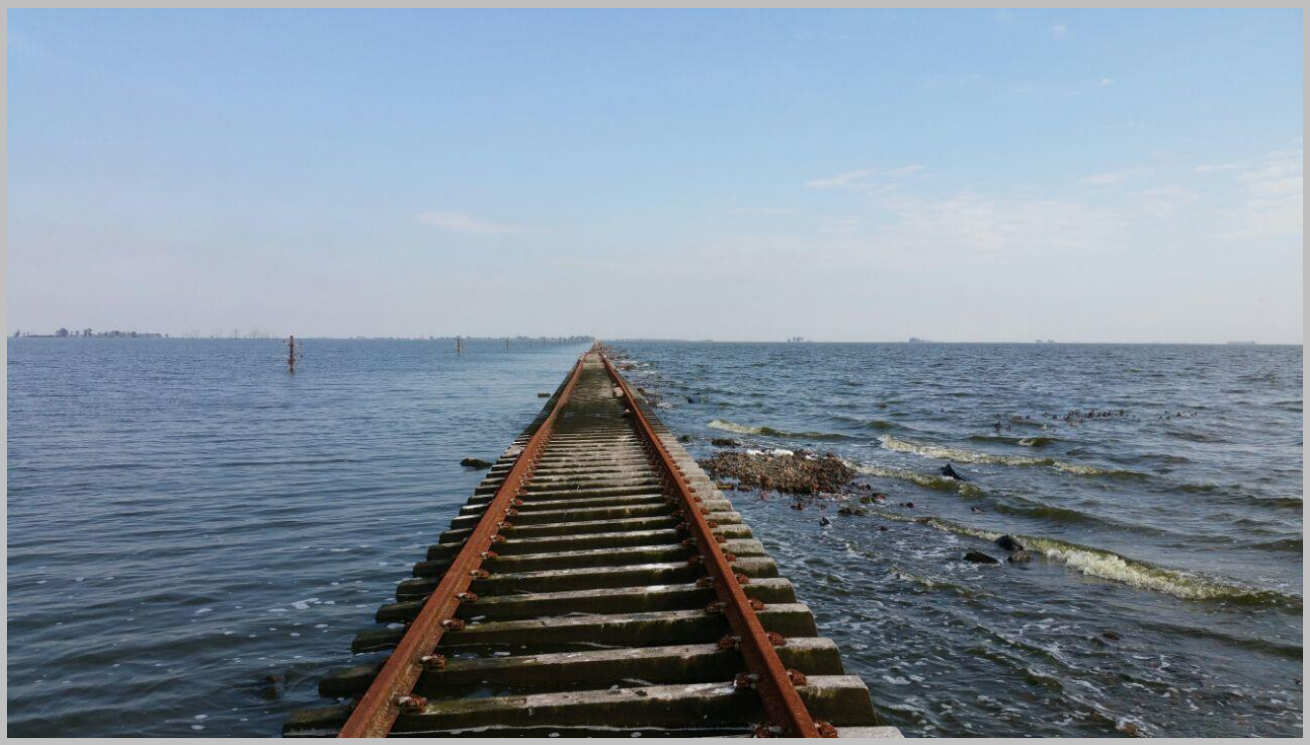

MASTER'S THESIS

NATURAL RESOURCES MANAGEMENT AND DEVELOPMENT (MSc)

TH Köln - University of Applied Sciences, Cologne
ITT – Institute for Technology and Resources Management in the Tropics and Subtropics

Universidad Nacional de Córdoba (UNC)
Laboratorio de Hidráulica – Centro de Estudios y Tecnología del Agua (LH-CETA)

THE ROLE OF WETLANDS IN ECOSYSTEM SERVICES TRADE-OFFS IN LA PICASA BASIN, ARGENTINA

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The Role of Wetlands in Ecosystem Services Trade-Offs in La Picasa Basin, Argentina

