary data – supply and reservoirs

Monthly river discharges

Average discharge (m3/s)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual average (m3/s)**
Spring Totorani	0.36	0.39	0.37	0.25	0.2	0.21	0.25	0.25	0.23	0.22	0.26	0.27	0.27
River Polobaya	0.41	0.44	0.41	0.28	0.22	0.24	0.28	0.28	0.26	0.26	0.3	0.31	0.31
River Yarabamba (alto Sogay)	0.31	0.35	0.31	0.23	0.19	0.19	0.25	0.23	0.24	0.24	0.24	0.28	0.25

Table XI- c: Monthly discharges of the rivers Totorani, Polobaya and Yarabamba (JJUU, 2000)

Monthly water demand

The average monthly water demand per irrigation sector was retrieved from the tables in appendix VI. This water demand represents the real demand, as the irrigation efficiency (coefficient 0.45) has already been taken into account.

		Monthly variation (%) - Average water demand (m3/s)											
	Annual water demand (Mm3)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Polobaya	**7.38**	**7%**	**6%**	**6%**	**8%**	**7%**	**7%**	**7%**	**8%**	**8%**	**11%**	**12%**	**11%**
		0.209	0.173	0.184	0.218	0.211	0.198	0.2	0.222	0.236	0.307	0.329	0.313
Alto Sogay	**1.48**	**7%**	**6%**	**6%**	**8%**	**7%**	**7%**	**7%**	**7%**	**9%**	**10%**	**11%**	**10%**
		0.042	0.036	0.036	0.047	0.042	0.04	0.042	0.042	0.051	0.058	0.064	0.058
Bajo Sogay	**2.65**	**7%**	**6%**	**6%**	**8%**	**7%**	**7%**	**8%**	**8%**	**9%**	**10%**	**11%**	**10%**
		0.076	0.062	0.062	0.084	0.076	0.071	0.078	0.078	0.093	0.102	0.116	0.104
Alto Quequeña	**1.39**	**7%**	**6%**	**6%**	**8%**	**7%**	**7%**	**8%**	**8%**	**9%**	**10%**	**11%**	**10%**
		0.04	0.033	0.033	0.044	0.04	0.038	0.042	0.042	0.049	0.053	0.06	0.056
Bajo Quequeña	**2.49**	**7%**	**6%**	**6%**	**8%**	**7%**	**7%**	**8%**	**8%**	**9%**	**10%**	**11%**	**10%**
		0.071	0.06	0.06	0.08	0.071	0.069	0.073	0.073	0.089	0.098	0.109	0.1
Bajo Yarabamba	**1.96**	**7%**	**6%**	**6%**	**8%**	**7%**	**7%**	**8%**	**8%**	**9%**	**10%**	**11%**	**10%**
		0.056	0.047	0.047	0.062	0.056	0.053	0.058	0.058	0.069	0.076	0.084	0.076
Agua Buena and Susihuaya	**2.65**	**7%**	**6%**	**6%**	**8%**	**7%**	**7%**	**7%**	**8%**	**8%**	**11%**	**12%**	**11%**
	1.55	0.044	0.036	0.038	0.047	0.044	0.042	0.042	0.047	0.049	0.064	0.069	0.067
	1.1	0.031	0.027	0.027	0.031	0.031	0.029	0.029	0.033	0.036	0.044	0.049	0.047
		0.075	0.063	0.065	0.078	0.075	0.071	0.071	0.08	0.085	0.108	0.118	0.114
San José de Uzuña and Totorani	**2.52**	**7%**	**6%**	**6%**	**8%**	**8%**	**7%**	**7%**	**8%**	**8%**	**11%**	**12%**	**11%**
	1.51	0.042	0.036	0.038	0.044	0.044	0.04	0.04	0.047	0.049	0.064	0.069	0.064
	1.01	0.029	0.024	0.024	0.029	0.029	0.027	0.027	0.031	0.031	0.042	0.044	0.042
		0.071	0.06	0.062	0.073	0.073	0.067	0.067	0.078	0.08	0.106	0.113	0.106

Table XI- d: WEAP modeling - monthly water demand for each sector

Appendix XII: Photo album

Picture 1: Head gate of Alto Quequeña

Picture 2: Head gate of Alto Sogay

Picture 3: Head Gate of Bajo Quequeña

Picture 4: Head gate of Bajo Sogay

Picture 5: Head gate of Bajo Yarabamba

Picture 6: Head gate of Polobaya

Picture 7: Valley of Quequeña

Picture 8: Valley of Sogay

Picture 9: Valley of Polobaya

Picture 10: The future dam in San José de Uzuña