Water, Energy, and Food Nexus in the Santa Eulalia sub-basin, Peru

Scoping Study for the Food Sector

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Summary: This report describes the food sector in the Santa Eulalia sub-basin, Peru, and is part of a nexus scoping study that aims to disentangle water-related interlinkages and trade-offs among the water-energy-food sectors, and to provide recommendations for interventions that contribute to alleviation of the competition for water among the sectors.

Keywords: climate change, water-energy-food nexus, Rimac basin, water use efficiency

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Preface

This report describes the food sector in the Santa Eulalia river basin, Peru, and is part of a scoping study that aims to disentangle water-related interlinkages and trade-offs among the water-energy-food sectors, and to provide recommendations for interventions that contribute to alleviation of the competition for water among the sectors. Other studies related to the water and energy sectors in the Santa Eulalia river basin have been carried out by Deltares and TNO, respectively.

The report supports the Netherlands Embassy in Lima to support the Government of Peru towards the strengthening the alignment between its water policies with energy and alimentation policies (WEF nexus). The study identifies current and potential trade-offs and synergies between the water, energy and food sectors by analysing their interdependencies and identifying practical solutions and good practices that contribute to an integrated management of the WEF resources and climate resilience .

The study was commissioned and financed by RVO in the context of Missies Private Sector Development, under contract number 201911159. Outcomes of the study will provide input to developing a Private Sector Development Water, Energy and Food nexus study for Santa Eulalia river basin (under the PSD Toolkit).

See table continuation on next page

Summary

The Water, Energy, Food (WEF) nexus is a relatively new approach that takes into account the interactions between these sectors and aims to minimize trade-offs (developing one sector at the expense of the other) and to maximize possible synergies between the sectors. The Government of the Netherlands supports the Peruvian Government in integrating WEF nexus aspects in its policies for sustainable development and climate change. To this end, a project has been formulated to develop a WEF nexus approach for the Santa Eulalia sub-basin in Peru. This sub-basin is part of the Rimac basin and has an important role in the provision of water and hydroelectric power for the Capital Lima, housing over 10 million people. Climate change is expected to further put pressure on the limited water resources through higher temperatures, more rapid melting of glaciers feeding into the sub-basin and changed precipitation patterns.

This report describes the food sector in the Santa Eulalia sub-basin and is part of a three-pronged scoping study. The water and energy sectors have been analysed by the Dutch partners Deltares and TNO, respectively. The scoping study aims to disentangle water-related interlinkages and trade-offs among sectors and stakeholders in the sub-basin, and to provide recommendations for interventions that could contribute to alleviation of the competition for water among the sectors.

The scoping study is based on a literature review (desk research) and on interviews with local stakeholders. Since international travelling of the authors was hampered by the Covid-19 pandemic, the interviews were performed by the local consultancy company *Futuro Sostenible*.

The study shows that agriculture in the Santa Eulalia sub-basin is highly diverse associated with differences in altitude. Livestock farming dominates in the upper zone (> 3,500 m asl), while custard apple and avocado are dominant fruits in the middle (2,300 – 3,500 m) and especially lower (900 – 2,300 m) zone of the sub-basin. In general, the production intensity of agricultural enterprises is low across the basin with low external inputs, except for irrigation water that is applied through inefficient flooding practices in the middle and lower zone. Consequently, agricultural yields are low and generate little income. Especially in the upper zone, poverty is widespread among the farm households. The major demand for water in the Santa Eulalia sub-basin is from agriculture and farmers in the middle and lower zone face water scarcity at least during parts of the year.

Many WEF stakeholders have been identified in the Santa Eulalia sub-basin and further downstream that are involved in or affected by the water management in the sub-basin. However, current efforts to coordinate the management of the water resources seem scattered without clear delineation of responsibilities.

A qualitative problem analysis of the agricultural-water relationships in the sub-basin shows both water demand and supply limitations. The water supply to agriculture is limited because of i) low annual rainfall, especially in the middle and lower zones, ii) decreasing groundwater levels, and iii) misalignment in water discharge from water reservoirs for hydroelectricity generation in the upper zone and the need for irrigation water in the middle and lower zones. The water demand by agriculture is high because of: i) inefficient irrigation practices, ii) conveyance losses in irrigation channels, iii) a shift to crops (e.g. avocado) with high water requirements, and iv) low organization level among farmers in the upper zone resulting in uncontrolled water use. Solving these water supply and demand problems in agriculture will result in various trade-offs with the water and energy sector. Various of such trade-offs have been identified and described qualitatively in this report. Further research is needed to quantify the identified trade-offs, and to assess interventions aimed at minimizing the trade-offs and maximizing possible synergies between the sectors.

An integrated climate, land, energy and water systems modelling approach is recommended go gain more quantitative insights in the problems, trade-offs and potential synergies of solutions to mitigate

problems. With such an approach the magnitude of problems can be made explicit supporting informed decision-making and operational water resources management. Furthermore, in view of the current and increasing claims for water by different sectors a number of no-regret activities are proposed that could contribute in the short term to reduced water demand and improved water supply:

1. Improve the capacity of farmers on good agricultural practices to improve resource use efficiencies, especially water use efficiency.
2. Improve the current irrigation infrastructure and practices ranging from reducing water conveyance losses, better irrigation scheduling and changes from the current flood irrigation practices to more efficient water supply methods.
3. Soil conservation measures in the upper zone of the basin to improve water infiltration and reduce water runoff and soil erosion.
4. Strengthening the local governance structure related to WEF nexus by setting up a policy dialogue with stakeholders to share information and develop common understanding of the problems, trade-offs, and choices that need to be made. This should support the development of a shared vision on how the scarce water resources in the Santa Eulalia sub-basin can be best used and managed, now and in the future.

1 Introduction

1.1 Santa Eulalia and the Water, Energy, and Food Nexus

The Santa Eulalia river is a sub-basin feeding into the Rímac basin, which flows from the Andes to the city of Lima, where it runs into the Pacific Ocean. The sub-basin is of great importance to Lima, which houses around 10 million inhabitants, about one third of Peru's population (OECD, 2020). In comparison to other South American cities, Lima has one of the lowest per capita water resource reserves rates, i.e. Lima is ill-prepared to meet increasing water demand over the next decades (*ibid*.). The Santa Eulalia sub-basin is a major source of drinking water and electricity for Lima: housing five dams with a combined power of 511 MW, supplying the main part Lima's electric power, and about half of its drinking water (Herz and Gamio 2018). In addition, the sub-basin provides livelihood to the residents of the sub-basin, the majority of which depends on agricultural production for their livelihood and income {GRADE, 2018 #17}. Because of the low rainfall, especially in the middle and lower part of the basin, crop production requires the use of irrigation water: 98% of the agricultural production is irrigated, forming a major consumptive demand on the water resources in the sub-basin {GRADE, 2018 #17}. Due to the water demand in the sub-basin for consumptive use (water, sanitation, and hygiene - WASH), energy generation, and agriculture, there is competition for this resource amongst the three sectors, and we speak of a Water, Energy and Food (WEF) nexus.

This report is part of a three-pronged scoping study to analyze the WEF nexus in the Santa Eulalia sub-basin, with each report focusing on one of the sectors. The water, energy, and food sectors were analyzed by the Dutch partners Deltares, TNO, and Wageningen Research, respectively. The scoping study aims to unravel water-related interlinkages and trade-offs between sectors and stakeholders in the sub-basin, and to provide recommendations for interventions that could contribute to alleviation of the competition for water among the sectors. The recommendations should be further explored in a follow-up project. In this report, we focus specifically on water use related to food and agricultural production in the sub-basin, and its interlinkages with the water and energy sectors.

We start by briefly describing the sub-basin's geographical scope and water balance in Section 2. We then explain what are the main stakeholders from the perspective of the agricultural sector[1] in Section3. We then analyze the current situation in Santa Eulalia in terms of agricultural production Section 4. Based on the gathered information, we identify in Section 5 the problems in the sub-basin with their root-causes, and the trade-offs and synergies that occur as a result. In Section 6 we identify the currently ongoing activities to address the identified problems. Finally, in Section 7 we state our main conclusions and list a number of recommendations and no-regret interventions specifically for the agricultural sector. The interventions could alleviate some of the identified problems and should be further investigated in a follow-up project.

1.2 Methodology

To gather information on the current situation in the sub-basin, this scoping study is based on a literature review (desk research) and on interviews with local stakeholders. The main source of literature used were reports of previous studies of the basin. As international travelling was hampered by the Covid-19 pandemic, the interviews were performed by the local consultancy company Futuro Sostenible. Analysis on interlinkages between the WEF sectors was done by the three Dutch partners through weekly information alignment in meetings between the institutes, and by collaboration on the problem analysis and proposal for interventions between October 2020 and March 2021.

[1] We use the terms 'agricultural sector' and 'food sector' as synonyms in this report. The agricultural sector is a broader concept also including non-food crops such as fiber and energy crops, but these crops are not produced in the Santa Eulalia.

2 Description of the Sub-basin

2.1 Geographical Scope

The Santa Eulalia sub-basin is the northern branch of the Rimac basin. The Rimac basin lies North-East of Peru’s capital, Lima, and flows into the Pacific Ocean in the city. The geographical scope of this study is limited to the Santa Eulalia sub-basin, as demarcated by the red dotted line in Figure 1, and its impact downstream in the city of Lima. The Santa Eulalia sub-basin is generally divided according differences in altitude into the upper (>3,500 m asl), middle (2,300 -3,500 m asl, and lower (900 – 2,300 m asl) zones. The districts in each zone are listed in Table 1. Notice that the districts of San Mateo de Otao and San Antonio are only partly included in the sub-basin. This is because those two districts are bisected by the mountain ridge that delineates the sub-basin.

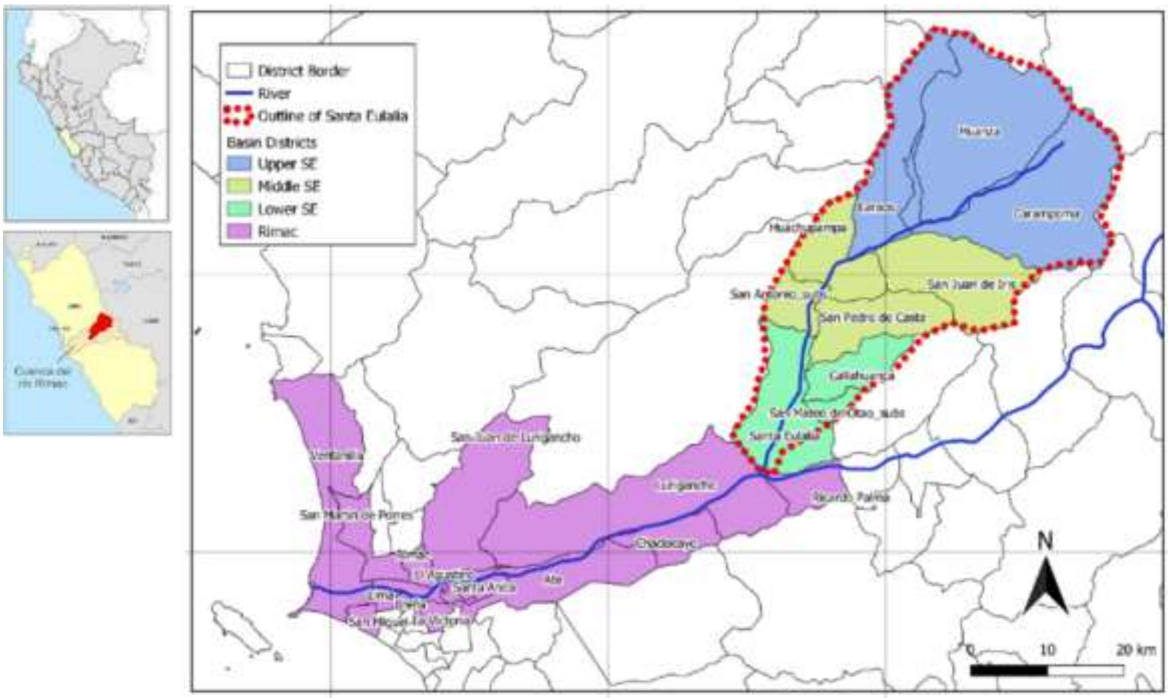

Figure 1. Geographical delimitation of the Santa Eulalia sub-basin indicated by red dotted line. The upper, middle, and lower zones of the sub-basin are indicated in blue, yellow, and green respectively. The pink area is the lower section of the Rímac basin including Lima. SE = Santa Eulalia. Sub-basin and zone delimitation as defined by Floríndez (2019).

