

Farmers' Strategies Coping with Water Shortage

-- A Case Study in the Irrigation District of La Joya Antigua, Peru

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ABSTRACT

Located between the Andes Mountains and the southwestern coastline of Peru, the irrigation district of La Joya Antigua has a typical sub-tropical desert climate with very little annual precipitation. Study on this irrigation district shows sufficient irrigation water on most of the farms in a wet year but a deficit of irrigation water in a dry year. In order to cope with water shortage, strategies such as focusing on irrigating certain crops, reducing the irrigation area, changing crops to less water demand crops, etc are applied by the local farmers. The farmers' strategies have been proved to be a very effective way of reducing the crop water demand in the irrigation district of La Joya Antigua.

KEYWORDS

Irrigation, Peru, Arid zones, Water shortage, Surface irrigation, Farmers' strategies, Prickly pear cactus.

Introduction

The irrigation district of La Joya Antigua, Arequipa, is located in the Chili-Quilca river basin, which lies between the Andes Mountains and the southwestern coastline of Peru. The irrigation district has a sub-tropical desert climate with annually very little (around 20 mm)² and concentrated period of precipitation (between December and March). Several dams and reservoirs were built along the upstream rivers of the basin to regulate flows for different water use sectors (population, hydropower, agricultural, industrial and mining use), dividing the Chili-Quilca river basin into areas with a so-called regulated system and areas with a non-regulated system. The irrigation district of La Joya Antigua belongs to the regulated system of the Chili-Quilca river basin. The limited amount of precipitation, the loamy sand type soil, the properties of the gravity irrigation system, and the low irrigation efficiency (42%)³ result for the irrigation district of La Joya Antigua in scarcity of irrigation water. However, irrigation activities have been performed in this irrigation district since 1939⁴. Thus, local farmers must have their ways to cope with the limited amount of irrigation water on their farms. In this paper, the farmers' strategies coping with insufficient amounts of irrigation water in the irrigation district of La Joya Antigua are studied and suggestions on the studied farms are given for a better irrigation performance. In **Map 1** the layout of the Chili-Quilca river basin and the location of the irrigation district of La Joya Antigua are shown.

Irrigation Activities and Crop Patterns

Located in the hilly plain area, gravity irrigation is applied in the irrigation district of La Joya Antigua. On most of the farms, surface irrigation (furrow irrigation for prickly pear cactus, maize, potato, onion, garlic, etc) and border irrigation for alfalfa⁵ is applied; drip irrigation is applied only on the farms whose owners are either rich or have high social status. A study performed by the agricultural and water authorities in Peru revealed that the total irrigation efficiency in the irrigation district of La Joya Antigua is 42%⁶. In **Table 1** the conveyance, distribution, application and total irrigation efficiencies in the irrigation district of La Joya Antigua are listed.

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2 Junta de Usuarios Del Distrito de Riego Chili La Joya Antigua (2010). *Plan de Cultivo y Riego 2010-2011*. Chapter 2.2 Clima.

3 Ministerio de Agricultura; Instituto Nacional de Recursos Naturales; Intendencia de Recursos Hidricos (Arequipa, Diciembre del 2004). *Administracion Tecnica del Distrito de Riego Chili*. Volumen I Informe Principal. P 149.

4 Official website of Municipalidad Distrital de La Joya. Historia -- La Irrigación de La Joya. Available online:
<http://municipalidadlajoya.gob.pe/historia.html>

5 Ministerio de Agricultura; Instituto Nacional de Recursos Naturales; Intendencia de Recursos Hidricos (Arequipa, Diciembre del 2004). *Administracion Tecnica del Distrito de Riego Chili*. Volumen I Informe Principal. P 146.

6 Ministerio de Agricultura; Instituto Nacional de Recursos Naturales; Intendencia de Recursos Hidricos (Arequipa, Diciembre del 2004). *Administracion Tecnica del Distrito de Riego Chili*. Volumen I Informe Principal. P 149.

Table 1 Irrigation Efficiencies of District La Joya⁷

Irrigation District	Conveyance Efficiency	Distribution efficiency	Application Efficiency	Total Irrigation Efficiency
La Joya Antigua	85%	83%	60%	42%

The irrigation sequence of farms in the irrigation district of La Joya Antiguais is from upstream to downstream of each irrigation canal and this sequence does not change over time. The irrigation frequency of each farm is usually 3.5 to 4.5 days depending on the location of the farm. The irrigation duration of each farm depends on the licensed irrigation area of the farm -- for each hectare, around 30 to 40 minutes' irrigation duration is assigned. The distribution of irrigation water is consecutive and farmers sometimes have to irrigate in the deep night or early morning.

What was noticed from the fieldwork is that most of the farmers in the irrigation district of La Joya Antigua are the employees of the farm owners. Further interviews of the farmers revealed that most of the owners of the smaller sized farms do not live in the irrigation district of La Joya Antigua but have a job in the City of Arequipa. This kind of owners usually hires one permanent farmer to work on his/her farm and several temporary workers during busy seasons. The owners of middle sized farms usually live close to their farms and hire workers during busy seasons. Owners of large sized farms usually have houses both close to their farms and in the City of Arequipa; and have both permanent and temporary workers working on their farms. The employees hired by the farm owners are called "field administrator" or "field manager" in the irrigation district of La Joya Antigua and they are paid either by money or by having autonomy on part of the farm.

The main crops that are planted in the irrigation district of La Joya Antigua are prickly pear cactus (Peruvian name: Tuna Blanca) and alfalfa. These two types of crops are planted on almost all the farms in the irrigation district of La Joya Antigua. Other crops that are planted are traditional crops such as onion, garlic, potato, and forage maize. Grape, avocado, and various vegetables are also planted in the irrigation district but in a relatively less percentage.

The Prickly pear cactus is grown in the irrigation district of La Joya Antigua not for its fruits, but as a media for the cochineals to parasite and multiplying on. The mature female cochineal body contains carminic acid (C₂₂H₂₀O₁₃) which can be made into a natural dye that is highly demanded in various industries such as clothing, cosmetic, food, medicine, etc. The prickly pear cactus farming is thus also called cochineal farming and can be traced back to more than 1500 years ago in Peru.⁸ The cochineals raised in the irrigation district of La Joya Antigua today are mainly used for export. According to the local farmers, the price of the cochineals had reached to 100 U.S. Dollars per kilo in 2010. To have a better understanding about the cochineal farming in the irrigation district of La Joya Antigua, photos of cochineal farming are attached in **Appendix 5** of the paper.

Alfalfa in the irrigation district of La Joya Antigua is mainly served as forage for the cattle. A milk factory named 'GLORIA' is located in the control area of Lateral 15 and is one of the largest milk producers in Peru. The milk factory 'GLORIA' raises dairy cattle itself as well as buying milk from the farmers that raise dairy cattle in the adjacent areas. Alfalfa is the main source of food for the dairy cattle in the irrigation district of La Joya Antigua. Besides alfalfa, forage maize also serves as food for the cattle and is widely planted as well.

In the irrigation district of La Joya Antigua, prickly pear cactus and alfalfa are multi-perennial crops with several cuts throughout the year. For prickly pear cactus, the cuts are usually 3 times per year; and for alfalfa, the cuts are every two months.

Grapes that are planted in the irrigation district of La Joya Antigua are not only facing the domestic market but export as well. Within the irrigation district of La Joya Antigua, grapes are mainly used for producing wine. One of the famous alcohols in Peru, 'Pisco' is a type of wine that is produced in the Department⁹ of Arequipa. Next to the irrigation district of La Joya Antigua, Vitor Vally is famous for its wine processing plants.

The main crop types in the irrigation district of La Joya Antigua are listed in **Table 2** and the economic value of each crop is listed in **Table 3**.

⁷ Ministerio de Agricultura; Instituto Nacional de Recursos Naturales; Intendencia de Recursos Hidricos (Arequipa, Diciembre del 2004). *Administracion Tecnica del Distrito de Riego Chili*. Volumen I Informe Principal. P 149.

⁸ AnaPeruana.com. (June 27th, 2010). Cochineal Farming in Peru. Available online: <http://www.anaperuana.com/2010/06/27/cochineal-farming-in-peru/>

⁹ Peru is divided into 25 Departments and each department is further divided into Provinces, Cities, District, etc.

Table 2 Main Crop Types in the Irrigation District of La Joya Antigua

Crop Type	Priority	Purpose of Growth	Reason of Growth
Prickly Pear Cactus	1	Cochineal farming	High price; Less irrigation water demand
Alfalfa	2	Forage	Forage for cattle and dairy cattle (milk)
Forage Maize	3	Forage	Forage for cattle and dairy cattle (milk)
Traditional Crops	3	Domestic market	Basic Living; Domestic market
Grape	Depends on the farm owner	'Pisco' wine	High price; Have access to drip irrigation

Table 3 Selling Price of the Main Crop Types in the Irrigation District of La Joya Antigua

Crop Type	Prickly Pear Cactus	Alfalfa	Potato	Grape	Garlic	Onion	Avocado
Price	\$ 80-100 / kg	350 S/. topo / cut	0.40 S/. kg	\$ 0.90-1.10 / kg	5-7 S/. kg	0.35-0.50 S/. kg (0.20 S/. kg in Dec. 2010)	\$ 1 / kg (Export) 3 S/. kg (Domestic)

Note:

- The rate between U.S. Dollar (\$) and Peruvian Nuevo Sol (S/.) fluctuated around 1 : 2.80 during the period of fieldwork.
- 1 topo = 1/3 hectare
- The fresh cochineal 'must be dried to about 30 percent of their original body weight before they can be stored without decaying.'¹⁰
- 'It takes about 155,000 insects to make one kilogram of cochineal.'¹¹
- Prickly pear cactus raises around 34,500,000 cochineal insects per hectare (Calculated according to the information give by Leggett 1994, p.83)¹²
- The harvest of cochineal is 200-500 kg / topo fresh cochineals (\approx 180- 450 kg/ha dry cochineals) depending on the irrigation water availability.
- The price of cochineal fluctuates. The selling price of cochineal was \$ 20 / kg in 2009, \$ 11 / kg in January 2010, \$ 80-100 / kg in December 2010, \$ 30 / kg in January 2011 and \$ 80-100 / kg in April 2011
- The income from cochineal is thus around \$ 14,400-45,000/ha.