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Content

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List of Abbreviations

CARSFE	Confederación de Asociaciones Rurales de Santa Fe (Confederation of Rural Associations in Santa Fe)
DEAD	Direción de Estimaciones Agrícolas y Delegaciones (Management of Agricultural Estimations and Delegations)
DRR	Disaster Risk Reduction
Eco-DRR	Ecosystem-based Disaster Risk Reduction
ESS	Ecosystem Service(s)
ETo	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
GI	Green Infrastructure
GIS	Geographical Information System
INTA	Instituto Nacional de Tecnología Agropecuaria (National Institute for Agricultural Technology)
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
IPCC	Intergovernmental Panel on Climate Change
ITT	Institute for Technology and Resources Management in the Tropics and Subtropics
LCCS	Land Cover Classification System
LH-CETA	Laboratorio de Hidráulica – Centro de Estudios y Tecnología del Agua
SES	Socio-Ecological System(s)
SsRH	Subsecretaría de Recursos Hídricos de la Nación (Under-Secretariat of Water Resources of Argentina)
TESSA	Toolkit for Ecosystem Service Site-Based Assessment
TH	Technische Hochschule (Technical University of Applied Sciences)
TU	Technische Universität (Technical University)
UNC	Universidad Nacional de Córdoba
UNISDR	United Nations International Strategy for Disaster Reduction
USDA	United States Department of Agriculture
WRB	World Reference Base for Soil Resources
WWF	World Wildlife Fund

List of Definitions

Some of the relevant terms mentioned in this thesis, are used in different scientific contexts with distinct characteristics and slightly changing definitions. To avoid confusion and enhance the accurateness of the thesis, the following list states the definitions used in this study:

	Definitions
Best management practices	Methods or techniques found to be the most effective and practical means in achieving an objective (such as preventing or minimizing pollution) while making the optimum use of the firm's resources. (Web Finance Inc, 2018)
Biological diversity (biodiversity)	"'Biological diversity' means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." (Haslett, 2003)
Disaster	"A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources." (UNISDR, 2009)
Disaster risk reduction	Disaster risk reduction (DRR) is defined as "reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events" (UNISDR, 2009).
Ecosystem	"An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit. Humans are an integral part of ecosystems." (Mooney *et al.*, 2005)
Ecosystem services	"Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, droughts, land degradation, and diseases; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits." (Mooney *et al.*, 2005)
Groundwater flooding	The UK Government's Department for the Environment and Rural Affairs (Defra, 2004) defined groundwater flooding is a 'flooding caused when water levels in the ground rise up above the natural surface, it will often occur when accumulated rainfall over a long period of weeks or months is significantly above normal. Groundwater flooding is most likely to occur in low-lying areas underlain by permeable strata.' (Hughes *et al.*, 2011)

Socio-ecological system	"Systems where social, economic, ecological, cultural, political, technological, and other components are strongly linked are known as socioecological systems, emphasizing the integrated concept of the 'humans-in-nature' perspective. Socioecological systems (SESs) are truly interconnected and co-evolving across spatial and temporal scales, where the ecological component provides essential services to society such as supply of food, fiber, energy, and drinking water." (Petrosillo, Aretano and Zurlini, 2015)
Stakeholders	"Stakeholders refer to persons, organizations or groups with interest in the way particular ecosystem services are used, enjoyed or managed" (Groot *et al*., 2011).
Sustainability	Sustainability is defined as "meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them, and more specifically, as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity". (Morelli, 2011)
The wise use of wetlands	"The wise use of wetlands involves their sustainable utilization for the benefit of humankind in away compatible with the maintenance of their ecological character within the context of sustainable development and achieved through the implementation of ecosystem approaches." (Mooney *et al.,* 2005)
Wetlands	"Wetlands, as defined by the Ramsar Convention on Wetlands, are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed six meters" (Article 1.1 of the Convention text). (Ramsar Convention Secretariat, 1971)

Abstract

The southeast of Córdoba province used to be originally covered by hundreds of wetlands that got heavily modified or drained in the last few decades. Since wetlands provide various important ecosystem services (ESS) for human well-being, their degradation created several problems in La Picasa basin, among which floods are the most obvious one. The wise use of wetlands is increasingly acknowledged to be part of nature-based solution approaches reducing disaster risk. However, in the study area these approaches remain a relatively new concept to decision makers and the lack of knowledge on their effectiveness and implementation process poses a serious barrier to their adoption.

To overcome this obstacle, this dissertation applies an ESS perspective on the current problems of La Picasa basin and sets it in a context of socio-ecological system (SES) theory. A comprehensive analysis of (1) the role wetlands have played in the historic development of the SES, (2) important stakeholder dynamics that create opportunities or restrictions for the conservation of wetlands and (3) possible management approaches to inverse negative ESS trade-offs and feedback loops, was performed.

Results demonstrate that the current problems of floods have both natural and anthropogenic causes. In this regard, wetlands hold a vital role in the complex historic interactions between the social and ecological drivers of changes in the water balance. Although a social network between stakeholders exists, several conflicts prevent a proper functioning of a basin-wide integrated management concept based on wetland restoration. Nature-based solution approaches, putting wetlands in the center of attention of future management strategies, were found to hold a high potential to reduce the risk of floods and, as a side-effect boost biodiversity and habitat quality in the study area.