Table 1. Districts in the upper, middle, and lower zone of the Santa Eulalia sub-basin, according to Floríndez (2019). Notice that of the districts San Mateo de Otao and San Antonio only a subsection is included in the sub-basin because they are bisected by the mountain ridge that delineates the sub-basin.

Upper Zone	Middle Zone	Lower Zone	Rímac
Huanza	Huachupampa	Callahuanca	Ricardo Palma
Carampoma	San Juan de Iris	Santa Eulalia	Lurigancho
Laraos	San Pedro de Casta	San Mateo de Otao (subsection)	Chaclacayo
	San Antonio (subsection)		Ate
			San Juan de Lurigancho
			Rimac
			...

2.2 Water supply and demand

2.2.1 Water supply

The water system of the Santa Eulalia sub-basin is composed of its main river, the Santa Eulalia, seven smaller rivers, 141 streams, 77 natural lakes, 26 dammed lakes, 2 dams, and 83 springs ('manantial') (Herz and Gamio 2018). The main sources of water for the basin are:

- **Melting water from glaciers**: The Santa Eulalia river originates from the melting water of the Uco glacier, at 5100 m.a.s.l. (OACHIRILU 2019). The gradual disappearance of mountain glaciers due to climate change is expected to have an impact on the water balance of the sub-basin, although the effects are difficult to predict (GRADE 2018).
- **Precipitation:** Precipitation contributes to the river flows (OACHIRILU 2019). In the upper zone precipitation is around 800 mm per year, and around 100 mm per year in the lower zone. There is a dry period between May and September when precipitation is generally below 35 mm per month in the whole sub-basin (GRADE 2018).
- **Springs and wells:** Water from underground sources contribute to the aboveground water flow in the basin (Herz and Gamio 2018).
- **Water transfer from Alto Mantaro basin:** Most of the water in the sub-basin is transferred artificially through tunnels from the adjacent Alto Mantaro basin, which is located at a higher altitude (OACHIRILU 2019). Manco Gómez and Paucar Baldeón (2015) reports a flow of 157 hm^3 per year from Alto Mantaro to Santa Eulalia. This water is transferred with the specific purpose of supplying water, sanitation, and hygiene (WASH) services to the city of Lima.

Quantitative estimates of the relative contribution of each of each source (aside from Alto Mantaro transfer) are unknown (Kerres 2010). The total water flow of the sub-basin was estimated by (Manco Gómez and Paucar Baldeón 2015) to fluctuate between 8 hm^3/month in the driest months (August and September) and 49 hm^3/month in the most rainy month (February).

2.2.2 Water demand

As outlined in the introduction, the water demand for the Santa Eulalia sub-basin is complex due to the competition for water from the water, energy, and food (WEF) sectors. This resource is necessary to provide water, sanitation, and hygiene (WASH) services to the population, for hydropower generation, mining, and as an input for agricultural production. The main water demands for the sub-basin are (Figure 2):

- **Demand for WASH in Lima:** The city depends for its consumptive water use on water from the Rimac basin, including the Santa Eulalia sub-basin. The drinking water and sewage company SEDAPAL[2] is responsible for the water supply to the city (SEDAPAL 2020). The Observatorio del Agua Chillón Rímac Lurín (OACHIRILU) reports this demand at 767 hm^3 per year in 2017 (OACHIRILU 2017). However, this demand can be covered with water of the whole Rímac basin, not only with the Santa Eulalia sub-basin.
- **Demand for WASH in the sub-basin:** the rural communities in the sub-basin have a consumptive water demand that is not centrally arranged. Each community must make its own arrangements to ensure the availability of clean water (Bernales and Mendoza 2021). Manco Gómez and Paucar Baldeón (2015) estimated this demand at 1.23 hm^3 per year.
- **Demand for agriculture:** Around 99% of the area used for agricultural production in the lower and middle area of the basin are irrigated, and in the upper zone around 91% is irrigated (GRADE 2018). Moreover, the animal production activities in the upper area of the sub-basin require drinking water for the livestock and for their feed production (Manco Gómez and Paucar Baldeón 2015). Due to the seasonality of precipitation in the sub-basin, the demand for this sector fluctuates throughout the year. As most of the population in the sub-basin depend on either crop or livestock production for food and income security, water availability for agriculture

[2] Servicio de Agua Potable y Alcantarillado de Lima

is an essential component for their well-being (GRADE 2018). However, throughout the scoping study it has become clear that there is little reliable quantitative data available on the agricultural water demand. Water use of many farmers is informal (without documented water use rights) and therefore not registered. Moreover, estimates using evapotranspiration deficits rely on crop area data, for which inconsistent data are available ((Manco Gómez and Paucar Baldeón 2015), (Buchhorn, Smets et al. 2020, MINAGRI 2020)). It is therefore difficult to provide a reliable estimate of the water demand for agriculture. OACHIRILU reports an agricultural water demand of 95 hm^3 per year for the whole Rímac basin (OACHIRILU 2017), while Manco Gómez and Paucar Baldeón (2015) estimate the demand at 107 hm^3 per year in the Santa Eulalia sub-basin.

- **Demand for mining:** There are four mining facilities in the Santa Eulalia sub-basin, all located in the upper zone. The mining companies use water for their production process, and their water demand is relatively constant throughout the year (Manco Gómez and Paucar Baldeón 2015). OACHIRILU (2017) reports a demand of 28 hm^3 per year for this sector.
- **Demand for industry:** Other industries in Lima also require water for their production processes. Together they have a yearly demand of around 13 hm^3 per year (OACHIRILU 2017). This demand can be supplied by the whole Rímac basin, not only by the Santa Eulalia sub-basin.
- **Demand for hydroelectric power:** There are five dams along the Santa Eulalia sub-basin, with a combined power of 511 MW (Herz and Gamio 2018). This water demand is not consumptive, as the water is passed through the turbines for energy generation and is not lost for other use. However, the timing of the water release throughout the day and year influences the water availability for other users. (OACHIRILU 2017) reports a water demand of this sector of 3,073 hm^3 per year in Rímac basin.

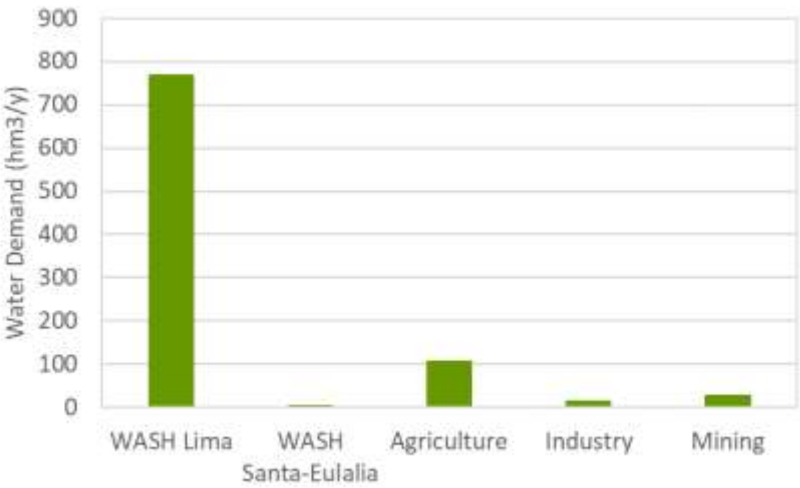

Figure 2. Water demand (hm^3/year) of different sectors in the Santa Eulalia sub-basin and the city of Lima. Sources: OACHIRILU (2017) and Manco Gómez and Paucar Baldeón (2015).

2.2.3 Water balance

Manco Gómez and Paucar Baldeón (2015) estimated the water supply and demand throughout the year, which are shown in Figure 3 for each zone of the sub-basin. The estimate of the supply is based on measured data of water volume flows, and the demand estimate includes the demand for agriculture, mining, and WASH in the sub-basin. The demand estimate does not include the demand for WASH in Lima. Due to the uncertainties in data, the absolute values of the water balances should be used with care. However, the order of magnitude of the figures shows that there is a water deficit in the sub-basin, which is the most pressing during the months of July to November. The deficit is present in all zones, but it is greatest in the middle and lower zones. The existence of a water deficit in the sub-basin is in line with the view of interviewed stakeholders such as the Autoridad Local del Agua (ALA) and the Dirección Regional de Agricultura de Lima (DRAL), who mention farmers having water shortages for their crops.

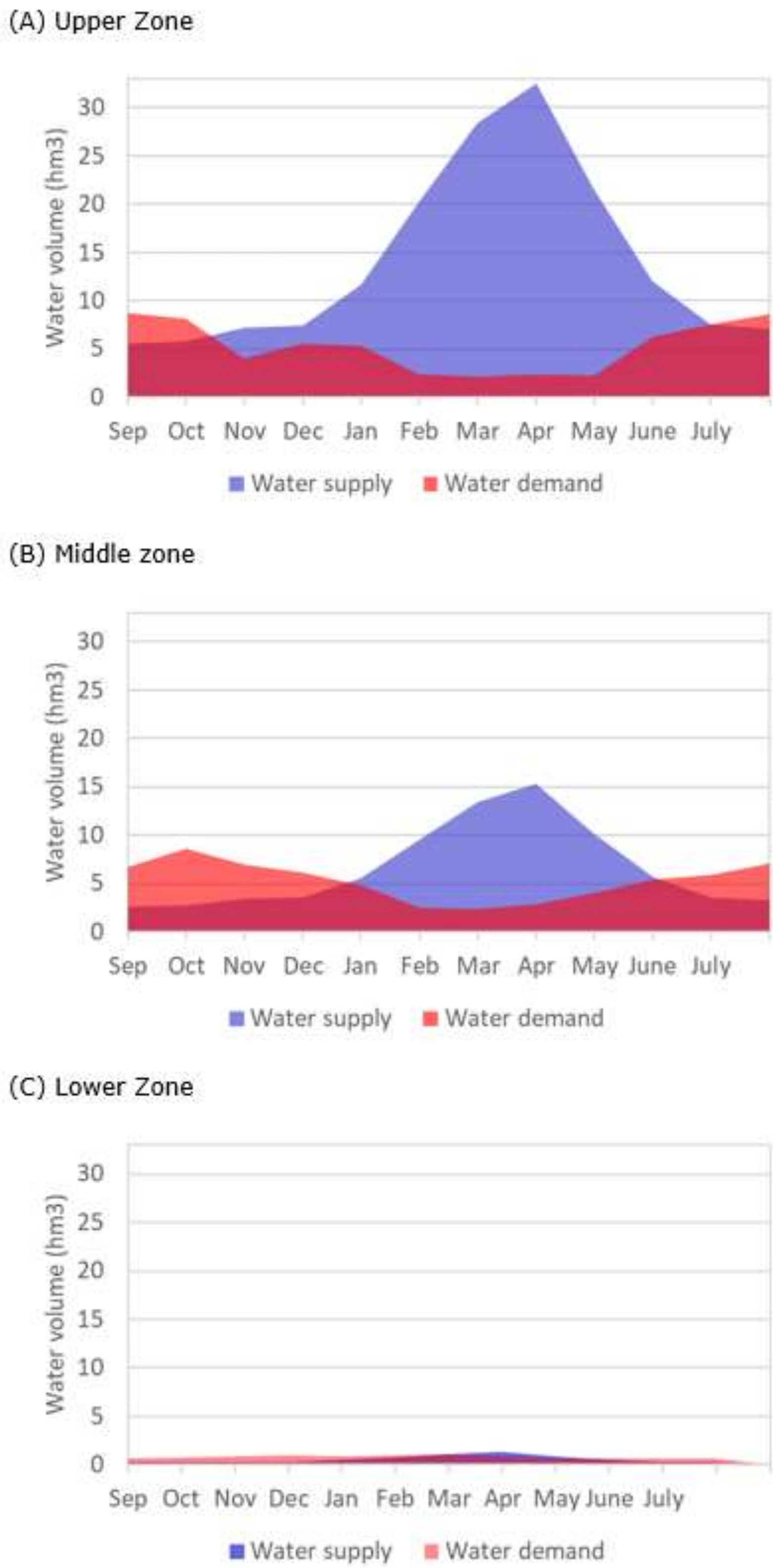

Figure 3. Estimated water supply (hm^3, blue) and water demand (hm^3, red) in the upper (A), middle (B) and lower (C) sub-basin. Source: Manco Gómez and Paucar Baldeón (2015). Estimate of demand does not include water for WASH in the city of Lima.