From the data above, it can be calculated that the cochineal farming provides the local farmers around \$14,400-45,000/ha income. In February 2011, the Peruvian government set the minimum monthly wage to 600 S/.¹³ (which equals at the time of fieldwork about \$214). And the total irrigation tariff (Irrigation water Tariff + Management Tariff) that farmers need to pay in the irrigation district of La Joya Antigua in the year 2010-2011 is 366 S/. /ha (which equals at the time of fieldwork about \$131/ha). From these numbers, it can be seen that prickly pear cactus farming has constituted a big income source for the local farmers.

Local Water Authorities

The local water authorities in the irrigation district of La Joya Antigua are the Junta de Usuarios (Board of Users) and its Comisiones de Regantes (Irrigation Commissions). The Junta de Usuarios is a regional organization that has the functions of: 'a) Operation and maintenance of irrigation infrastructures; b) distribution of irrigation water; and c) collection and administration of the water tariff' (Article 28, Act N° 29338)¹⁴. It works under the administration and supervision of the Autoridad Nacional del Agua (ANA), the Autoridad Administrativas del Agua Caplina-Ocoña (AAA Caplina-Ocoña) and the Administracion Local de Agua Chili (ALA Chili). In practice, the Junta de Usuarios La Joya Antigua focuses on drawing up the yearly irrigation plan, administrating irrigation activities over the whole irrigation district, and taking charge of the irrigation water distribution and irrigation infrastructure maintenance on the first and second order irrigation canals; the Comisiones de Regantes are responsible for the irrigation infrastructure maintenance on the sub-irrigation canals as well as dealing with the irrigation issues within the range of the commission. Local farmers are responsible for maintaining the end irrigation canals by themselves and informing the Junta de Usuarios about their cropping plans for the next year in advance. The structure of the administrative organizations related to the irrigation district of La Joya Antigua is shown in **Diagram 1**.

During the period of field study, it could be observed that Junta de Usuarios La Joya Antigua is functioning well. It keeps a good relation with the local farmers; follows a certain routine to distribute irrigation water, maintains irrigation canals regularly; and plays a leading role in the regional cultural and sports activities. The local farmers voted for their authorities and most of the farmers are satisfied with the authorities' work.

10 Cochineal. The Dirt Doctor. http://www.dirtdoctor.com/Cochineal_vq1321.htm

11 Cochineal. The Dirt Doctor. http://www.dirtdoctor.com/Cochineal_vq1321.htm

12 Leggett, W.F., 1944, Ancient And Medieval Dyes: Chemical Publishing Co., Inc., Brooklyn, New York. 94p. P83.

13 Perú 21.PE (Miércoles 26 de enero del 2011, 08:45). Sueldo mínimo será de S/.600 en febrero. Available online: <http://peru21.pe/noticia/704400/sueldo-minimo-600-febrero>

14 Autoridad Nacional del Agua; Ministerio de Agricultura (Lima, Perú, Junio 2009). Ley de Recursos Hídricos - Ley N° 29338. © Artículo 26.

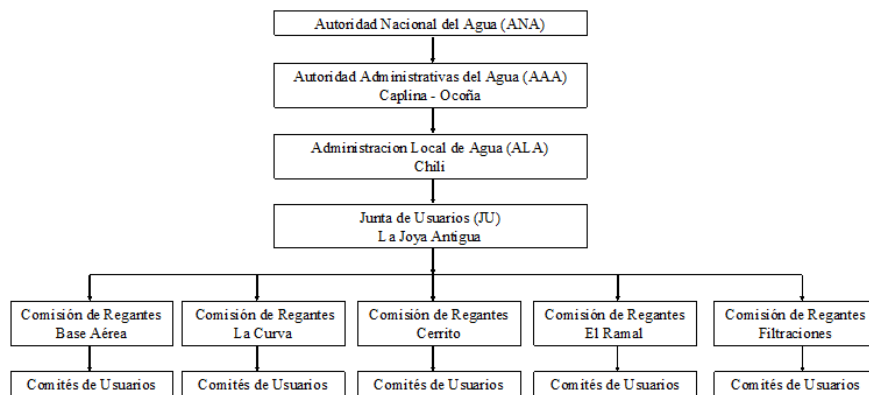


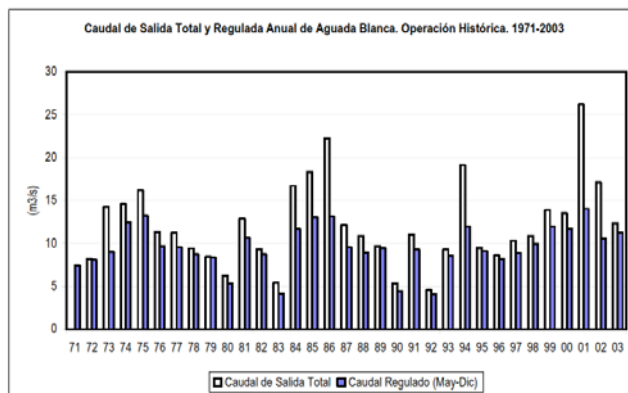
Diagram 1 Structure of the Administrative Organizations Related to the Irrigation District of La Joya Antigua

Research Questions

Although the local authorities in the irrigation district of La Joya Antigua insisted that there has been more or less sufficient irrigation water over the years, the farmers had experienced several dry years. The most mentioned dry years during the interviews are Year 1980 and Year 1983. A study performed by the agricultural and water authorities in Peru shows the sensitivity of the regulated discharges from the upstream reservoir Aguada Blanca¹⁵. As is shown in **Graph 1**, both the total and the regulated discharges from the Reservoir Aguada Blanca in a wet year (Year 1974, 1975, 1984, 1985, 1986, 1994, 1999 and 2003) are high; while in a extreme dry year (Year 1980, 1983, 1990, and 1992), the regulated discharge is low and is insufficient to meet the irrigation demand.¹⁶

However, the irrigation system of the irrigation district of La Joya was built from 1933 till 1938 and the irrigation activities have been performed since 1939¹⁷. In order to continue the irrigation activities and minimize the yield losses during water shortages, not only the regulation of the upstream reservoirs is necessary, but also the farmers' strategies coping with water shortage are important.

Thus, the research questions of this paper are: What strategies do farmers use to cope with water shortage in the irrigation district of La Joya Antigua? Do these strategies help to relieve water shortage? Furthermore, in order to compare with the farmers' strategies, crop water demands under deficit irrigation are modeled in this study to see whether the application of deficit irrigation^{18,19} can bring a better crop performance during water shortage.



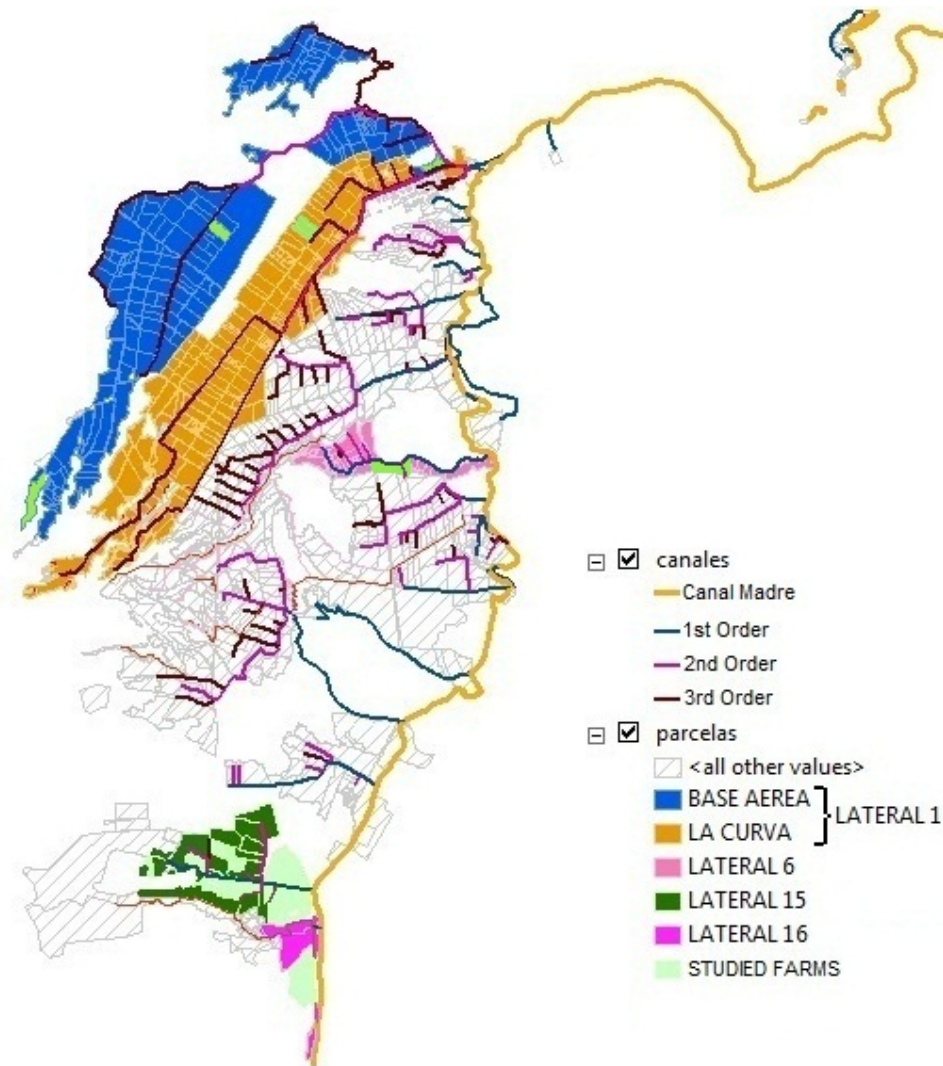
Graph 1 Annually Total and Regulated Flow of Reservoir Aguada Blanca (Historical Operation, 1971-2003)²⁰