Key words: wetlands, ecosystem services trade-offs, socio-ecological systems, Eco-DRR, stakeholders

Resumen

Originalmente, el sudeste de la provincia de Córdoba solía estar cubierto por cientos de humedales, que fueron considerablemente modificados o drenados en las últimas décadas. Dado que los humedales proporcionan varios servicios ecosistémicos (ESS) importantes para el bienestar humano, su degradación ha generado varios problemas en la cuenca de la laguna La Picasa, entre los cuales las inundaciones son los mas evidentes. El uso adecuado de los humedales es reconocido cada vez mas como parte de enfoques que incluyen a la naturaleza para reducir el riesgo de desastres. Sin embargo, en el área de estudio estos enfoques siguen siendo un concepto relativamente nuevo para los tomadores de decisiones y la falta de conocimiento sobre su efectividad y proceso de implementación plantea una barrera seria para su adopción.

Para superar este obstáculo, esta tesis de maestría emplea el enfoque basado en ESS sobre los problemas actuales de la cuenca de la laguna La Picasa en el marco de la Teoría de los Sistemas Socioecológicos (SES). A tal fin se realizó un análisis exhaustivo de (1) el rol que los humedales han desempeñado en el desarrollo histórico de los sistemas socioecológicos, (2) dinámicas de los actores clave involucrados que promueven o restringen las posibilidades de conservar los humedales y (3) posibles enfoques de manejo para revertir las retroalimentaciones negativas de los ESS.

Los resultados demuestran que los problemas actuales de inundaciones tienen causas naturales y antropogénicas. En este sentido, los humedales tienen un papel vital en la compleja interacción histórica entre las causas ecológicas y sociales de los cambios en el balance hídrico. A pesar que existe una red entre las partes interesadas, varios conflictos impiden la aplicación de un manejo integrado a nivel de cuenca basado en la restauración de los humedales. Se concluye que los enfoques que incluyen a los humedales como puntos estratégicos de las futuras propuestas de manejo tienen un alto potencial para reducir el riesgo de inundaciones y, al mismo tiempo, promover la biodiversidad y la calidad de hábitat en el área de estudio.

Palabras clave: humedales, trade-offs de los servicios ecosistémicos, sistemas socioecológicos, Eco-DRR, partes interesadas

1 Introduction

Being one of the world's most important types of ecosystems, wetlands are also one of the most threatened habitats on earth (Hu *et al.*, 2017). It is widely recognized that they provide a broad variety of ecosystem services (ESS), among which some of the most important ones are the supply of fish and fresh water, climate regulation and the mitigation of risks (Mooney *et al.*, 2005). Although human well-being, especially of the population living close to wetlands, is acknowledged to be strongly related to the ESS wetlands provide (Mooney *et al.*, 2005), they got heavily degraded on a global scale within the last decades (Mooney *et al.*, 2005; Douglas, 2015; Hu *et al.*, 2017).

From a biodiversity perspective, although only 1% of the earth's surface is covered by freshwater wetlands, these wetlands provide a home to > 40% of the world's species and are therefore of vital importance to fight the loss of biodiversity on a global, regional and local scale (Mitra, Wassmann and Vlek, 2003). Reversely, wetland's key functions like biodiversity support, water quality improvement, flood abatement, and carbon sequestration are impaired when they get lost or degraded (Zedler and Kercher, 2005). Depending on the regional setting, climatic regimes and population affected, the loss of functioning wetlands accompanied by a loss of the related ESS they offer, can have a tremendous impact on human well-being.

This phenomenon can be observed within the study area 'La Picasa basin', covering parts of southeast Córdoba, south Santa Fe and northwest Buenos Aires with a total area of 5,300 km² (compare Figure 1). Wetlands and rolling hills are the predominant landscape characteristics and with its brackish lagoons the study area is part of the Pampa ecoregion (Benzaquen *et al.*, 2016).