3 Agricultural Stakeholder Analysis

Due to the many different demands on water of the sub-basin, there are many stakeholders involved in its use and regulation. For a complete overview of all involved stakeholders, see the stakeholder matrix developed by Bernales and Mendoza (2021). In this report we focus only on the main stakeholders that have a direct influence on the agricultural sector.

3.1 Water regulators: policy development and implementation

3.1.1 MIDAGRI: DRAL and AASE

The Ministerio de Desarrollo Agrario y Riego (MIDAGRI) is the ministry of agriculture and irrigation of Peru. It is in charge of the development and implementation of agricultural policy at a national level. The ministry has offices at a regional level called Direcciónes Regionales de Agricultura (DRA). Each DRA has multiple Agencias Agrarias (AA) under their jurisdiction. The DRA covering the Santa Eulalia sub-basin is the Dirección General de Agricultura de Lima (DRAL), and the local AA is the Agencia Agraria Santa-Eulalia (AASE). The main purpose of DRAL is to improve agricultural production and supply chains by coordinating development projects between farmers, the local AA, and local governments. It was unclear from the collected information how active the DRAL and AASE are in implementing projects in practice.

3.1.2 MIDAGRI: ANA, AAA and ALA

One of MIDAGRI's "branches" is the Autoriadad Nacional del Agua (ANA). ANA is responsible for the formulation and implementation of water policy at a national level in Peru. ANA has multiple regional offices which are referred to as Autoridades Administrativas de Agua (AAA). Each AAA has multiple local offices, called Autoridades Locales de Agua (ALA). Policy that is developed at a national level by ANA is implemented at a local level by the AAA and ALA offices. The AAA has a liaison function, it collects information from ALAs and reports back to ANA to feed into the development of new policy. The Santa Eulalia sub-basin falls under the jurisdiction of the AAA Cañete-Fortaleza, and the ALA Chillón-Rímac-Lurín (ALA CHIRILÚ) (Figure 4).

ANA was created 2008, with the aim of better regulating the water use in Peru (ANA). It is in the process of formalizing the water use rights across the country. The AAA Cañete-Fortaleza and ALA CHIRILÚ participate in the Consejo de Recursos Hídricos de Cuenca CHIRILÚ, which is a platform aimed at a better coordination of stakeholders in the sub-basin (see Section 3.3.1). Interviews with a range of stakeholders led to the impression that AAA and ALA in Santa Eulalia are not strongly represented in the middle and upper area of the sub-basin, and that as a result their capacity to change and formalize water use patterns is undermined.

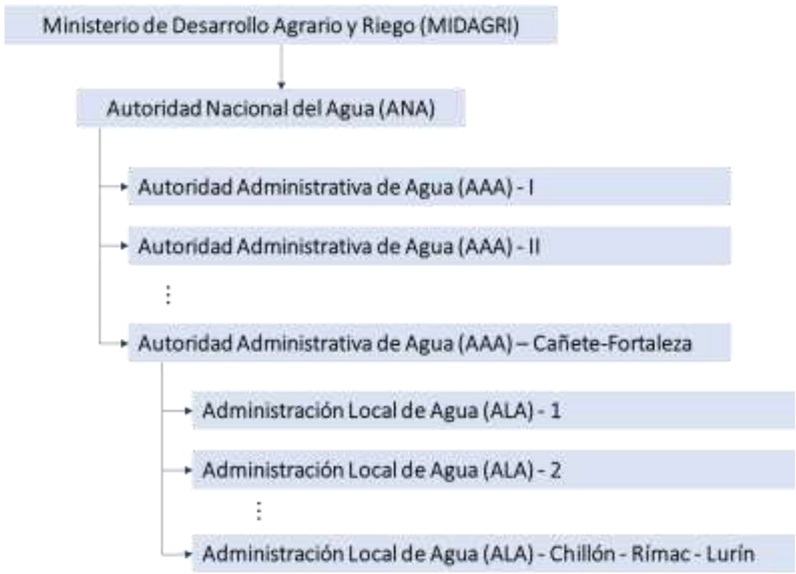

Figure 4. Simplified organization structure of MIDAGRI, ANA, AAA, and ALA.

3.1.3 Government: Regional, Provincial, and District

Below the national government, Peru is organized into departments, each with multiple provinces, that are divided into multiple districts. A department has a regional government (Gobierno Regional - GORE), while provinces and districts have provincial and district municipalities (Municipalidad provincial y distrital) (Figure 5). The Rímac basin flows through the departments Lima, Callao, and Metropolitan Lima. Within the department of Lima, it flows through the provinces of Lima and Huarochirí. Within both provinces, the basin flows through multiple districts. The Santa Eulalia sub-basin only flows through districts in Huarochirí. Matters concerning the Rímac basin therefore involve the regional governments of Metropolitan Lima, Callao, and Lima, the provincial municipalities of Lima and Huarochirí, and several district municipalities (Figure 6).

The governments at each level are in charge of designing policies and strategies, setting priorities, and developing programs and projects that promote regional development in a participatory manner. This also entails water management. However, it seems that coordination between district municipalities in the middle and upper zones of the sub-basin and the regional and district governments is lacking (Manco Gómez and Paucar Baldeón 2015).

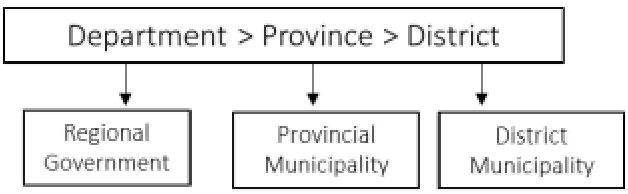

Figure 5. Government levels in Peru.

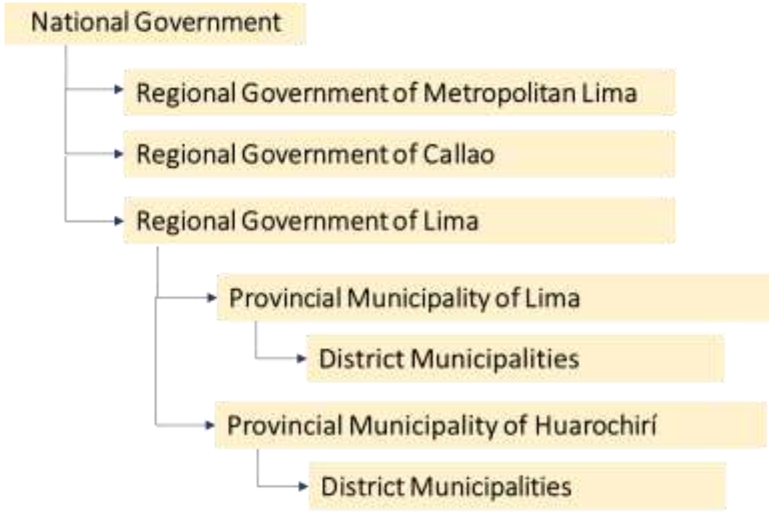

Figure 6. Government levels involved in the water management of the Rímac basin.

3.2 Water users

3.2.1 Energy companies

The companies generating hydroelectricity in the sub-basin are ENEL, Andean Power, and Conenhua (specifically Huanza). To generate electricity, they have built water reservoirs using dams, and release the water from the reservoirs when there is an electricity demand. As a result, the energy companies have a strong effect on the water flow regulation in the sub-basin. The companies work together closely with SEDAPAL (see next sub-section), the company supplying drinking water to Lima. Of the mentioned companies, only Huanza takes into account the ecological flow of the sub-basin in their water management. Huanza is also the only energy company to participate in the Grupo de Trabajo Santa Eulalia (coordination platform of stakeholders). The reservoirs are potentially beneficial to the farmers in the sub-basin as they act as buffers to distribute the water availability throughout the year. However, the timing of the water release into the sub-basin can be problematic for farmers. Electricity demand, and therefore water flow, is highest in the evening, but crops need water during daytime. There are some agreements on water use between energy companies and communities, but details are unclear. When new infrastructure is developed, it seems that the companies reach agreements with the community in the specific area where the project will be developed, but not necessarily with the communities downstream whose water supply will also be affected.

3.2.2 Servicio de Agua Potable y Alcantarillado de Lima (SEDAPAL)

SEDAPAL is the state-owned company responsible for supplying the city of Lima with drinking water. The company works together closely with the energy companies regulating the water flow in the sub-basin, to ensure that the water demand in the city is always covered. It develops the large infrastructure necessary to ensure a stable water supply, such as the water transfer from Alto Mantaro, and monitors the quality of the water along the sub-basin. The company is starting to implement a system called MEcanismos de REtribución por Servicios Ecosistémicos (MERESE), in which they slightly increase the price of water in Lima in order to finance projects along the basin that provide ecosystem services (Section 6.2.1).

3.2.3 Farmer communities

The communities in the sub-basin depend mostly on agricultural production for their incomes. In general, socio-economic development is low, especially in the upper and middle zones of the sub-basin. Incomes and education levels are low, and basic household services such as piped drinking water and electricity are lacking (Figure 19 in the Appendix). The general knowledge level of farmers on water efficient farming practices is limited. Moreover, low income levels have led to migration from the sub-basin to Lima, in search of better incomes. This has led to the abandonment of terraces at the mountain slopes and consequently to their deterioration, with negative consequences for water infiltration and erosion (Bedriñana and Susana 2017).

When using water from the sub-basin, farmers can do this either formally, with water use rights registered at the Padrón de Uso Agrario (Registry for agricultural use) of ALA, or informally, without registered water use rights. Informal water use is free, while registered water use must be paid for: users pay a fee for the hydraulic structures to the operator (tarifas) and a fee for the actual water to ALA (retribución económica). To obtain formal water use rights, farmers must organize themselves into Comités de Regantes (irrigation committees). The committees must be registered at the Junta de Usuarios Rímac (Figure 7). The Junta de Usuarios represents the farmers in dealing with ALA and at the Consejo de Recursos Hídricos de Cuenca (CRHC, see next section).

In the lower zone of the sub-basin, farmers are generally organized in committees and have registered water use rights. In the middle and upper zones of the sub-basin there is a high degree of informal water use. The disadvantage of informal water use is that, in times of water scarcity, farmers have little legal basis to claim a share in the available water resources. Throughout the scoping study it has also become clear that there are social and economic conflicts between some of the communities, especially in the upper zone. The conflicts are generally driven by differences in interests in the development of large infrastructure projects and by border disputes. Relatively recently, the communities have started working together in the Asociación de Comunidades de Norhuarochirí. This is an association which they have formed to work together in their shared interest in dealings with large energy and mining companies and SEDAPAL.

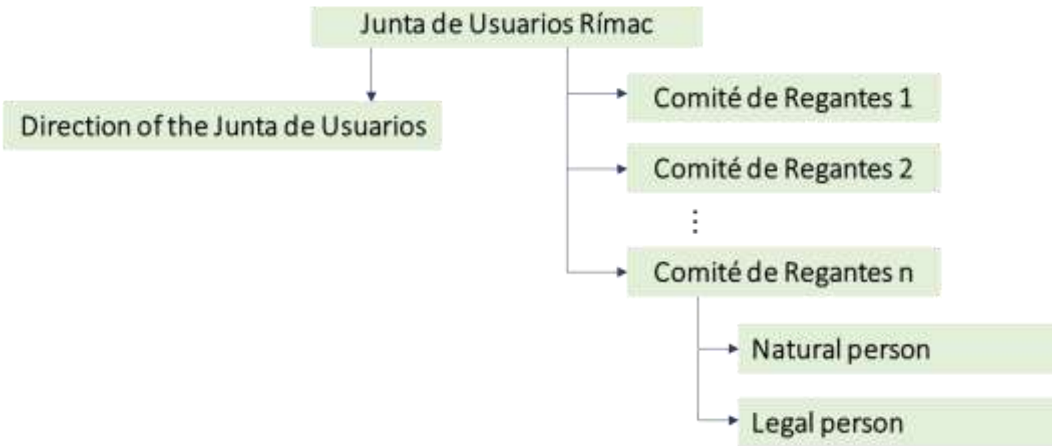

Figure 7. Organization structure of water users for agricultural purposes.