15 Water users mentioned here includes population, agricultural, hydropower, industrial, and mining water use.
 16 Ministerio de Agricultura; Instituto Nacional de Recursos Naturales; Intendencia de Recursos Hídricos (Arequipa, Diciembre del 2004). *Administracion Tecnica del Distrito de Riego Chili*. Volumen I Informe Principal. P 119.
 17 Official website of Municipalidad Distrital de La Joya. Historia -- La Irrigación de La Joya. <http://municipalidadlajoya.gob.pe/historia.html>
 18 Deficit irrigation is defined as an optimization strategy 'whereby water supply is reduced below maximum levels and mild stress is allowed with minimal effects on yield. Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains than maximizing yields per unit of water for a given crop.' (FAO (2002). *Water Reports* 22)
 19 Food And Agriculture Organization of the United Nations (Rome, 2002). *Deficit Irrigation Practices, Water Reports* 22. ISBN: 92-5-104768-5.
 20 Ministerio de Agricultura; Instituto Nacional de Recursos Naturales; Intendencia de Recursos Hídricos (Arequipa, Diciembre del 2004).

Research Methodology

With a total area of 4589 hectares and a licensed irrigation area of 3986 hectares²², the entire irrigation district of La Joya Antigua cannot be studied within a short time study like this work. Thus, several typical irrigation canals (called 'lateral' in the irrigation district of La Joya Antigua) and farms were selected to represent the whole irrigation district.

To guarantee the selected laterals are representative, laterals in the upstream, midstream and downstream of the irrigation district of La Joya Antigua needed to be selected. With this purpose, Lateral 1 (located at upstream), Lateral 6 (located at midstream), Lateral 15 (located at downstream) and Lateral 16 (located at downstream) were chosen. For each lateral, farms that are located in the upstream, midstream and downstream area were selected to represent all the farms along one lateral. These studied farms were selected during the fieldwork to ensure the farmers' presence on the studied farms and their willingness to be interviewed. The selected laterals and farms are marked in **Map 2** with dark green and light green colours.



In order to have an overview of the irrigation water availability in the irrigation district of La Joya Antigua, three methods are used -- Calculation of the discharge officially assigned; Field measurements; and Simulation using a SOBEK model. For each method, irrigation water availability in both a wet year and a dry year is included.

The discharges assigned to the irrigation district of La Joya Antigua through Canal Madre (the main irrigation canal of

²² Information from Administracion Local de Agua Chili.

²³ GIS Map provided by Administracion Local de Agua Chili..

the irrigation district of La Joya, which includes the irrigation district of La Joya Antigua (upstream) and the irrigation district of La Joya Nueva (downstream)) and the first order irrigation canals are calculated by multiplying the licensed irrigation area with the irrigation module. The irrigation module is approved by ALA Chili according to the release of the upstream reservoirs and is the same for all the irrigation districts within the regulated system of the Chili-Quilca river basin.²⁴ In **Table 3**, the factors that influence the value of the irrigation module and the calculation method of the irrigation module are listed. The calculated irrigation module should only be used as a reference value since many of its influencing factors vary from time to time.

When comparing the calculated irrigation modules with the historical irrigation modules²⁵, the calculated irrigation modules give an acceptable inaccuracy around 10% in a normal or a wet year, while an unacceptable inaccuracy of around 20% to 50% inaccuracy in a dry year. Thus, the irrigation modules for a typical dry year are calculated by averaging the historical irrigation modules of the dry years. Since most of the first-hand data were collected during the fieldwork (agricultural year²⁶ 2010-2011) and the year was reported as a wet year, the agricultural year 2010-2011 was taken as a typical wet year.

The calculation of the irrigation modules and the discharges in the studied laterals are listed in the **Appendix 6**.

Table 3 Calculation Method of the Irrigation Module

Influencing Factors	Unit	Month
① Discharge -- Represa Aguada Blanca	m3/seg	Input -- Discharge Represa Aguada Blanca ^{25,26}
② Discharge -- Return Waters	m3/seg	2.300
③ Discharge -- Recovery 45%	m3/seg	$=((1)-(2)-(5))*0.45$
④ Discharge -- Available Flow	m3/seg	$=1+2+3$
⑤ Discharge -- Non-agricultural Uses	m3/seg	$=0.05+0.15+1.5+1=2.700$
⑥ Area -- Agricultural Uses	Ha	$=7+8=15542$
⑦ Area -- Chili Regulated	Ha	Input -- $6720.4+(110*0.73) = 6800.700$
⑧ Area -- La Joya Regulated	Ha	Input -- $3986.3429+5896-365.45 = 9516.8929$
⑨ Irrigation Modules	l.p.s./Ha	$=(((4)-(5))/(6)*1000)$

Note: The texts with red colour are the required input data.

Due to the lack of time and facilities, **Field measurements** were performed using the float method. The measured discharges reflect flows in a 'real' situation and are compared with the calculated assigned discharges. Besides, the field measurement was also applied to collect data for setting up the SOBEK model. During the field measurements, some exceptions on the float method were made considering the conditions of the weather and the irrigation canals:

- 1) The distance for the float method was fixed to be 10 meters for each measurement. However, a straight section less than 10 meters was applied when the irrigation canal encountered frequent winding or dimension change.
- 2) Two types of floats were used for the measurements -- short branches and a 1.5 litre plastic bottle filled with 50% of water. The short branches were mainly used for the middle and small sized irrigation canals; while the plastic bottle was used for the big sized irrigation canals. The water in the plastic bottle has the purpose of avoiding external influences (such as wind and rapid flow) to the float. A rope of 50 meters long was tied to the plastic bottle to drag the bottle back after each measurement to protect the irrigation system and the environment.
- 3) During the field measurement, if the float deviated from the middle line of the irrigation canal or the float was obviously influenced by wind, the measurement became invalid and another round needed to be performed.

The data obtained from the field measurements are listed in the **Appendix 7**.

A **SOBEK modeling** was used to simulate the flows in the irrigation canals that could not be measured. To set up the SOBEK model, some necessary assumptions were made:

- 1) When Canal Madre meets its flow capacity, all the first and second order irrigation canals meet their capacity as well;

²⁴ Information provided by the technical manager from Junta de Usuarios La Joya Antigua.

²⁵ Gabriel Riega (2002). Thesis: *Planeamiento de La Cuenca Chili*. Anexos -- Cuadro 40.

²⁶ The agricultural year in the irrigation district of La Joya Antigua starts from August to July in the next year.

- 2) Gates along similar irrigation canals were assumed to have the same dimensions;
- 3) Bed levels of the downstream irrigation canals are connected with the bed levels of the upstream canals.
- 4) In order to prevent the influence of variable annual precipitations on the simulated flows, the precipitations are set to be zero in the model.

For canal information that was not available, a report containing the studies on the irrigation canals of the irrigation district of La Joya Antigua was used.²⁷

The layout of the SOBEK model is shown in **Appendix 8**. The SOBEK model for the irrigation district of La Joya Antigua and the input data are attached on the CD.

The crop water demand on each farm studied is simulated using the AquaCrop model. To set up the model, the local climate, crop types, rooting depth of each crop, irrigation method, and soil information on each studied farms are needed. Most of this information was collected through interviews with the local farmers. The outputs of the AquaCrop Model are the net crop water demand of the simulated crop, which needs to be divided by the total irrigation efficiency (42%)²⁸ of the irrigation district to obtain the gross crop water demand. Besides the simulation of the crop water demand, the crop water demand under the farmers' strategies during water shortage was also simulated. Even though it was known from the interview that the farmers' strategies are mostly based on their experience, these strategies are supposed to relieve water shortage. The crop and soil information collected from interviews are listed in **Table 4**.

It is also suggested that farmers do and could apply deficit irrigation. Deficit irrigation allows farmers keeping the variety of crops on their farms with relatively good yields but with much less crop water demand. It is defined as an optimization strategy '*whereby water supply is reduced below maximum levels and mild stress is allowed with minimal effects on yield. Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains than maximizing yields per unit of water for a given crop.*'²⁹ (FAO Water Reports 22, 2002) To apply deficit irrigation, re-distribution of the received irrigation water received is needed, which means the necessity of reservoirs being installed on the farms.

The percentage of Readily Available Water (RAW) in the soil is an important factor deciding crop water demand. RAW is defined as '*the fraction of Total Available Water (TAW, which is the difference between the water content at field capacity and wilting point) that a crop can extract from the root zone without suffering water stress.*'³⁰ (FAO Paper 56, 1998). In this study, the percentage of RAW for each crop under the present irrigation method is calculated and is called 'present percentage RAW'; to simulate the crop water demand when deficit irrigation is applied, an optimized percentage of RAW for each crop based on the optimization between crop water demand and crop yield is also calculated and is called 'optimized percentage RAW'.

The interview questions to the local farmers and the calculation of the present and optimized percentage of RAW can be found in **Appendix 9**. The AquaCrop model for each crop on the studied farms is attached on the CD.

To have an overview of the crop water demand under the present percentage of RAW, the farmers' strategies, and under the optimized percentage of RAW, six scenarios are set up for each crop on each studied farm:

Scenario 1: Simulation of the crop water demand under the present percentage RAW.

Scenario 2: Simulation of the crop water demand under the present percentage RAW with the farmer's solution to cope with water shortage.

Scenario 3: Simulation of the crop water demand under the present percentage RAW with the farmer's will of changing crop types (only for the farms that have this information).