3.3 Multi-stakeholder platforms

3.3.1 Consejo de Recursos Hídricos de Cuenca Chillón, Rímac, Lurín (CRHC CHIRILÚ)

The CRHC (translated: Water Resource Council, WRC) is a platform where the stakeholders of basins Chillón, Rímac, and Lurín can work together to better coordinate the water management in the basins. It is made up of representatives of the regional governments, the AAA Cañete Fortaleza, universities, agrarian and non-agrarian user organizations, district municipalities, farmer communities. It is chaired by the Regional Government Program of the Metropolitan Municipality of Lima. The main goal of the council is the development of the Plan de Gestión de Recursos Hídricos (PGRH) (translated: Water resources management plan) for the three basins. The council has multiple Grupos de Trabajo (GT) (Working Groups):

- **GT Santa Eulalia:** Developed to improve the integrated water resource management specifically in the Santa Eulalia sub-basin. It used to be the Programa de Agua, Clima, y Desarrollo (PACyD).
- **GT Infraestructura Natural y Conservación de Agua de las Cuenas CHIRILÚ:** Promotes investments to improve water security through ecosystem services.
- **GT Observatorio del Agua:** Its main purpose is to collect information on the basins to feed into decision making of the other working groups.
- **GT Cultura del Agua:** Coordinates activities to improve the general water culture (i.e. appreciation for water value and scarcity) in the basins.
- **GT Plan de Aprovechamiento de Disponibilidades Hídricas:** Develops a yearly plan on water distribution amongst the water users in the basins.

3.4 Agricultural Investing Entities

3.4.1 Agrobanco

Agrobanco (Agricultural bank) is the most important means of financial support of the government to farmers. Its objective is to promote and facilitate the granting of credit to small farmers in Peru. It focuses on the financial inclusion of small farmers, individually and/or in partnership. Agrobanco administers the Agroperú Fund with MIDAGRI and benefits agricultural producers organized in an associative manner, such as cooperatives, peasant communities, water users, producer associations, among others (Agrobanco 2021). The bank can be approached by farmers looking to invest in improvements to their water management, such as technification of their irrigation systems.

3.4.2 AGRO RURAL

The Programa de Desarrollo Productivo Agrario Rural - AGRO RURAL (Rural Agricultural Production Development Program) is an executing unit attached to MIDAGRI, created in 2008. Its purpose is to promote rural agrarian development through the financing of public investment projects in rural areas with lower levels of economic development (AGRORURAL). The program can be involved in community investments for improved water management in the agricultural sector.

4 Agricultural Production

To formulate interventions for the agricultural sector it is first necessary to understand the current situation of agricultural production in the sub-basin. We characterize the most relevant agro-climatic conditions, the terrain characteristics, and the production practices in the next sub-sections.

4.1 Agroclimatic conditions

The three most important climatic conditions defining productivity of an area are rainfall, temperature, and relative humidity. They are described below.

4.1.1 Rainfall

The sub-basin has a dry period from May to September, and a rainy period from October to April (Figure 8). The monthly rainfall during the wet period is much higher at the upper (±40-120 mm/month) and middle (±10-90 mm/month) zones of the sub-basin than in the lower zone (±10 mm/month). Total precipitation in the upper, middle, and lower zones of the basin is 624, 373, and 27 mm/year respectively. As an indication of order of magnitude, a minimum rainfall of 500 mm/season is considered necessary to sustain viable agricultural livelihoods (Funk, Rowland et al. 2012). Therefore, irrigation is necessary to sustain crop production in the sub-basin. This is especially true for the lower sub-basin, where irrigation is necessary year-round.

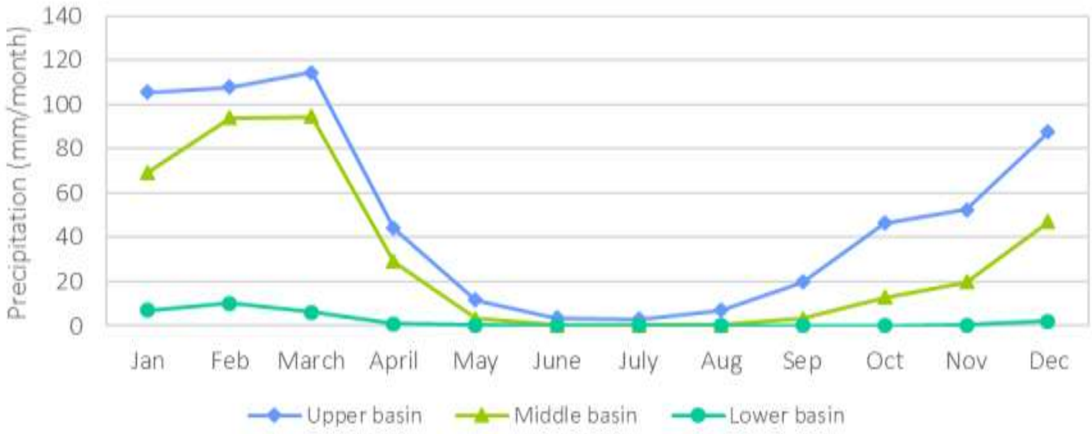

Figure 8. Monthly precipitation (mm) in the upper, middle, and lower sub-basin. Averages of data from 1990 to 2010. Source: Manco Gómez and Paucar Baldeón (2015)

4.1.2 Temperature

The temperature in all three zones is quite constant throughout the year (Figure 9). In the lower and middle zones the temperature ranges between 15 and 25 °C, which is a suitable temperature range for many crops (Landon 2014). In the upper zone the average temperature is around 5 °C. This is quite low and unsuitable for most common food and cash crops. This area is therefore more suitable for fodder production, such as grass and alfalfa, which can grow at relatively low temperatures (Moot, Scott et al. 2000, Mueller 2005). All three zones seem suitable for livestock such as cattle and alpacas, which have a thermoneutral zone between -15 to +25 °C and -15 to +20 °C, respectively (Riek, Brinkmann et al. 2017, Ohnstad 2021).

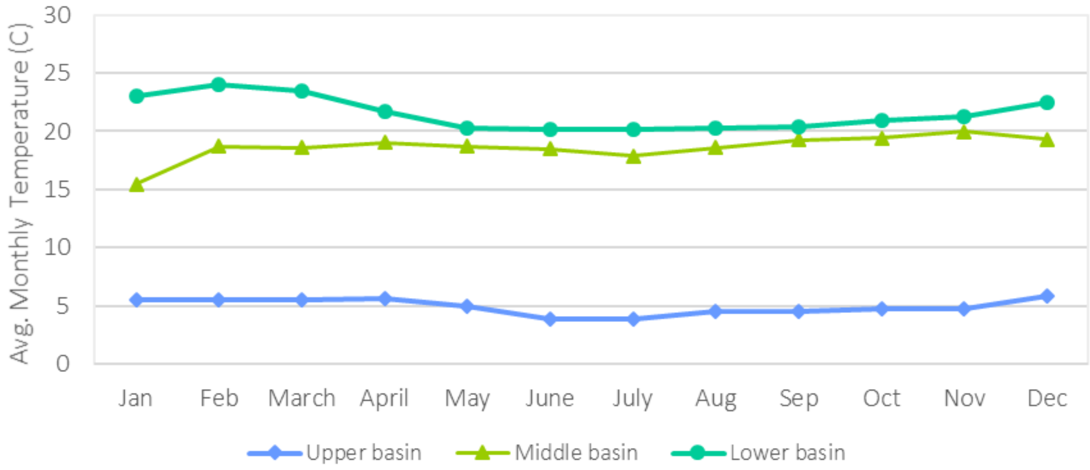

Figure 9. Average monthly temperature (°C) in the upper, middle, and lower zones of the sub-basin. Source: (Manco Gómez and Paucar Baldeón 2015)

4.1.3 Relative humidity

The average relative humidity in all three zones ranges between 64 and 74%. This is a suitable humidity level for most crops. A humidity level that is very low leads to a greater water demand of the crops (especially in combination with high temperatures), and a high relative humidity generally leads to a higher crop disease pressure. As a reference, humidity in The Netherlands is between 68 and 76% (KNMI 2020).

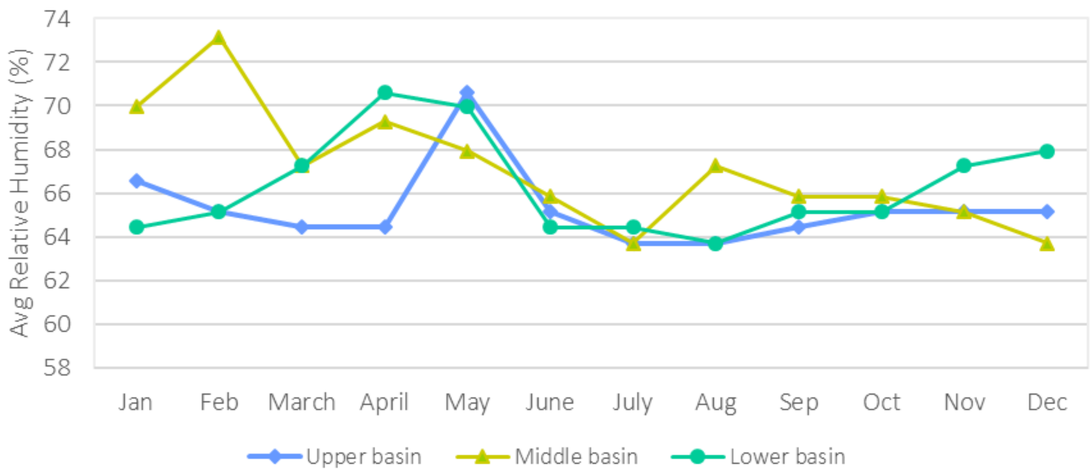

Figure 10. Average monthly temperature (°C) in the upper, middle, and lower zones of the sub-basin. Source: Manco Gómez and Paucar Baldeón (2015)

4.2 Terrain characteristics

4.2.1 Slope

The sub-basin is located in the outer skirts of the Andes mountains. A large fraction of the terrain in the basin has extremely steep slopes of over 50% inclination (Figure 11). Crop production on such steep slopes is almost impossible. The steep slopes can lead to soil erosion and consequently to soil fertility loss. Moreover, at steeper slopes soils are generally shallower, with lower water holding capacity (Sanders 1986). To mitigate erosion risks it is necessary to work with terraces and to use soil conservation techniques.

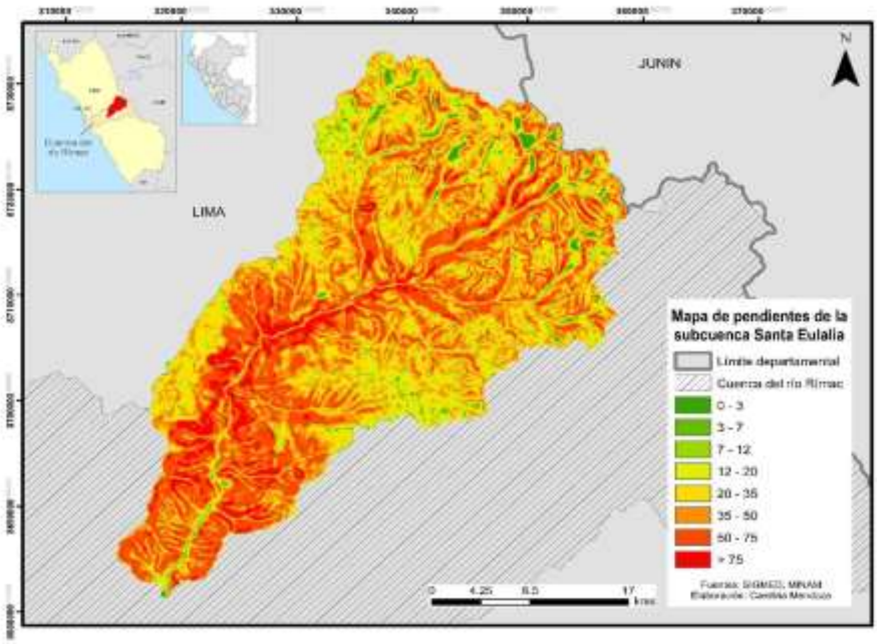

Figure 11. Slope (%) in the sub-basin area. Source: Bernales and Mendoza (2021).

4.2.2 Soil texture

One of the main components of soil quality is the soil texture. The texture of the topsoil along the sub-basin is classified (by majority) as sandy loam in the lower and middle zones, and sandy clay loam in the upper zone. Loams contain sand, clay, and silt particles, and as a result have the ability to retain water relatively well and to also allow for enough drainage to prevent waterlogging[3] (Landon 2014). They are generally considered good agricultural soils. However, other soil characteristics such as rockiness, soil depth, and organic matter content should also be examined to be able to better assess the soil quality.

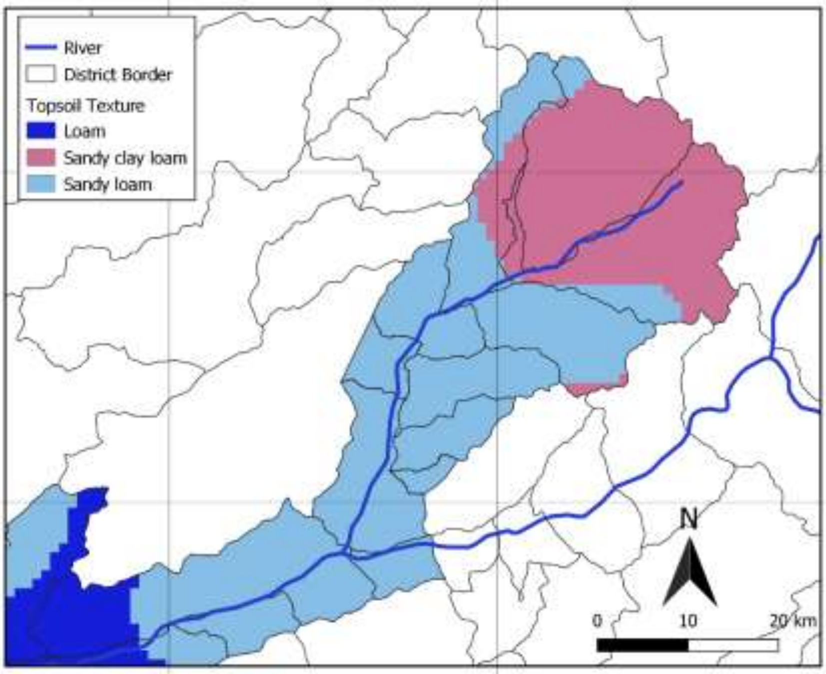

Figure 12. Topsoil texture in the Santa Eulalia sub-basin. Source: Fischer, Nachtergaele et al. (2008)

[3] Waterlogging causes damage to plants because the soil contains too much water for too long. The plant roots are not aerated enough and start to rot.

4.3 Agricultural production structure

In this sub-section the current agricultural production in the three zones of Santa-Eulalia is characterized in general terms. We assess the farm size, cropping area, cropping calendar, water use of the currently cultivated crops, irrigation and other management practices, crop yields, livestock production, and make an overall assessment.

4.3.1 Farm size

An important indicator to understand the type of agriculture that is performed in a region is the average farm size. This gives an impression of the intensification level. Throughout the scoping study we did not find a reliable estimate for the average farm sizes in the zones of the sub-basin. Data from the Censo Nacional Agropecuario (national agricultural census) from 2012 is available but has not been analyzed yet due to the time constraint on the project. For now, we therefore rely on the estimate of the Dirección Regional de Agricultura de Lima (DRAL), a regional branch of the ministry of agriculture (MINAGRI) (Sub-section 3.1.1). The census data can be analyzed in a follow-up project to get more accurate values. The average farm size was estimated at 0.5 to 1 ha, and an average parcel size at 0.5 ha (Bernales and Mendoza 2021). This is a quite small farm size and is generally indicative for subsistence agriculture and a low intensification level.

4.3.2 Total cropland area

The total cropland area[4] and its spatial distribution was assessed to understand the relative size of the agricultural sector in the sub-basin. Figure 13 shows the percentage cropland in each 100x100m cell as estimated by the Copernicus Global Land Cover satellite dataset. Although there are some clusters of cropped areas, in general the cropland area is quite sparse. Notice that the maximum percentage in each cell is only 46% (the darkest blue). The sparseness of the cropland area is related to the extreme steep slopes in the region, which limits cropping.

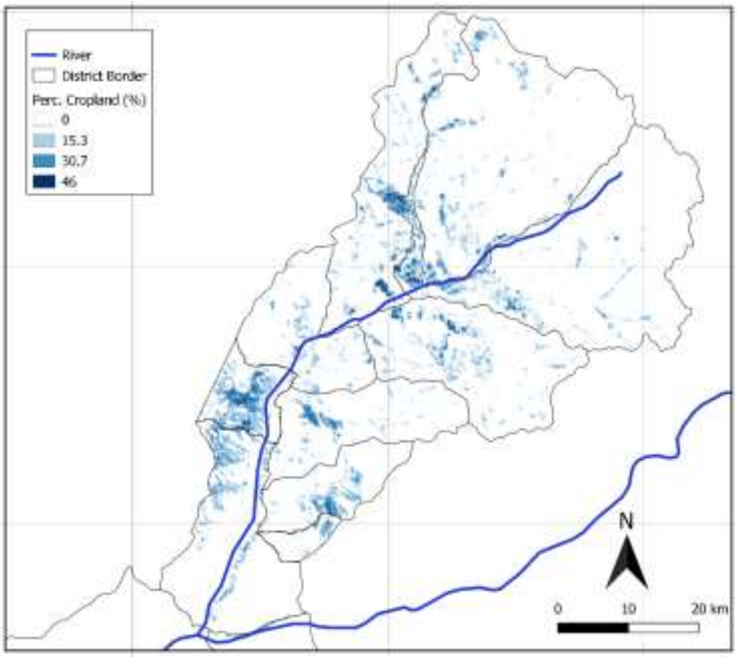

Figure 13. Map of percentage cropland area in each 100x100m cell of the sub-basin. Source: Buchhorn, Smets et al. (2020) (Copernicus Global Land Cover dataset)

[4] The crop area is the land occupied by annual food crops and perennial food crops; It does not include grassland area. The combination of crop area and grassland area is called agricultural area.

The total cropland area in each district is shown in Figure 14 as reported by MINAGRI in their Sistema Integrado de Estadística Agraria (SIEA) (MINAGRI 2020) and the area calculated based on the Copernicus satellite data. Figure 14 shows a large discrepancy between the two data sources, especially in the middle and lower zones. Due to these differences, the actual cropland area in the sub-basin is uncertain, and the data only provide insight in the orders of magnitude: Each district has approximately somewhere between 100 and 500 ha of cropland, with the exception of San Pedro de Casta and Santa Eulalia, for which MINAGRI reports area 920 and 803 ha, respectively.

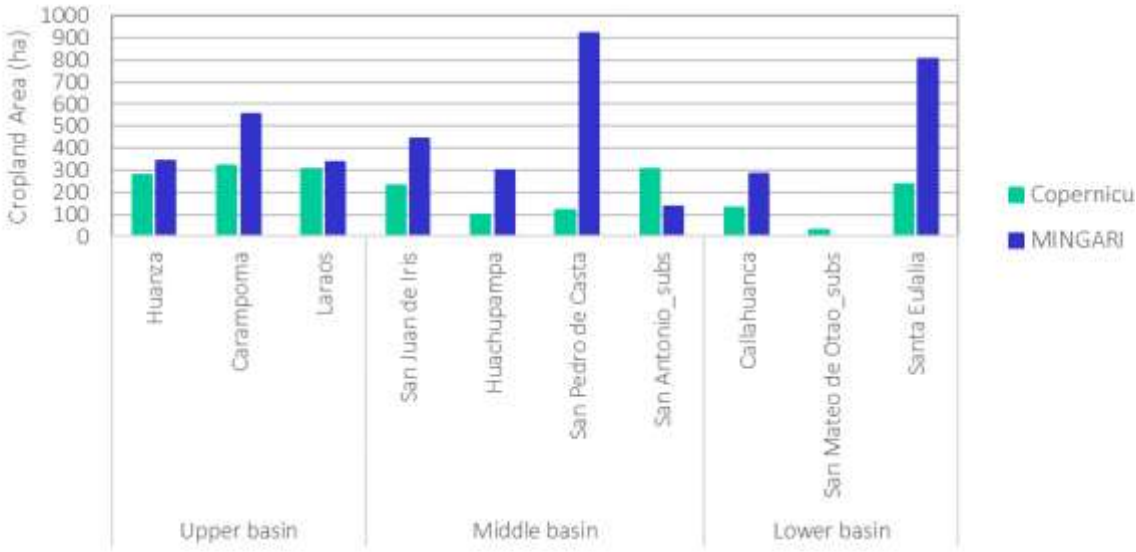

Figure 14. Cropland area in each district according to data from the Copernicus Global Land Cover dataset (Buchhorn, Smets et al. 2020) and by MINAGRI's Sistema Integrado de Estadística Agraria (MINAGRI 2020)

4.3.3 Relative crop area

The three zones of the sub-basin produce different crops due to their differences in climate. To provide an overview of the most important crops in each zone, we used the crop areas reported in the SIEA 'Calendario de Siembras y Cosechas'. However, the sum of the areas of all crops was not equal to the total cropland area reported in the SIEA, so the quality of the crop area data is unclear. We use the data to get an impression of the relative importance of the crops in each zone, as is shown in Figure 15. The results show that in the upper sub-basin the most common crop is alfalfa, which is used as a fodder crop for livestock. Other than that, they produce legumes (peas and beans), maize, and tubers (potato and olluco), which are generally subsistence crops when produced at such a small scale. In the middle and lower sub-basin, the dominating crops are avocado and custard apple (chirimoya), produced as cash crops, with a much smaller fraction of food crops. The relative importance of the crops indicated by the data was in line with the qualitative characterization of the basin given by the DRAL (Bernales and Mendoza 2021).

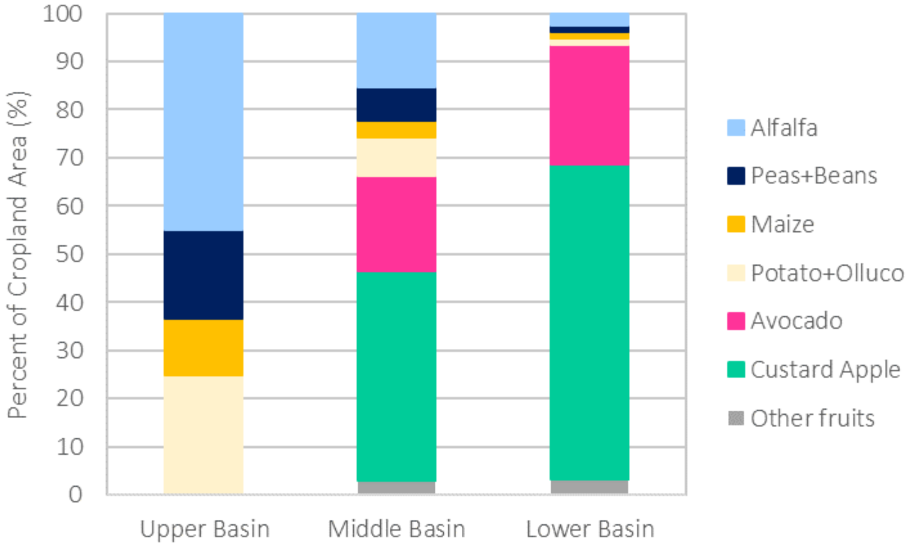

Figure 15. Percent of cropland area dedicated to each crop in each sub-basin zone. Source: MINAGRI (2020)

4.3.4 Cropping calendar

The cropping calendar in each zone of the sub-basin is shown in Table 2 to Table 4 for the three sub-basin zones. In the upper basin, alfalfa and grasses are grown year-round. Peas and olluco are only grown in the rainy season. Common crop rotations are maize with potato and beans with amaranth (kiwicha), which are all grown in both the dry and the rainy season. In the middle and lower zone of the sub-basin, fruit trees (avocado and custard apple) are grown year-round. However, in the middle zone food crops such as maize, potato, beans, cereals, and vegetables are grown mostly in the dry season, while in the lower zone these crops are grown in the rainy season.