For the studied farms that have reservoirs installed for irrigation, the following scenarios are set up:

27 Junta De Usuarios Del Distrito De Riego Chili La Joya Antigua (2006). Inventario de La Infraestructura de Riego y Drenaje y Vías de Comunicación del Junta de Usuarios La Joya Antigua.

28 Ministerio de Agricultura; Instituto Nacional de Recursos Naturales; Intendencia de Recursos Hídricos (Arequipa, Diciembre del 2004). *Administración Técnica del Distrito de Riego Chili*. Volumen I Informe Principal. P 149.

29 Food And Agriculture Organization of the United Nations (Rome, 2002). *Deficit Irrigation Practices*. Water Reports 22. ISBN: 92-5-104768-5.

30 Richard G. Allen, et al. FAO - Food and Agriculture Organization of the United Nations (Rome, 1998). *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage*. P 56. ISBN 92-5-104219-5. Available online: <http://www.fao.org/docrep/X0490E/X0490E00.htm>

Scenario 4: Simulation of the crop water demand under the optimized percentage RAW (The biomass or yield reduction of the simulated crop is within 5% compared to the yield under the present percentage RAW. This is applied also to Scenario 5 and Scenario 6.).

Scenario 5: Simulation of the crop water demand under the optimized percentage RAW with the farmer's solution to cope with water shortage.

Scenario 6: Simulation of the crop water demand under the optimized percentage RAW with the farmer's will of changing crop types (only for the farms that have this information).

In order to avoid the influence of the variable annual precipitations on the simulated crop water demand, the precipitations are set to be zero.

Table 4 Crop and Soil Information

Location	Water Source	Soil Type	Soil Depth (m)	Crop Type	Plant Density (Plants/m ²)	Effective Rooting Depth ³¹ (m)	Planting / Harvest Time
L1 Upstream	L 1A-A	Loamy Sand	1 m	Cactus (50%)	6	0.4	January - December
				Garlic (25%)	55.6	0.3	January - July
				Alfalfa (25%)	22.2	1	6 cuts per year. Planted in May 2010, will be replanted in May 2012
L1 Midstream 1	L 1C-1	Loamy Sand	0.5 m; Assume 1 m	Garpe (100%)	0.8	1	Planted 4 years ago. The harvest is in October and lasts 40 days of harvest.
L1 Midstream 2	L 1A-2	Loamy Sand	0.5 m; Assume 1 m	Onion (20%)	55.6	0.3	February - late May
				Garlic (40%)	55.6	0.3	January - late June
				Cactus (40%)	6	0.4	Recently planted. The harvest to be in August
L1 Downstream	L 1A-4	Loamy Sand	1.5 m; Assume 1 m	Cactus (99%)	6	0.4	Has been planted for 13 years. The harvest is very 4 months.
				Alfalfa (1%)	22.2	1	Has been planted for one year. Planted in October. Has 12 cuts a year.
L6 Midstream	L 6, L 6-1, L6-1-1	Sandy	1 m	Potato (30%)	4	0.4	February 6 th - May Another variety: March 19 th - June
				Garlic (10%)	55.6	0.3	February 8 th - August.
				Cactus (20%)	6	0.4	Has been planted for 3.5 years. Harvested in February. The harvest is every 4 months.
				Avocado (20%)	0.2	0.5	Planted in 2008. In 2009 was harvested a little because the production takes two years.
				Onion (10%)	55.6	0.3	April - May
				Alfalfa (10%)	22.2	1	(American Variety) Planted in 2010. Two cuts per year.
L15 Upstream	L 15	Loamy Sand	0.5-0.7 m; Assume 1 m	Potato (5/3 ha)	4	0.4	July to September
				Maize (7 ha)	7.5	1	
				Paprika (5/3 ha)	8.3	0.5	Winter - summer
				Leek (4/3 ha)	66.7	0.3	
				Celery (2/3 ha)	16	0.3	
				Alfalfa (the rests)	22.2	1	
	L 15	Loamy Sand	0.5-0.7 m; Assume 1 m	Maize (5 ha)	7.5	1	
				Garlic (5 ha)	55.6	0.3	
				Oats (the rests)	30.9	1	
				Barley (the rests)	120	1	
L15 Midstream 1	L 15, GOMEZ	Loamy Sand	1 m	Cactus (80%)	6	0.4	Planted in October, November and December. The 1st harvest is in May.
				Onion (20%)	55.6	0.3	January - April

31 Richard G. Allen, et al. FAO - Food and Agriculture Organization of the United Nations (Rome, 1998). Crop evapotranspiration - *Guidelines for computing crop water requirements - FAO Irrigation and drainage*. P 56. ISBN 92-5-104219-5. Chapter 8 - ETC under soil water stress conditions. Available online: <http://www.fao.org/docrep/X0490E/X0490E00.htm>

L15 Midstream 2	L 15, L 2-15	Sandy	0.3 m; Assume 1 m	Cactus (70%)	6	0.4	Planted in January 2010. The 1st harvest in June.
				Potato (15%)	4	0.4	March 15th - June.
				Maize (5%)	7.5	1	May - September 15.
				Alfalfa (10%)	22.2	1	Planted in June 2010. 7 cuts per year.
L15 Midstream 3	L 15	Sandy	0.2 m; Assume 1 m	Cactus (100%)	6	0.4	Has planted for 8 years. 10% is 8 months old. 4/3 ha harvests every 4 months.
L15 Downstream 1	L 15, L S/N-15	Clay	7 m	Cactus (98%)	6	0.4	Planted 10 years ago. Replanted every 4 years. Harvested every 4months.
				Alfalfa (2%)	22.2	1	Planted in 2010. Every 1.5 months each cut is made.
L15 Downstream 2	L 15	Loamy Sand	0.3 m; Assume 1 m	Cactus (100%)	6	0.4	Has been planted about 10 years. The harvest is every 4 months. Replanted when there is no longer cactus springs.
L16 Upstream	L 16	Sandy	0.4 m; Assume 1 m	Alfalfa (50%)	22.2	1	Planted in June 2010. The cut is every 25 days. 9 cuts per year.
				Maize (50%)	7.5	1	Planted in December. Another variety: Planted in July. 4 to 5 months of harvest.

Note: - 'cactus' is used as a short name for 'prickly pear cactus';
- The soil depths on most of the farms studied were assumed to be 1 meter since the effective rooting depth of the perennial crops are around 1 meter.

Results

Comparisons between the calculated assigned discharge, discharge from the field measurement, and the discharge indicated on the canal rulers/control gates are shown in **Table 5**. As can be seen from the Table, the discharges measured in Lateral 6 and Lateral 15 are in the same order of magnitude as the discharges indicated on the canal rulers/control gates, which indicates the field measurement is more or less accurate. However, the measured discharges are twice as big as the assigned discharges. This was further confirmed with one of the engineers from ALA Chili-- when ALA Chili received complaints from the downstream irrigation district of La Joya Nueva, engineers were sent to check the discharges that were taken by the laterals in the irrigation district of La Joya Antigua. Most of the time, a double amount of the allowable assigned discharges was found in the laterals in the irrigation district of La Joya Antigua. There are several reasons that ALA Chili could not enforce their power to control the amount of irrigation water taken by the irrigation district of La Joya Antigua: 1) ALA Chili does not have enough money to pay for a person to permanently control the amount of irrigation water that was taken by each lateral; 2) The local farmers do not know technically that they are taking too much water but instead, they always think they do not have enough water -- when engineers from ALA Chili tried to regulate the discharges taken by the laterals, the farmers resisted by force. Thus, more irrigation water was taken by the irrigation district of La Joya Antigua, while leaving the downstream irrigation district La Joya Nueva a lack of irrigation water. In coping with this situation, the irrigation district of La Joya Nueva is 'forced' to use the irrigation water more efficiently and is seeking money from ALA Chili to build their own irrigation canal directly from the water source.

Table 5 Comparison between Maximum Allowable Assigned Discharge and Measured Discharge

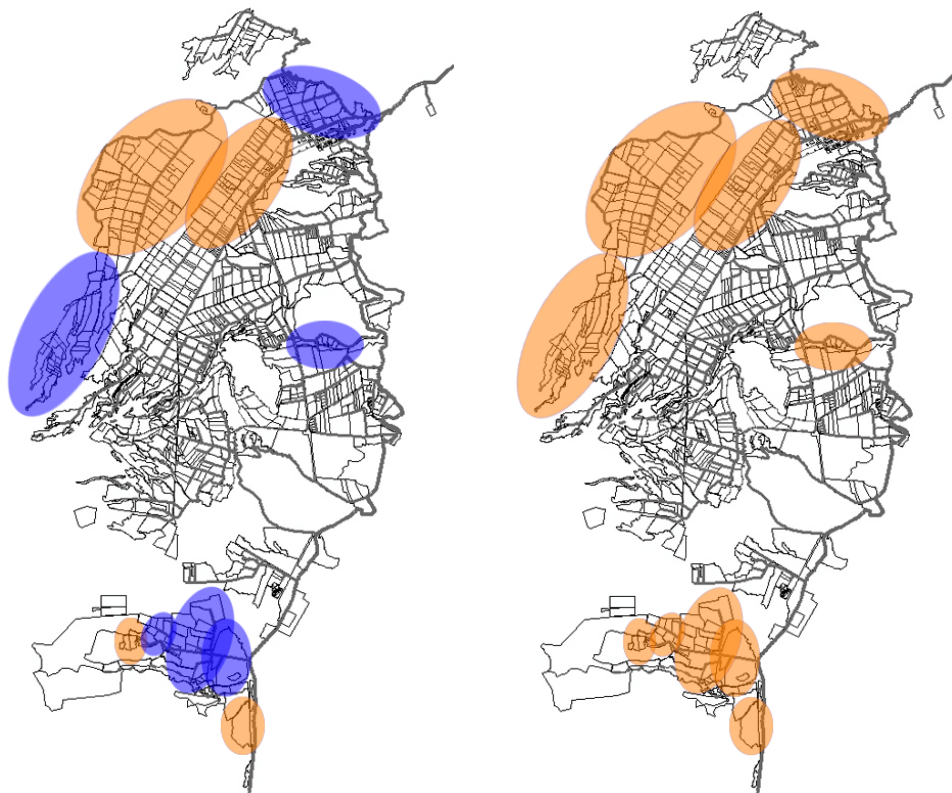
Laterals	Assigned Discharge (l/s)	Field Measurement -- Float Method (l/s)	Canal Ruler/ Control Gate (l/s)	Time & Date
Lateral 1	1400	--	1400 (Canal Ruler)	April 25 11:15 am
Lateral 6	73	156 (Branches) 134 (Bottle)	210 (Canal Ruler)	April 26 12:00 pm
Lateral 15	117	226 (Branches)	225 (Control Gate)	April 29 4:50 pm
Lateral 16	53	117 (Branches)	--	April 26 3:40 pm