Table 2. Cropping calendar in the upper zone of the sub-basin. Crop 1 is grown in months shaded yellow and Crop 2 in months shaded green. Rainy season months are shaded blue. Source: Manco Gómez and Paucar Baldeón (2015)

Crop 1	Crop 2	Jan	Feb	Mrch	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Maize	Potato												
Potato	Maize												
Beans	Amaranth												
Amaranth	Beans												
Olluco													
Peas													
Alfalfa + Grasses													

Table 3. Cropping calendar in the middle zone of the sub-basin. Crops are grown in months shaded yellow. Rainy season months are shaded blue. Source: Manco Gómez and Paucar Baldeón (2015)

Crop	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Maize												
Potato												
Beans												
Cereals												
Vegetables												
Fruit trees												
Alfalfa + Grasses												

Table 4. Cropping calendar of crops in the lower zone of the sub-basin. Crops are grown in months shaded yellow. Rainy season months are shaded blue. Source: Manco Gómez and Paucar Baldeón (2015)

Crop	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Maize												
Vegetables												
Peas												
Beans												
Fruit trees												
Alfalfa + Grasses												

4.3.5 Crop water use

From interviews with DRAL, it also became clear that the sub-basin is going through a shift in crop production. Farmers are moving from subsistence food crops, such as maize, potatoes, and beans, to fruit crops such as avocado and custard apple, as cash crops for the international market. This shift in the type of crop production can have an impact on the sector's water demand, as crops differ in water demand. We estimated the water demand on a yearly basis in Figure 16, expressed as evapotranspiration. From this analysis, we can conclude the following points:

- For all crops in the figure, water demand is greater if the crop is produced lower in the sub-basin. This is likely due to the higher temperature in the lower region.
- Perennial fruit trees have a water demand that is about twice as high as the annual food crops. Alfalfa and grasses also have a much greater water demand than the food crops. This difference in water demand between the crops is partly because the fruit trees and fodder crops are grown all year round, whereas the food crops are only grown for five to six months of the year. Moving from food crops to fruit trees could therefore be placing an increasing strain on the sub-basin's water resources.
- The food crops have a fallow period of around six months, in which the area can be left bare or a cover crop can be grown on it. A cover crop can help reduce erosion problems, but it is unclear how common this practice is amongst farmers at the moment. Any water demand by cover crops is not included in the estimates in Figure 16. It is possible that the positive effect of cover crops against erosion could be offset by an increased water demand. Further research into crop water balances would be necessary to better estimate the effect of the crop transition from food to fruit crops on the sub-basin's water demand.

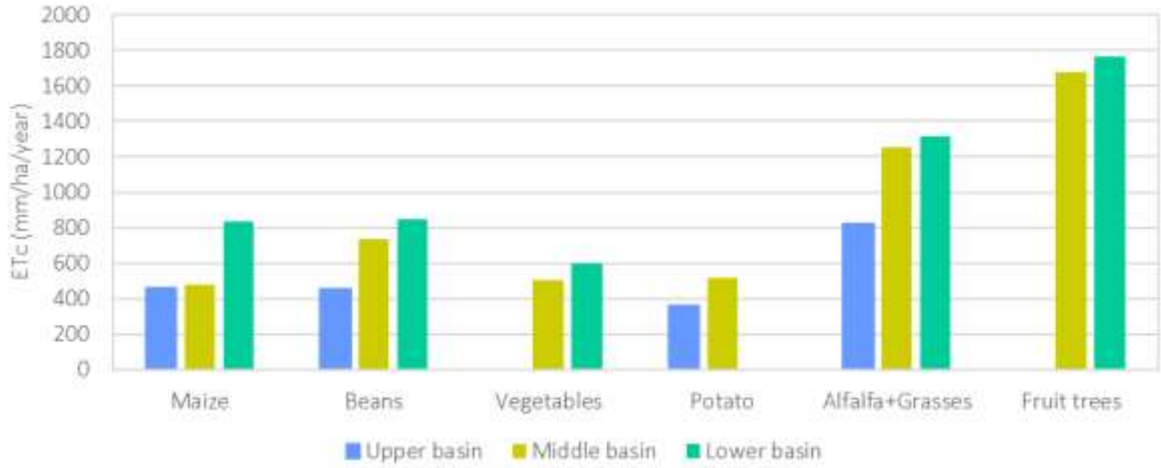

*Figure 16. Actual Evapotranspiration (ETc, in mm/ha/year) for different crops in the upper, middle, and lower zones of the sub-basin. ETc was calculated as the sum of the ETc in each month of the growing season. Each month's ETc was calculated as ETc = ETp*Kc, with ETp = potential evapotranspiration and Kc = crop coefficient. We assume a single growing season per year. Evaporation from the soil or evapotranspiration of cover crop during fallow months was not included. ETp and Kc values were obtained from Manco Gómez and Paucar Baldeón (2015).*

4.3.6 Irrigation management

According to the national agricultural census data from 2012, as analyzed by GRADE (2018), almost all cultivated land in the sub-basin is irrigated (92 to 99%). Of the irrigated land, the vast majority is irrigated using flooding (i.e. gravity) systems. This was confirmed by the interviews with DRAL and the ALA. Although flooding irrigation systems have the advantage of having low investment costs, they also have a very low irrigation efficiency. The OECD (2020) reported that most of the water extracted for irrigation (65%) is lost due to inefficient irrigation systems in Peru. Estimated total efficiency of water use in irrigation systems was approximately 35%, which is considered poor performance and is mainly due to leaking distribution systems and the extensive use of unimproved gravity or flood irrigation methods. The low irrigation efficiency leads to greater water use per kg product, and therefore places a strain on the sub-basin's water demand.

Table 5. Percentage cultivated land in the sub-basin that is irrigated (column 1), and percentage of irrigated land using flooding, sprinkler, and drip systems (columns 2 to 4). Source: GRADE (2018). Data from 2012.

	Crop Area Irrigated (%)	Flooding (%)	Sprinkler (%)	Drip (%)
Upper Zone	92	99.6	0.4	0.0
Middle Zone	98	100.0	0.0	0.0
Lower Zone	99	99.8	0.0	0.2

4.3.7 Other management practices

Aside from irrigation, other management practices by farmers were also investigated in the interview with the DRAL and are reported in Table 6. No quantitative data was found on this other than the national agricultural census, which will be analyzed in the follow-up project. Management practices give an indication of the general level of production intensification. From the results, it seems that farmers use very few external inputs, with little to no fertilizers nor crop protection products. Although this can be beneficial to the local biodiversity due to the lack of chemicals lost to the environment, low input systems generally lead to a low productivity. Improved crop varieties and livestock breeds with higher yields are also not commonly used. Low productive systems have the disadvantage of needing more land than high productive systems to achieve the same total production and, therefore, lead to a greater water demand.

Table 6. Common management practices in the Santa Eulalia sub-basin according to the DRAL. Source: Bernales and Mendoza (2021)

Management Practice	Common Practice
Use of chemical fertilizer	Limited
Use of organic fertilizer	Yes
Use of improved crop varieties	No
Use of improved livestock breeds	No
Use of chemical crop protection products	No
Use of chemical herbicides	No

4.3.8 Crop yields

The yield levels also give an impression of the level of agricultural intensification in the sub-basin. Sub-basin yield levels as reported in the SIEA are shown in Figure 17. As a reference, average crop yields at the national level are also shown. For all crops, yields in the sub-basin are much lower than the national average yield. This is in line with the low intensity management that was found.

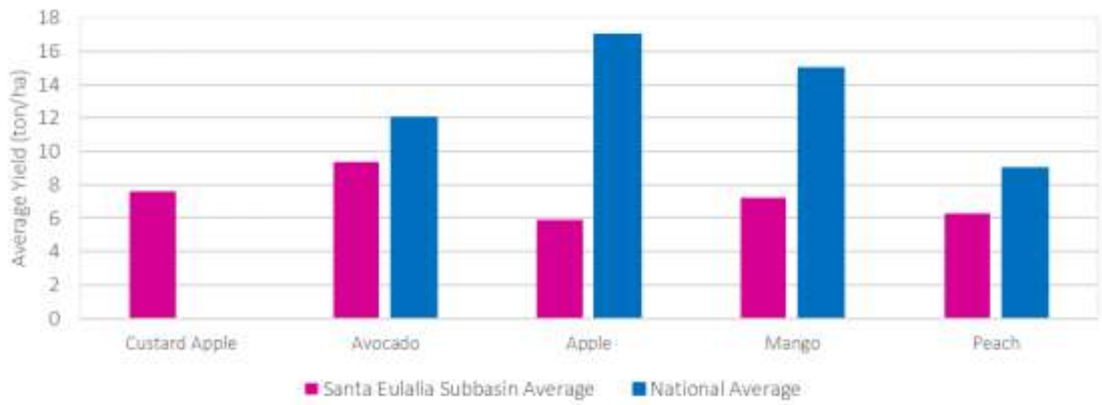

Figure 17. Crop yields in the Santa Eulalia sub-basin (source: MINAGRI (2020)) and at the national level (source: FAO (2020)).

4.3.9 Livestock & Fisheries

Based on the interviews performed with stakeholders, there are five fish farms in the sub-basin, three in the upper zone and two in the lower zone. However, they appear to be in a poor condition, but their economic performance is not known.

Livestock production is common in the sub-basin (Figure 18). Most of the livestock is kept in the upper zone, and some in the middle zone. Predominant types of livestock are bovines, sheep, alpacas, and llamas, with the latter three kept for their wool and the bovines for dairy. Most animals are local breeds (Table 6). No data was found on livestock productivity.

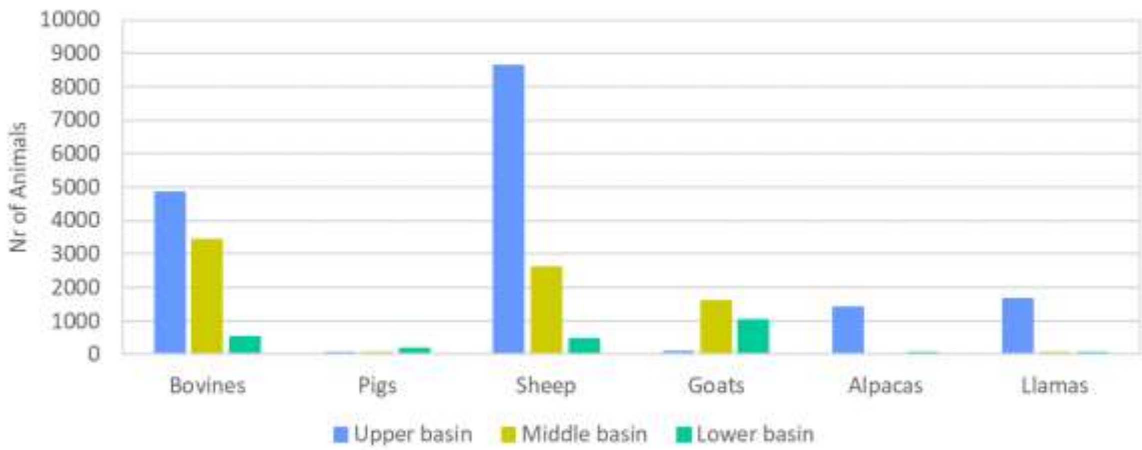

Figure 18. Number of animals of different types of livestock kept in the upper, middle, and lower zones of the sub-basin. Source: Manco Gómez and Paucar Baldeón (2015). Data from 2012.

4.3.10 In summary

Overall, the agricultural production in the Santa Eulalia can be characterized as follows:

- Most agricultural activities are performed on small farms between 0.5 and 1 hectare. The intensity of management is low, with low inputs and non-improved crop varieties and livestock breeds.
- Almost all crop land is irrigated, practically all through flood irrigation.
- In the upper zone of the sub-basin the climate is unsuitable for most annual and perennial crops. Farms are generally dedicated to livestock production (bovines, sheep, alpacas, and llamas), and produce alfalfa and grasses for fodder. Some subsistence crops such as maize, potatoes, and legumes are also common. This is the zone with most rainfall and lowest temperatures, and therefore requires the least irrigation.
- The middle zone of the sub-basin has more suitable temperatures for crop production. It has some livestock production (bovines, sheep, and goats), with alfalfa and grass production for fodder. The

area also produces custard apple and avocado for the export market, and some subsistence crops for home consumption.

- The middle and lower zone of the basin are mainly used to produce custard apple and avocado. These zones receive little rainfall, also in the rainy season, and agriculture requires year-round irrigation.
- The sub-basin has seen a shift in production from subsistence crops (maize, potato, beans) to fruit production (custard apple and avocado) as cash crops. This could lead to a greater crop water demand, but further research is needed to confirm this.

5 Problem and Trade-off Analysis

5.1 Problem Analysis

Based on the information gathered on the current situation in the sub-basin in Chapters 2 to 4, we identified the main problems and unraveled the drivers behind them. In this section, we outline our three main identified problems and their root causes. Issues which are still uncertain are followed by a question mark.

Problem 1: Scarce water available for WASH in the city of Lima

1. The main drivers identified behind this are:
    - 1.1. There are long periods in the year with little to no rainfall
    - 1.2. There is a decreasing water supply in the Rímac basin due to melting glaciers as a result of increasing temperatures (?)
    - 1.3. There is a competing water demand for agriculture along the Rímac basin
    - 1.4. There is a misalignment in time between the demand for water and electricity (water demanded during the day, electricity in the evening)
    - 1.5. Water reservoir capacity in Lima is limited (?)

Problem 2: Scarce water available for agricultural production in the Santa Eulalia sub-basin

The main drivers identified behind this are:

1. Water **supply** for agriculture is limited
    - 1.1. There are long periods in the year with little to no rainfall
    - 1.2. Groundwater levels are decreasing (?). This might be occurring due to:
        - 1.2.1. Groundwater use for agriculture
        - 1.2.2. Deforestation (effects on hydrology are uncertain). This might be occurring due to:
            - 1.2.2.1. Land expansion for agriculture (?)
            - 1.2.2.2. Land expansion for mining (?)
        - 1.2.3. Reduced water infiltration in upper basin crop areas. This is occurring due to:
            - 1.2.3.1. Poor maintenance of the terraces (leading to run-off). Due to:
                - 1.2.3.1.1. Migration to the city
    - 1.3. Misalignment in water discharge (in quantity and time) between hydroelectric companies and farmers in the middle and low zones. Water supply is not available to farmers when they need it. This occurs because:
        - 1.3.1. Peak demand for electricity occurs during the evening (6-10 pm)
        - 1.3.2. Demand for irrigation water occurs during daytime, when crops photosynthesize and farmers work
        - 1.3.3. There is weak cooperation and agreements between farming communities downstream and energy companies upstream
2. Water **demand** by agriculture is (unnecessarily) high. This is mainly because of:
    - 2.1. Inefficient irrigation practices (irrigation through flooding, water supply is higher than crop needs). These practices are used by farmers because:
        - 2.1.1. Tradition and knowledge level. Flooding irrigation is what the farmers are familiar with.
        - 2.1.2. Investment costs for flood irrigation are low
    - 2.2. Conveyance losses in the water channels due to poor maintenance of the channels.
    - 2.3. Transition of farmers to crops with higher water demand (?). This is occurring because:
        - 2.3.1. New (fruit) crops have higher value and lead to greater income
    - 2.4. Low level of formality and organization (comités and juntas) between farmers in the upper basin resulting in uncontrolled water use. This is because:

2.4.1. Land tenure of farmers is weak. (?) Without land tenure it is not possible to get registered water rights (?).
2.4.2. There are ongoing conflicts between communities (a) about community borders and (b) about infrastructure development by SEDAPAL, energy companies, and mining companies.
2.4.3. There is generally a low level of development and education, associated with the upper basin's remoteness and limited work opportunities

Problem 3: Low drinking water quality for communities in the sub-basin.

The main drivers that were identified for this problem are:
1. Sanitation services are decentralized, so each community must make its own arrangements for water sanitation.
2. There is a limited budget available at municipalities for WASH, while investment costs for sanitation infrastructure are high
3. Contamination of water by communities in the sub-basin

5.2 Trade-offs and synergies

Using the problems analysis from the previous section, we can identify potential trade-offs and synergies that are at play. Trade-offs occur in situations where a resource is limited, as is the case with water in the Santa Eulalia sub-basin. Because of this, a trade-off will always involve a win-lose situation, in which for one side or aspect to gain, the other must give. If this is not the case and there is a possibility of a win-win situation, we do not consider this a trade-off but rather a synergy. In a trade-off situation it is necessary to find a balance such that all parties are satisfied. This is especially important in a case where there is an imbalance of power between the involved stakeholders, when the decision on who gives and who takes falls in the hands of only one of the involved parties. Understanding trade-offs and synergies is essential for a nexus approach, because it gives insight into (a) where the bottlenecks are in a system and (b) the impact that potential interventions would have not only on the intended beneficiary but also on other stakeholders in different sectors.

The identified trade-offs and synergies are shown in Table 7. For this analysis, we consider a trade-off a situation in which a sectoral choice is beneficial for the sector, and in doing so has a detrimental impact on either another sector or on a different aspect of the own sector. If the choice were inverted, then the impact would also be inverted. For example, if SEDAPAL would choose to allocate more water for WASH in the city of Lima, that would potentially lead to less water available for agriculture and WASH for farmers and communities in the sub-basin (assuming all else in the system remains the same). We consider a synergy a situation in which the choice by one sector leads not only to a beneficial impact for the own sector, but also for another sector. This is also how the trade-offs and synergies in Table 7 should be read.

Table 7. Potential trade-offs and synergies identified in the water management of the Santa Eulalia sub-basin. Each delineated set of rows represents a trade-off or synergy. The choice made in column 1 by the sector stakeholder(s) in column 2 has a positive (blue) or negative (red) effect stated in column 3 on the sector stakeholder(s) in column 4.

Choice	By	Potential effect of choice	For
More water for WASH in Lima	Citizens of Lima (SEDAPAL)	• Less water available for agriculture and WASH in sub-basin	Farmers + Communities
More regulated water flow through reservoirs for energy production	Energy companies SEDAPAL	• Water availability is better spread throughout the year for agriculture and WASH in the sub-basin	Farmers
		• Water availability is better spread throughout the year for WASH in Lima	Citizens of Lima (SEDAPAL)
More electricity available during peak hours (evening) in Lima	Citizens of Lima (Energy companies)	• Less water available for WASH in Lima during daytime	Citizens of Lima (SEDAPAL)
		• Less water available for agriculture and WASH in sub-basin during daytime	Farmers + Communities
More land used for agriculture, urbanization, and mining (deforestation)	Farmers Mining companies	• Less groundwater available for agriculture and WASH in sub-basin (?) due to reduced infiltration	Farmers + Communities
		• Less groundwater available for WASH in Lima (?) due to reduced infiltration	Citizens of Lima (SEDAPAL)
		• Declining forest ecosystems/biodiversity (?)	The environment
		• More run-off water available for farmers (?)	Farmers
Neglect / Low maintenance of terraces in upper basin	Farmers	• Less groundwater available for agriculture and WASH in sub-basin due to reduced infiltration	Farmers + communities
		• Lower soil quality in upper basin due to erosion	Farmers
		• Higher sedimentation in reservoirs (?)	Energy companies
Little investments in current irrigation system with low water use efficiency	Farmers	• Higher water demand per hectare for agriculture in sub-basin	Farmers
	ANA	• Higher infiltration in the sub-basin	Farmers (lower zone)
	DRAL	• Less water available for WASH in Lima	Citizens of Lima (SEDAPAL)

See table continuation on next page

Choice	By	Potential effect of choice	For
Little investments in improving the current knowledge level of farmers to use water efficient	DRAL Farmers	• Higher water demand per hectare for agriculture in the sub-basin • Less water available for WASH in Lima	Farmers Citizens of Lima (SEDAPAL)
Little investments in maintaining irrigation infrastructures (channels)	Farmers (?) ALA	• Less water available for agriculture (due to greater conveyance losses) • Less water available for WASH in Lima (due to greater conveyance losses)	Farmers Citizens of Lima (SEDAPAL)
Production of higher value crops (resulting in higher income)	Farmers	• Higher water demand for crops • Less water available for WASH in Lima	Farmers Citizens of Lima (SEDAPAL)
Low intensity agricultural production (low inputs & no improved varieties and breeds)	Farmers	• Higher water demand per kg product • Less water available for WASH in Lima	Farmers Citizens of Lima (SEDAPAL)
Little coordination with downstream communities during infrastructure development	Energy companies SEDAPAL	• Less control over water supply for irrigation	Farmers (middle and lower area)
Little coordination with downstream communities on operation of reservoir (water flow)	Energy companies SEDAPAL	• Less control over water supply for irrigation	Farmers (middle and lower area)
Low formalization of water rights of upper basin farmers	ANA/ALA Farmers	• Weaker water rights in times of water scarcity • More conflicts on water use between farmers	Farmers (upper area) Farmers (upper area)
Low overall investment in development of upper basin	MINAGRI ANA MINEDU[5] VIVIENDA[6]	• Low level of organization of farmers and communities, leading to weaker water rights in times of water scarcity	Farmers (upper area)
Low investment in WASH services in the sub-basin (due to decentralization)	ANA	• Low water quality in the sub-basin	Communities
More energy production (higher water flow)	Energy companies	• Ecological flow is not met	The environment
Sediment removal in reservoirs	Energy companies	• Lower quality of water for aquaculture	Aquaculture producers

[5] Ministry of Education
[6] Ministry of housing, construction, and sanitation

5.3 Data gaps

Potential trade-offs and synergies have thus far been identified on a qualitative level. Although this gives some insight into the linkages between stakeholders in the water, food and energy sectors of the sub-basin, a quantitative analysis is needed to provide a better understanding of the relative importance of each issue at play. A quantitative analysis has thus far not been possible due to the lack of quantitative data. The main data gaps that were identified for the agricultural sector were:

i. Spatial information on land use (change) in the Santa Eulalia sub-basin:
    a. Total cropping areas
    b. Areas per crop
    c. Total areas of other land use types (forest, wetland, urban)

ii. Temporal and spatial data on irrigation water use and management in different crops across the Santa Eulalia sub-basin.

iii. Data on soil characteristics (e.g. water holding capacity, rooting zone, soil texture, soil organic matter content)

iv. Data on the farming structure across the sub-basin (land size, crop and livestock holdings, level of mechanization, crop and livestock yields, etc.)

See table continuation on next page

6 Ongoing Activities

Multiple ongoing activities aim at improving water management and agricultural production in the sub-basin. These initiatives address some of the problems and trade-offs identified in Section 5. We highlight some of the most important activities in the following sub-sections.

6.1 Governance

Regarding governance, there seems to be an awareness that it is necessary to improve the water management to prepare for a future in which this resource becomes increasingly scarce. There are multiple initiatives going on to improve the water governance in the basin.