Comparison between irrigation water availability and crop water demand shows irrigation water sufficiency in the irrigation district of La Joya Antigua. In **Map 3**, irrigation water sufficiency under the present percentage RAW in a wet year is shown; in **Map 4**, irrigation water sufficiency under the present percentage RAW in a dry year is shown. Since the studied farms were selected to represent the farms within the upstream, midstream and downstream region, the

irrigation water sufficiency of the studied farms are extended to the upstream, midstream and downstream regions as well.

From **Map 3** and **Map 4** it can be seen that although farmers on the downstream farms of Lateral 1 and Lateral 15 are not satisfied with the amount of irrigation water assigned to their farms, there is sufficient irrigation water in both of the regions. The reason for this contradiction is the crop types on the farms -- On the downstream farms of Lateral 1 and Lateral 15, more than 98% of the irrigation area of each farm studied is planted with prickly pear cactus. Interviews to the farmers on these farms revealed that half of the interviewed farmers had given up the traditional crops years ago due to the lack of irrigation water; the rest of the farmers confirmed that there is insufficient irrigation water on their farms while the prickly pear cactus has a much lower crop water demand than other crop types. Besides, 100% of the interviewed farmers considered prickly pear cactus as an important economic crop.

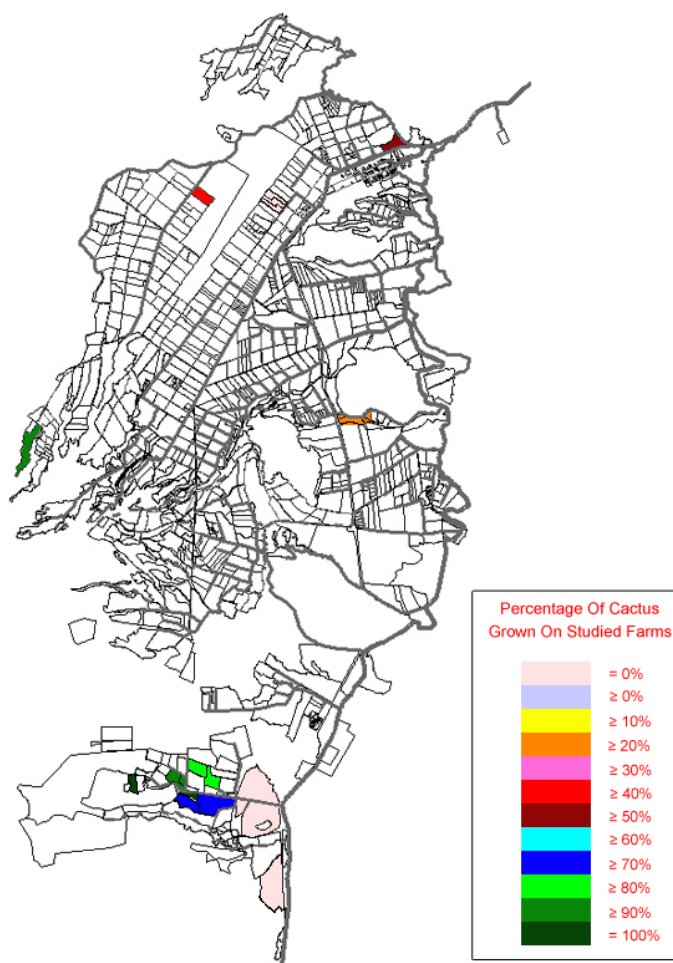
In **Map 5**, the percentage of prickly pear cactus that is planted on each farm studied is shown. As can be seen from the map, the percentage of prickly pear cactus increases from upstream to downstream along the laterals studied. For example, along Lateral 15, 0% prickly pear cactus is planted at upstream compared to 100% at downstream. When taking the irrigation water sufficiency into consideration (**Map 3**), the percentage of prickly pear cactus corresponds to the irrigation water sufficiency along the laterals studied.



Map 3 Irrigation Water Sufficiency - Wet Year

Map 4 Irrigation Water Sufficiency - Dry Year

Note: - The dark blue colour represents sufficient irrigation water within the region; while the orange colour represents insufficient irrigation water within the region.
 - The downstream farms of Lateral 15 and Lateral 16 have access to the upwelling groundwater.



Map 5 Percentage of Prickly Pear Cactus Grown on Each Studied Farm

In order to cope with water shortage, local farmers have certain strategies according to the irrigation water availability, the locations of their farms, and their economic conditions. Although the farmers' strategies are mainly based on experience, these strategies have contributed to the continuous development of the irrigation district for more than 70 years. In **Map 6**, an overview of the farmers' strategies on each farm studied is shown.

In the following paragraphs, the analyses of the farmers' strategies are discussed. Furthermore, deficit irrigation is taken into consideration to see whether it helps to relieve water shortage in a large extent. At the end of each analysis, recommendations on the farms studied are given to allow a better irrigation performance.

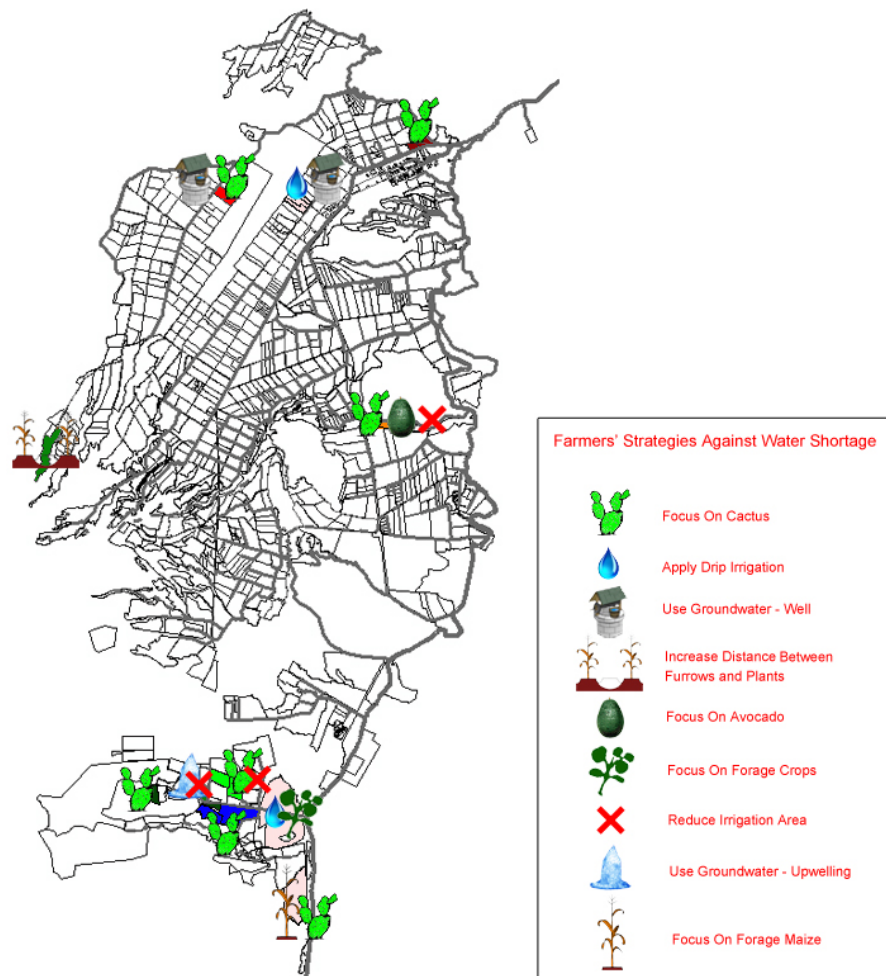
During the analyses, the prickly pear cactus becomes a very interesting crop. The first outputs of the AquaCrop modeling indicated that prickly pear cactus would have a high crop water demand resulting in insufficient irrigation water on most of the farms. However, this result contradicts with the farmers' statements that the prickly pear cactus requires less irrigation water than the traditional crops. Based on the fact that the farmers usually know the best about what is happening on their farms, a reconsideration on the prickly pear cactus was made. The prickly pear cactus is a type of vegetation that is different from a normal crop. As a C4 crop surviving in the extreme situations in the deserts, the prickly pear cactus stores water in its pads; its stomatas only open in the night. Besides, the prickly pear cactus is extremely tolerant to water stress and is very sensitive to water logging. As mentioned in the Introduction, the prickly pear cactus in the irrigation district of La Joya Antigua is grown as a media for the cochineal farming and the harvest is every 4 months. Thus, a minimum amount of irrigation water that can keep the pads of prickly pear cactus growing is sufficient.

In order to obtain a reasonable crop water demand, the monthly crop water demand of the prickly pear cactus from the report *Plan de Cultivo y Riego 2010-2011 Junta de Usuarios Del Distrito de Riego Chili La Joya Antigua*³² are used in

32 Junta de Usuarios Del Distrito de Riego Chili La Joya Antigua (2010). *Plan de Cultivo y Riego 2010-2011*. Anexos -- Table No. 03 Modulos Y

this study.