6.1.1 Plan de Gestión de Recursos Hídricos (PGRH)

A PGRH (translated: Water Resource Management Plan) is being developed by the Consejo de Recursos Hídricos de Cuenca CHIRILÚ (Water Resource Council CHIRILÚ) for the basins Chillón, Rímac, and Lurín (recall that Santa Eulalia is a sub-basin of Rímac). The PGRH is the council's main tool to coordinate the interests of all the stakeholders of the basins (ANA 2019). The objective of the PGRH is to provide solutions related to water quality and availability for a reliable and climate resilient water supply and effective water governance.

6.1.2 Gestión Integrada de Recursos Hídricos (GIRH) in Santa Eulalia

Within the CRHC CHIRILU (Water Resource Council CHIRILÚ), the Grupo de Trabajo Santa Eulalia (Santa Eulalia Working Group) was formed from what was originally an independent group of stakeholders called the Programa de Agua, Clima, y Desarrollo (PACyD, Water, Climate and Development Program). The main purpose of the working group is to improve stakeholder cooperation in the Santa Eulalia sub-basin. They are developing their view on how water could and should be managed inter-sectorally in a strategy of Gestión Integrada de Recursos Hídricos (GIRH, Integrated Management of Water Resources). Their vision is submitted as input for the development of the PGRH (Alarcón 2021). It is not clear what the differences are in approach between the GIRH and the PGRH.

6.1.3 Plan de Aprovechamiento de Disponibilidad Hídricas (PADH)

Within the CRHC CHIRILU (Water Resource Council CHIRILÚ), another working group is developing the yearly Plan de Aprovechamiento de Disponibilidades Hídricas (PADH, Plan for the Use of the Available Water) (Section 3.3.1). The plan is meant as a tool to make agreements at the beginning of the year between water users on the amount of water allocated to them during that year. By making these agreements beforehand, conflicts between stakeholders can be avoided. However, this approach requires users to know their (approximate) yearly water demand. For companies such as SEDAPAL and the energy generating companies this is not a problem, but for farmers this is more difficult. As explained in Section 3.2.3, much of the water used by farmers is used on an informal basis, with no registered water use rights. Moreover, water use by farmers is not measured. As a result, it is difficult to know the agricultural sector's water demand, and it is unclear whether their needs are included in the plan. In times of water scarcity, the PADH can therefore be used by water users such as SEDAPAL or the mining companies to claim water resources, while claims of farming communities are ignored.

6.2 Environmental restoration

There are different ongoing activities with the purpose of restoring ecosystems. The main ones are outlined below.

6.2.1 MEcanismos de REtribución por Servicios Ecosistémicos (MERESE)

The water sanitation company SEDAPAL is starting to implement a system called MEcanismos de REtribución por Servicios Ecosistémicos (MERESE, Retribution Mechanisms for Ecosystem Services). The basic concept of the system consists in slightly increasing the price of water in Lima to finance environmental projects along the basin that provide ecosystem services (GRADE 2018). The projects are formulated by SEDAPAL, ideally in cooperation with the communities, and must be approved by SUNASS (Superintendencia Nacional de Servicios de Saneamiento) (GRADE 2018). A first project that is planned in this context is the restoration of the Milloc wetland, in the district of Carampoma (Bernales and Mendoza 2021).

6.2.2 Siembra y cosecha de agua

There are multiple initiatives going on about the Siembra y Cosecha de Agua (sowing and harvesting water). This is the process by which people collect and infiltrate (sow) rainwater and surface runoff into the subsoil in order to recover (harvest) it sometime later (Sergio Martos-Rosillo, Alfredo Durán et al. 2020). Water infiltration can be stimulated through different means such as reforestation, terracing, ditches, and canals. Some ongoing projects on this topic are:

- SEDAPAL has created the program "Sembramos Agua" (We sow water), financed by SUNASS. The program implements projects that are meant to recover ecosystem services in the CHRILÚ basins (Bernales and Mendoza 2021). It is unclear whether this program falls under the MERESE system of SEDAPAL.
- In 2015, AGRORURAL and the Sierra Selva Alta Project of MIDAGRI financed the pilot project for sowing and harvesting water in San Antonio de Chaclla (Bernales and Mendoza 2021).
- In 2020, a pilot project for planting and harvesting water was implemented in San Mateo, starting with a workshop, promoted by the Regional Government of Lima and carried out by the Agrarian Agency of Santa Eulalia. The same was implemented in other localities, such as Tupicocha, Pariapongo, San Pedro de Casta, Laraos and Mariatana (Bernales and Mendoza 2021).

6.2.3 Reforestation of Árbol de Quina

AgroRural has financing the planting of 50,000 saplings of Árbol de Quina, an endangered species in Perú. This is being done in the context of the Plan de Acción para el Repoblamiento Forestal con Especies del género *cinchona* (Árbol de la Quina) 2020-2022 (Action plan for the forest repopulation with the *cinchona* genus) (Bernales and Mendoza 2021).

6.3 Farmer incomes

There are also some initiatives going on with the purpose of increasing farmer income. These are listed below.

6.3.1 Ecoferia Santa Eulalia

The Ecoferia Santa Eulalia is a local produce market promoted by the Regional Government of Lima and the Instituto de Desarrollo y Medio Ambiente (IDMA, Institute for Development and Environment). The market was created in 2015 to promote agroecological production of various sectors of the sub-basin. The producers were given a Participatory Guarantee System (SGP) certificate. Agricultural products are promoted, such as avocado, custard apple, banana, among others, and it seeks to stimulate agrotourism and the participation of more than 25 thousand organic producers.

6.3.2 De la chacra a la olla

The markets 'De la chacra a la olla' (From the farm to the pot) are an alternative to local stores for communities to buy unprocessed food products, such as vegetables, tubers, fruits, and meats. The markets are financed by AGRORURAL. The concept is promoted on a national scale and seeks the participation of famers rather than intermediaries (Bernales and Mendoza 2021). It is meant to increase incomes of farmers and to lower food prices for consumers by eliminating the middlemen.

7 Conclusions and Recommendations

7.1 Conclusions

Due to the COVID-19 crisis and international travel restrictions this scoping study has been carried out remotely, i.e. based on the available literature and with the support of a local consultant who performed interviews with the most important nexus stakeholders. Although this approach had its limitations, the scoping study has resulted in mapping of the most important stakeholders in the agricultural sector and their linkages with the water and energy sector (Chapter 3), an overview of on-going initiatives in the sub-basin to improve climate resilience and agricultural water management (Chapter 6), and an assessment of the current agricultural food system in the Santa Eulalia sub-basin (Chapter 4). More importantly, the collected information provided insights in the current and potential future nexus problems and causes (Chapter 5). This problem analysis allowed to identify knowledge and data gaps, and various potential trade-offs and synergies among sectors and stakeholders.

The identified synergies relate to the water reservoirs developed for the generation of hydroelectricity in the upper zone of the sub-basin. Because of the short rainy season and low amounts of rainfall, especially in the middle and lower part of the sub-basin, water availability in the dry season depends almost completely on water from melting glaciers and the inter-basin water transfer from the Mantaro basin. In principle, the reservoirs help to regulate the water supply more evenly through the year thus improving the availability of water for WASH and agriculture in the lower parts of the basin. With the expected reduction of water from melting glaciers due to climate change, the management of artificial reservoirs and natural lakes in the upper zone may become more important in the future to distribute available water resources throughout the year.

The extent of the identified trade-offs and the way they affect stakeholders is uncertain. However, competition for water resources is likely to intensify in the future considering the effects of climate change on the local hydrology, increased demand for consumptive water and energy driven by the rapidly growing population of Lima, and the growing demand for consumptive water and agriculture by the local population in the Santa Eulalia basin. More quantitative insight in current trade-offs, developments that potentially intensify these trade-offs and options to mitigate or adapt to trade-offs is needed to support nexus decision making contributing to the equal access to water for all.

To improve quantitative insights in the tradeoffs the following data and knowledge gaps have been identified: i) spatial information on land use (change) in the Santa Eulalia sub-basin, and ii) temporal and spatial data on irrigation water use and management in different crops in the Santa Eulalia sub-basin.

7.2 Recommendations

To gain more quantitative insights in the problems and trade-offs an integrated climate, land, energy and water systems modelling approach is recommended. With such approach the magnitude of problems can be made explicit and the extent of current tradeoffs quantified supporting policy decision-making and operational water resources management. In the proposed modelling approach potential consequences of future scenarios can be made transparent, for example, consequences of the growing demand for WASH and energy by the metropolitan area of Lima, the contribution of improved irrigation practices to the downstream water supply, effects of constructing new water reservoirs in different zones of the Santa Eulalia basin, and the effects of climate change on the local hydrology.

Given the vulnerability of the Santa Eulalia basin for climate change (and thus the water and energy supply of Lima) it is further advised to intensify research into the effects of climate change on the local hydrology and land use. The available literature on climate change effects in relation to the sub-basin that was reviewed in this study was more than 10 years old and reported large uncertainties including the unknown contribution of glacial water to the Rimac river (Kerres, 2010). Recently, global climate change models have been updated and downscaling techniques improved which could help to narrow down the uncertainties in climate change predications. In addition, more knowledge should be produced on the contribution of melting glaciers to water flows in the Santa Eulalia basin and on the relationships between climate change and glacier melting.

Furthermore, in view of the current and increasing claims for water by different sectors a number of no-regret activities are proposed that could contribute in the short term to reduced water demand and improved water supply:

1. Improve the knowledge and skills of farmers on good agricultural practices to improve resource use efficiencies, especially water use efficiency, through training and capacity building.
2. Improve the current irrigation infrastructure and practices ranging from reducing water conveyance losses, better irrigation scheduling and changes from the current flood irrigation practices to more efficient water supply methods such as drip or sprinkler irrigation systems. Training and capacity building of relevant stakeholders is needed to improve current irrigation practices.
3. Promote soil and water conservation measures in the upper zone of the basin to improve water infiltration and reduce water runoff and soil erosion.
4. Strengthen the local governance structure related to the WEF nexus. Many stakeholders in the Santa Eulalia sub-basin and further downstream are involved in the use and management of the water resources. Current efforts to coordinate management of the water resources seem scattered without clear delineation of responsibilities. Setting up a policy dialogue with interested stakeholders is a first step towards information sharing and common understanding of the problems, trade-offs, and choices that need to be made, and to develop a shared vision on how scarce water resources can be best used and managed, now and in the future.

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Annex 1 Extra Figures

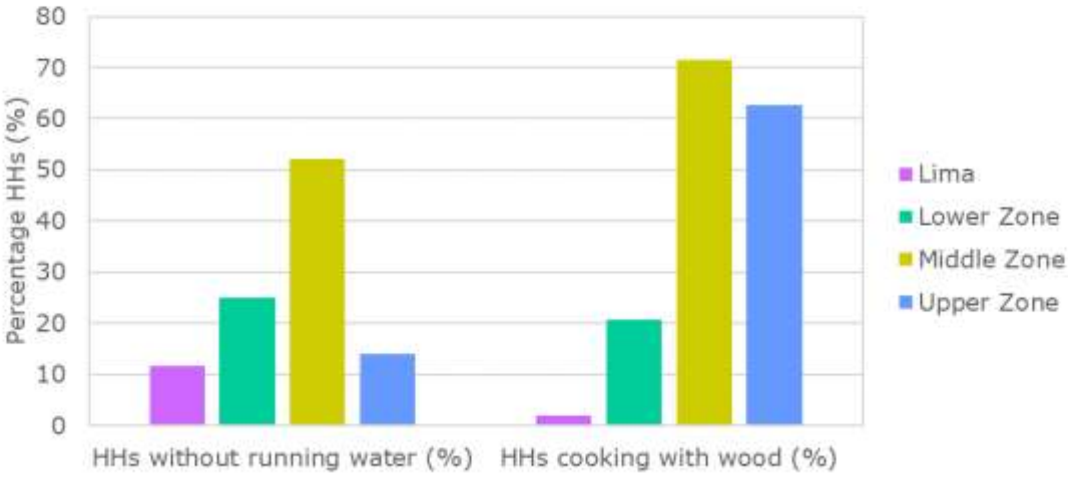

Figure 19. Percentage of interviewed households without running water inside their buildings and cooking with wood in Lima and all three zones of the sub-basin. Source: National census 2017.(INEI 2017)
(INEI 2017)

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