A further study on the AquaCrop model for the prickly pear cactus revealed that a crop transpiration coefficient (K_{cb}) of 0.55 and a default value for the soil evaporation coefficient (K_e) may bring the water demand of the prickly pear cactus close to the referred value.



Map 6 Summarization of the Farmers' Strategies

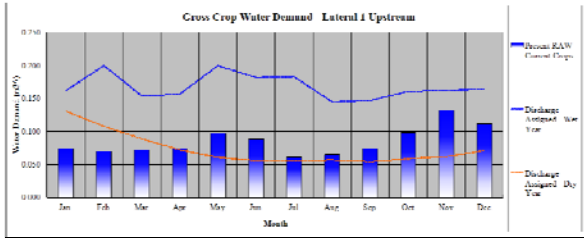
The farmers' strategies coping with water shortage can be classified as follows:

- **Focusing on irrigating certain crops while giving up others:** This strategy is mostly used by the farmers in the irrigation district of La Joya Antigua. During water shortage, most of the farmers choose to focus on irrigating the crops that either require less irrigation water or have a high (potential) market price. Crops of these types are prickly pear cactus and alfalfa. These two crops are chosen because of the low crop water demand of prickly pear cactus, high selling price of the cochineals, and the necessary food source for the dairy cattle.

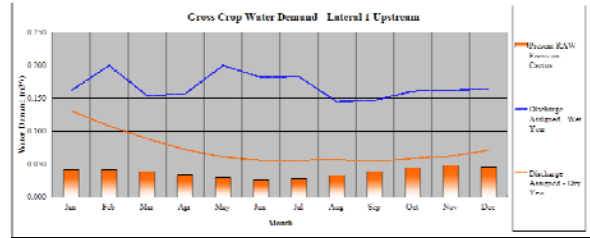
Examples for this type of strategy can be found at the upstream of Lateral 1. On the farms (Farm 00133.01 and Farm 00133.02), the farm owner was not satisfied with the amount of irrigation water supplied to his farms. During water shortages, the farmer chose to focus on irrigating prickly pear cactus and gave up alfalfa and garlic. Besides, the farmer showed his interest to change all the crops to prickly pear cactus.

From **Graph 2.1** it can be seen that under the current crop types and the present percentage RAW, the irrigation water supply is sufficient for the crop water demand in a wet year; while insufficient in a dry year. Under water shortage, the

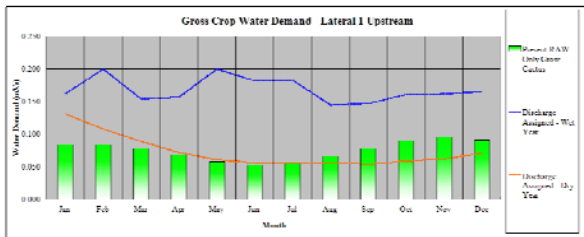
farmers' strategy of focusing on irrigating prickly pear cactus while giving up garlic and alfalfa can greatly reduce the crop water demand (**Graph 2.2**), resulting in a sufficient irrigation water supply in a dry year. If the water shortage continues, the farmer would like to change all the crops on the farms to prickly pear cactus. As can be seen from **Graph 2.3**, there would be a sufficient irrigation water supply in a wet year; while in a dry year, a reduction of 1.2 hectares (35%) of the irrigation area should be made between August and December. However, based on the fact that the minimum total soil intake of the prickly pear cactus lies between 300 and 400 mm/year³³ (around 1/3 to 1/2 of the present water demand), there shouldn't be a big influence on the growth of the prickly pear cactus even if no reduction of the irrigation area was made. In the following graphs, 'cactus' is used as a short name for 'prickly pear cactus'.



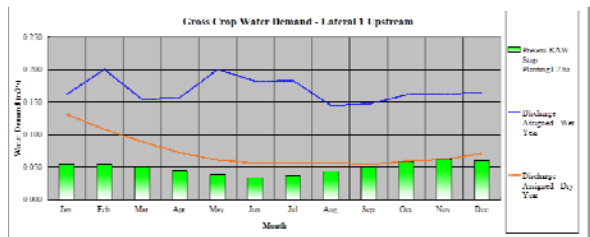
Graph 2.1 Crop Water Demand -- Current Crops



Graph 2.2 Crop Water Demand -- Focusing on Cactus



Graph 2.3 Crop Water Demand -- Grow 100% Cactus

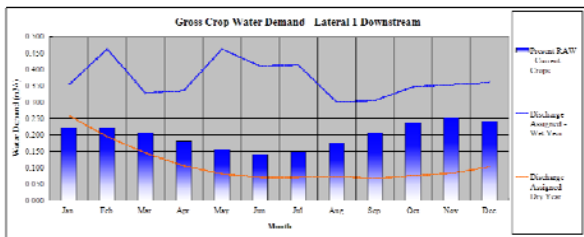


Graph 2.4 Crop Water Demand -- Stop Planting 1.2 ha of 100% Cactus

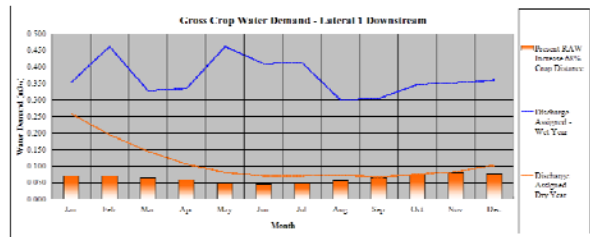
- **Increasing the distance between the furrows and plants:** This method is usually applied by the farmers that have large percentage of prickly pear cactus on their farms. Since the effective rooting depth of the prickly pear cactus is relatively shallow (around 40cm³⁴), it is not difficult to remove the plant.

Examples for this type of strategy can be found at the downstream of Lateral 1. On the farm (Farm 00118), 99% prickly pear cactus and 1% alfalfa are grown. The farmer was not satisfied with the amount of irrigation water supplied to his farm. Since the prickly pear cactus requires less irrigation water than the traditional crops, the farmer is not willing to change the crop types on his farm. During water shortage, the field manager chose to increase the distance between the furrows and plants.

From **Graph 3.1**, it can be seen that under the current crop types and the present percentage RAW, the irrigation water supply is sufficient for the crop water demand in a wet year; while insufficient in a dry year. Under water shortage, an increment of the distance between the furrows and plants up to 68% would bring a balance between the irrigation water supply and crop water demand (**Graph 3.2**). However, due to the extreme draught tolerance of prickly pear cactus, the percentage of the distance increment can be reduced to 40% - 50% (**Graph 3.3** and **Graph 3.4**).



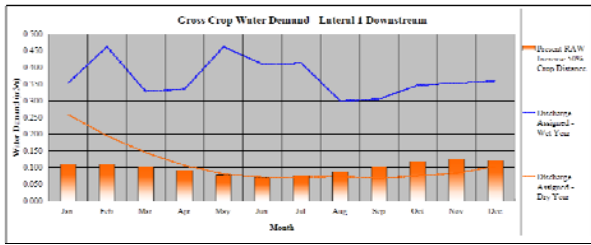
Graph 3.1 Crop Water Demand -- Current Crops



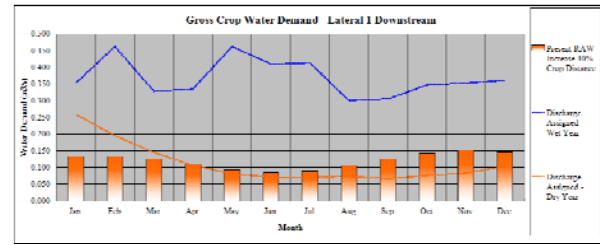
Graph 3.2 Crop Water Demand -- Increase 68% Crop Distance

33 Henry N. Le Houérou (1996). The role of cacti (*Opuntia* spp.) in erosion control, land reclamation, rehabilitation and agricultural development in the Mediterranean Basin. *Journal of Arid Environments* (1996) 33: 135-159. P138.

34 FAO-ICARDA International Technical Cooperation Network on Cactus. *Cactusnet Newsletter, Issue 8*. Page 4. Available online: http://www.cactusnet.org/cactusnet_newsletter.php



Graph 3.3 Crop Water Demand -- Increase 50% Crop Distance

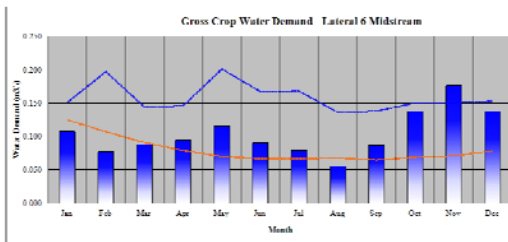


Graph 3.4 Crop Water Demand -- Increase 40% Crop Distance

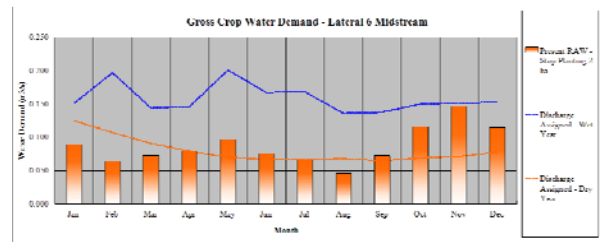
- **Reducing the irrigation area:** Under water shortage, some farmers choose to decrease the irrigation area on their farms. The reduction of the irrigation area is usually from 1 topo (1/3 hectare) to 2 hectares of the irrigation area of their farms.

Examples for this type of strategy can be found at midstream of Lateral 6. The farms (Farm 00615, Farm 00618, Farm 00616, Farm 00617, Farm 30006, etc) within this region are owned by the brothers and sisters from one big family. Since the brothers and sister of the family were abroad, they asked the interviewed farmer to take care of their farms. On these farms, a variety of crops (potato, garlic, prickly pear cactus, avocado, onion and alfalfa) are grown. The farmer was not satisfied with the amount of irrigation water supplied to her farms and was disappointed that her land on the other side of the irrigation canal could only be left barren. Under water shortage, the farmer would stop planting 2 hectares of the irrigation area; and under severe water shortage, the farmer would focus on irrigating prickly pear cactus and avocado while giving up potato, garlic, onion and alfalfa. The farmer would like to change the crop types on her farms only if drip irrigation could be applied. However, this is not possible on the short term since the farmer does not have enough money to install the facilities for drip irrigation. Furthermore, a reservoir is present on the farms.

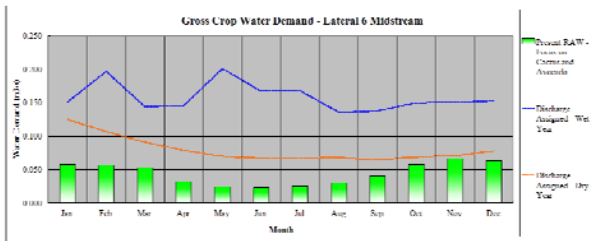
From **Graph 4.1**, it can be seen that under the current crop types and the present percentage RAW, the irrigation water supply is sufficient (except for November) for the crop water demand in a wet year; while insufficient in a dry year. Under water shortage, the farmer's strategy of stop planting 2 hectares of the irrigation area does reduce the crop water demand but cannot fully cope with the water shortage in a dry year (**Graph 4.2**). When focusing on irrigating prickly pear cactus and avocado while giving up other crops, from **Graph 4.3** it can be seen that the irrigation water supply becomes sufficient for the crop water demand in a dry year.



Graph 4.1 Crop Water Demand -- Current Crops



Graph 4.2 Crop Water Demand -- Stop Planting 2 ha



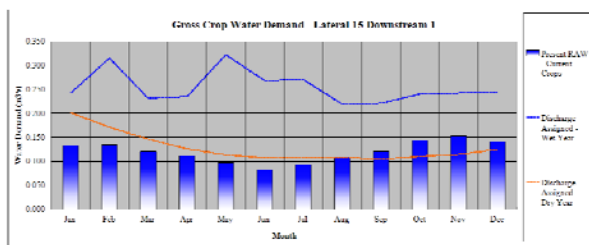
Graph 4.3 Crop Water Demand -- Focusing on Cactus and Avocado

- **Seeking groundwater:** The soil in the irrigation district of La Joya Antigua is loamy sand and it has a good infiltration capacity. Together with the topography of the irrigation district of La Joya Antigua, the excess irrigation water from upstream farms infiltrates into the ground rapidly and flows to the downstream of the irrigation district. At the places where the ground level is low (such as downstream of Lateral 15, downstream of Lateral 16, and Irrigation Commission Filtraciones), upwelling groundwater is present and has provided these regions with an extra source of

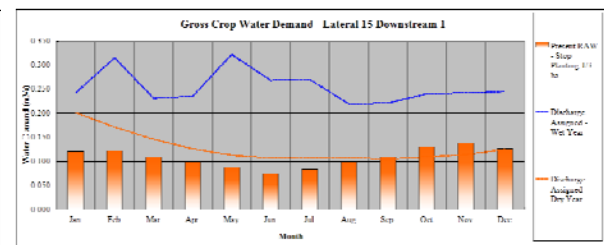
irrigation water supply.

Examples for this type of strategy can be found at downstream of Lateral 15. On the farms (Farm 00858 and Farm 00859), 98% prickly pear cactus and 2% alfalfa are planted. The owner of these farms was not satisfied with the amount of irrigation water supplied to his farms. According to him, an additional water supply for 1 hectare of the farm is needed. Under water shortage, the farmer chose to stop planting 1/3 of the irrigation area and at the same time use the upwelling groundwater as another source of irrigation water supply. Since 98% of the irrigation area is covered by prickly pear cactus, the farmer was not willing to change crop types. Furthermore, there is one reservoir on the farms.

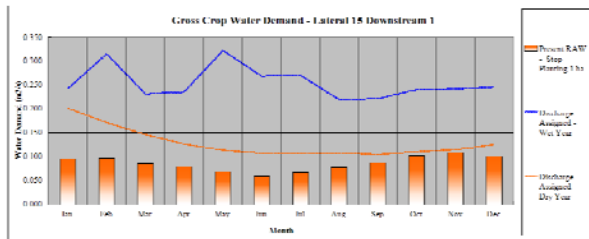
From **Graph 5.1**, it can be seen that under the current crop types and the present percentage RAW, the irrigation water supply is sufficient for the crop water demand in a wet year; while insufficient in a dry year. Under water shortage, the farmer's strategy of stop planting 1/3 hectare of the irrigation area reduces the crop water demand but there is still an insufficient irrigation water supply between September and November in a dry year (**Graph 5.2**). With the upwelling groundwater as an additional source of irrigation water supply, there would be sufficient irrigation water supply in a dry year. Except for the upwelling groundwater, a reduction of the irrigation area of 1 hectare also results in a sufficient irrigation water supply in a dry year (**Graph 5.3**).



Graph 5.1 Crop Water Demand -- Current Crops



Graph 5.2 Crop Water Demand -- Stop Planting 1/3 ha



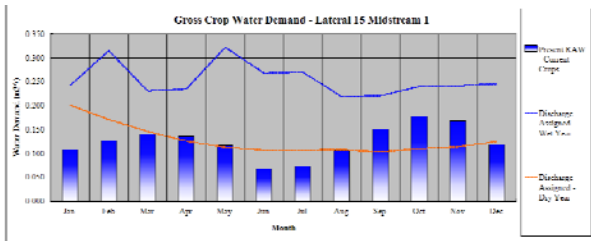
Graph 5.3 Crop Water Demand -- Stop Planting 1 ha

- **Changing crops to less water demand crops:** Farms located at the downstream of the irrigation canals usually experience more frequent water shortage. Since the prickly pear cactus requires less irrigation water while bringing a high economic value, it has become the main crop type of the downstream farms. During interviews, quite a few farmers showed their interest in changing all the crops on their farms to prickly pear cactus in case of water shortage. However, this may not be recommended because monoculture may have severe impacts on the local biodiversity, soil nutrition, crop yield and crop price.

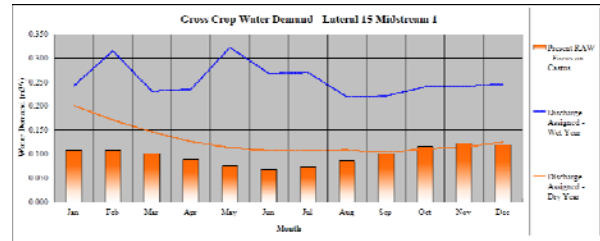
Examples for this type of strategy can be found at midstream of Lateral 15. On the farms (Farm 00735 and Farm 00849 with 2 hectares extension), 80% prickly pear cactus and 20% onion are planted. The field administrator of the farms showed dissatisfaction with the amount of irrigation supplied to the farms. Under water shortage, the farmer chose to focus irrigating prickly pear cactus while giving up onion. Besides, the farmer showed his interest in changing all the crops on the farms to prickly pear cactus while giving up onion. Furthermore, there is one reservoir present on the farms studied.

From **Graph 6.1**, it can be seen that under the current crop types and the present percentage RAW, the irrigation water supply is sufficient for the crop water demand in a wet year; while insufficient in a dry year. Under water shortage, the farmer's strategy of focus on irrigating prickly pear cactus brings a balance between the irrigation water supply and crop water demand in a dry year (**Graph 6.2**). With the farmer's interest of changing all the crops to prickly pear cactus, an insufficiency of the irrigation water supply is shown between September and December in a dry year. Since the prickly pear cactus is extremely tolerant to water stress, the insufficiency of the irrigation water supply in a dry year would not cause problem to the growth of the plant (**Graph 6.3**). However, stop planting 1.8 hectares (26%) of the irrigation area

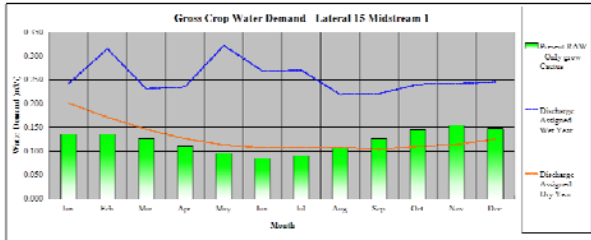
could be an option to bring a balance between the irrigation water supply and crop water demand in a dry year (**Graph 6.4**).



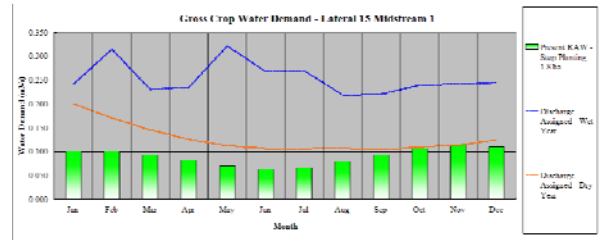
Graph 6.1 Crop Water Demand -- Current Crops



Graph 6.2 Crop Water Demand -- Focusing on Cactus



Graph 6.3 Crop Water Demand -- Grow 100% Cactus

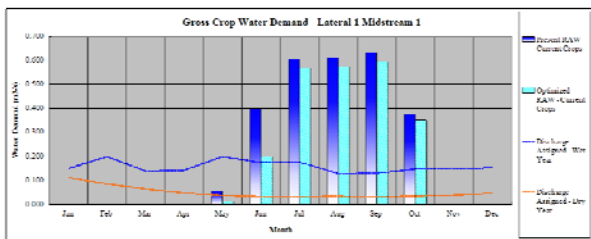


Graph 6.4 Crop Water Demand -- Stop Planting 1.8 ha of 100% Cactus

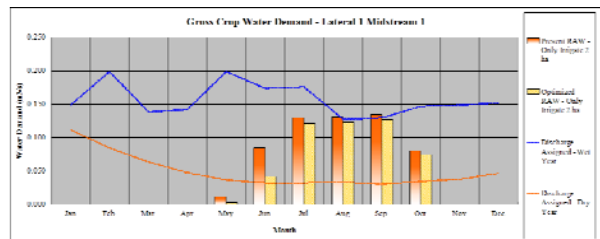
- **Applying "advanced irrigation" methods:** Drip irrigation is considered as an advanced irrigation method in the irrigation district of La Joya Antigua. The local farmers are aware that drip irrigation can reduce the amount of irrigation water applied to the crops and allow them to grow a variety of crops which cannot be grown under the present irrigation water supply. With these benefits, the local farmers are willing to change their current irrigation method to drip irrigation. However, there is no financial support for the farmers who would like to change their current irrigation method to drip irrigation and most of the farmers in the irrigation district of La Joya Antigua do not have enough money to invest in drip irrigation. Thus, drip irrigation is only applied by the people that are either rich or have a high social status.

Examples for this type of strategy can be found at midstream of Lateral 1. On the farm (Farm 00162), only grapes are grown. According to the field manager, the irrigation water supplied to this farm is only sufficient for 2 hectares of the irrigation area. To cope with the insufficient water supply, the farm owner decides to change from gravity irrigation to drip irrigation at 2 months before harvest. By this way, it is said that the irrigation water supply is enough for the other 7 hectares of the farm.

From **Graph 7.1** it can be seen that under the current crop types, the irrigation water supply is insufficient for the crop water demand under either the present or the optimized percentage RAW. However, the farmer's statement that the irrigation water supply is only sufficient for 2 hectares of the irrigation area is confirmed in **Graph 7.2**. Since the owner of the farm would neither change the crop type nor reduce the irrigation area, drip irrigation is necessary to reduce the gross crop water demand on the studied farm.



Graph 7.1 Crop Water Demand -- Current Crops



Graph 7.2 Crop Water Demand -- Only Irrigate 2 ha

- **Asking for more water:** When asked whether it is possible to ask for more irrigation water, all the farmers under interviewed stated that it was very difficult. Besides, none of the interviewed farmers sell or buy the irrigation water from their farm neighbours. Although it is very difficult to ask for more water, exceptions were made to the rule offenders, who are supposed to receive no irrigation water as penalty. During the fieldwork, the irrigation water supply

to one farm was cut off due to the delay in handing in the water tariff. However, the farmer received his water back soon after negotiating with the operator.

- **Using reservoirs and wells:** Most of the farms studied in the irrigation district of La Joya Antigua have either reservoirs or wells installed. It is not sure whether farmers use reservoirs to re-distribute the irrigation water supplied to their farms, but most of the farmers choose to first fill the reservoirs before irrigating crops during their irrigation turn.

Since there is no financial support for the construction of either reservoir or well, the dimensions of the reservoirs on the different farms vary a lot. For the farms with rich owners, large reservoirs with dimensions larger than 50m*50m*2m are present; while for the farms with poor farmers, there is usually one small reservoir for garden or cattle use only. In **Picture 1** and **Picture 2**, the reservoirs belonging to the rich and poor farmers are shown, respectively.



Picture 1 Large Reservoirs at Upstream of Lateral 15



Picture 2 Small Reservoir at Downstream of Lateral 1
-- For Garden Use Only

- **Checking the upstream gates:** Since the gates along the end irrigation canals are controlled by farmers themselves, it is not surprising to see farmers wandering around the upstream gates before and during their irrigation turn. By this way, the downstream farmers make sure that the upstream farmers do not take more than the assigned amount of irrigation water. However, this strategy would lead to – and is a sign of – potential tensions between the farm neighbours when the downstream farmers found out or thought that their farm neighbours were taking more than the assigned amount of irrigation water.

During the interviews, most of the farmers showed their satisfaction to the Junta de Usuarios La Joya Antigua's work, but complained that they did not solve the water related conflicts between farm neighbours and did not enforce their power to eliminate the stealing of irrigation water well.

- **Stealing of irrigation water:** According to the interviews with the local farmers, stealing of irrigation water is not frequent but exists. Although most of the farmers do not know exactly how much water they are getting, they recognize whether other farmers are taking their share of irrigation water by observing the discharge flow into their farms. Besides, most farmers choose to walk along the irrigation canals to make sure that the stealing of irrigation water would not happen. The Junta de Usuarios La Joya Antigua had drawn up the regulations on the penalties of stealing irrigation water. However, stealing is not eliminated. During fieldwork, my assistant and I found that a farmer slightly opened the gate to his/her farms right after the downstream farmer had left; In another lateral, a farmer who frequently steals irrigation water was pointed to by many farmers. In **Picture 3** and **Picture 4**, the stealing of irrigation water in the irrigation district of La Joya Antigua is shown.

Another type of stealing water is in the form of stealing crops. The crop that is prone to be stolen is prickly pear cactus due to the high price of cochineals. According to the local farmers, the thieves are not from the farm neighbours but from the market. The stealing usually happens in the night during the periods that the cochineals are ready to be harvested. Although this type of stealing water is not related to the water-related conflicts between farm neighbours, the water in the shape of crop is lost. To prevent this stealing, most farmers hire guards to watch their farms in the night; some farmers also have big dogs watching their farms.



Picture 3 Gate Opening after Irrigation Turn



Picture 4 Farmer that Frequently Steals Water

Besides the irrigation activities, other uses of irrigation water are common and frequent in the irrigation district of La Joya Antigua. Male farmers like to shower in the irrigation canals after one-day's work and bus drivers prefer to use the irrigation water to wash their buses. It is not safe to apply these activities beside the irrigation canals since the flows in most of the irrigation canals in the irrigation district of La Joya Antigua are quite rapid. In **Picture 5** and **Picture 6**, other uses of irrigation water in the irrigation district of La Joya Antigua are shown.



Picture 5 Other use of Irrigation Water



Picture 6 Other use of Irrigation Water

Conclusions and Recommendations

Conclusions

Analyses comparing irrigation water availability and crop water demand in the irrigation district of La Joya Antigua indicate a sufficient irrigation water supply on most of the studied farms in a wet year; while an overall water shortage in a dry year. Along each lateral studied, the increasing percentage of prickly pear cactus planted on the farms (**Map 5**) corresponds to the decreasing irrigation water sufficiency. Through the study, the research questions of this paper can be answered:

What strategies do farmers take to cope with water shortage in the irrigation district of La Joya Antigua?

The farmers' strategies coping with water shortage are based on the irrigation water availability, the locations of their farms, and their economic conditions. The farmers' strategies can be classified as follows:

- Focusing on irrigating certain crops while giving up others

- Increasing the distance between the furrows and plants
- Reducing the irrigation area
- Seeking groundwater
- Changing crops to less water demand crops
- Applying "advanced irrigation" methods
- Asking for more water
- Using reservoirs and wells
- Checking the upstream gates
- Stealing of irrigation water

From these strategies, focusing on irrigating certain crops while giving up others, reducing the irrigation area and changing crops to less water demand crops are mostly applied in the irrigation district of La Joya Antigua.

Do these strategies help to relieve water shortage?

Although mainly based on experience, the farmers' strategies reduce the crop water demand in a large extent. On most of the farms, the farmers' strategies bring a balance between the crop water demand and the irrigation water supply in a dry year. The farmers' strategies have contributed to the development and continuous irrigation activities in the irrigation district of La Joya Antigua for more than 70 years.

Does deficit irrigation bring a better crop performance during water shortage?

The farmers' strategies give good enough results on reducing the crop water demand. Since a large percentage of prickly pear cactus is grown in the irrigation district of La Joya Antigua, the shortage of irrigation water would not cause problem to these farms. Although simulations of the deficit irrigation were made to the crops on each farm studied, the results cannot compete with the farmers' strategies: On most of the farms, deficit irrigation only reduces very little of the crop water demand and cannot bring a balance between the crop water demand and the irrigation water supply.

The analyses of irrigation sufficiency and the deficit irrigation on the farms studied are given in **Appendix 14**.

Recommendations

During the interviews, many farmers showed their interest in changing all the crops on their farms to prickly pear cactus in case of water shortage. Based on the fact that prickly pear cactus has already been planted in a large percentage in the irrigation district of La Joya Antigua, it is advisable that the local authorities and farmers be aware of the impacts of the monoculture.

One of the reasons that the farmers choose to focus on irrigating prickly pear cactus under water shortage is because there is not sufficient irrigation water while prickly pear cactus is the type of vegetation that requires less irrigation water than the traditional crops. The local farmers are aware that by applying drip irrigation, the irrigation water can be saved and a variety of crops can be planted. However, there is no financial support for farmers who would like to change their current irrigation method to drip irrigation; and the farmers cannot afford the expenses. Thus, it is recommended that the local authorities provide financial support as well as technical support to the farmers who would like to change their irrigation method to drip irrigation.

The local farmers voted for the local authorities and they support the local authorities' work. However, most of the farmers complained that the Junta de Usuarios La Joya Antigua does not solve the water-related conflicts between farm neighbours and does not enforce their power to the rule offenders. Thus, it is suggested that the Junta de Usuarios La Joya Antigua put certain attention on solving the water-related conflicts between farm neighbours and enforce their power to the rule offenders.

Last but not the least, it is recommended that local authorities put attention on the water treatment before delivering water to the farms. The irrigation water used in the irrigation district of La Joya Antigua is directly from the Chili River, which contains the untreated domestic and industrial wastewater from the City of Arequipa. Although farmers in the irrigation district of La Joya Antigua have been appealing the government for the clean irrigation water, no action had been taken over the past decades.

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