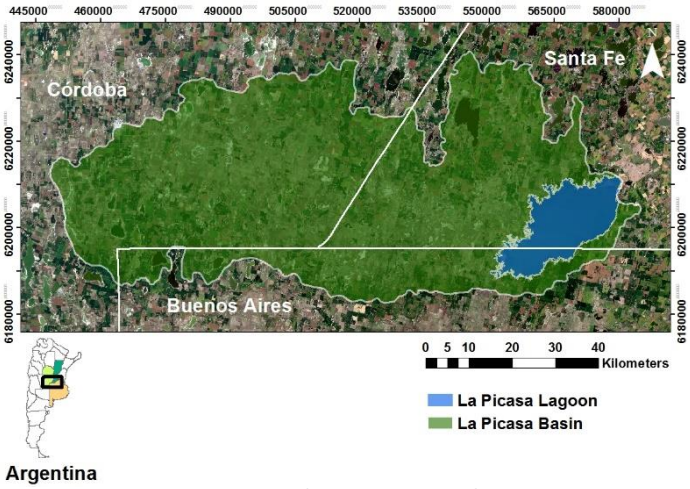


Figure 1: Study Area La Picasa basin (own elaboration based on SsRH (2017))

Over the last decades, an increase in precipitation in combination with a decrease in evapotranspiration rates due to land-use changes led the groundwater table in the Pampas of Argentina to rise (Aradas and Thorne, 2001; Kuppel *et al.*, 2015; Nosetto *et al.*, 2015). Today, it reaches the surface level in the study area and, in its interplay with surface water, has been identified as the main driver for groundwater flooding (Aradas and Thorne, 2001). During the last years, flooding due to rising groundwater levels was recognized as one of the major disasters in Argentina with flooded areas accounting for 3,927,778 hectares in the Pampa ecoregion (DEAD, 2017). Human well-being in La Picasa basin is highly affected by this disaster, defined as "a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts which exceeds the ability of the affected community or society to cope using its own resources" (UNISDR, 2009).

Future prospects of an improvement of the situation are improbable, given the increase in precipitation rates since 1970 (Aradas and Thorne, 2001; Viglizzo, Frank and Carreño, 2006; Venencio and García, 2011; Brandolin, Ávalos and De Angelo, 2012; Pereira *et al.*, 2014) caused by a westward displacement of isohyets (Viglizzo *et al.*, 1995). This emphasizes the need to deal with the current trend of continuous flooding events that will probably persist and continue creating complex socio-economic problems such as the loss of critical infrastructure, fertile agricultural lands and private properties (Rosenstein *et al.*, 2009).

To avoid that every flooding hazard turns into a disaster, investments have been made focusing on grey infrastructure. With the aim to reduce the disaster risk of the region, defined as "systematic efforts to analyze and manage the causal factors of disasters, including a reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events" (UNISDR, 2009), a vast number of drainage canals have been implemented and pumping stations are supposed to function as artificial water exits for the naturally endorheic basin (CARSFE, 2003).

The intensive agriculture performed in the study area, highly impacted the native ecosystems in the region from an environmental point of view (Carreño, Frank and Viglizzo, 2011). As farmland in Argentina expanded quickly this development came at the expense of natural land, and took place without a consideration of the related ecological costs (Carreño, Frank and Viglizzo, 2011). Especially natural grasslands and wetlands were highly affected by this degradation of natural land (Bilenca and Miñarro, 2004a; Booman *et al.*, 2012; Brandolin, Ávalos and De Angelo, 2012; Modernel *et al.*, 2016; Sica *et al.*, 2016).

It is widely accepted that environmental degradation, like observed in the study area, accelerates vulnerabilities and can in addition increase exposure to hazards (IPCC *et al.*, 2014; Renaud, Sudmeier-Rieux and Estrella, 2015; United Nations Office for Disaster Risk Reduction (UNIDSR), 2015). Although many factors influence disaster risks, degradation and destruction of ecosystems can severely limit their ability to serve as protective barriers against the physical impacts of a disaster event, to provide goods and services for basic needs as well as livelihood opportunities (Sudmeier-Rieux, Ash and Murti, 2013).

Ecosystems and disasters interact in multiple ways. Major disasters lead to severe environmental consequences while well-managed environments can have a buffer-function against disasters and reduce risks of impacts (Monty, Murti and Furuta, 2016). However, despite the fact that environmental management holds a high potential to reduce disaster risks, the ecosystem-based approach to disaster risk reduction (Eco-DRR), defined as a "strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" is still underexplored among practitioners and policy makers (Monty, Murti and Furuta, 2016) and also neglected in the study area so far. Difficulties in understanding the study area's socio-ecological system (SES) and relevant ESS, as well as uncertainties among local stakeholders about the effectiveness and implementation process of Eco-DRR measures, pose serious barriers to its adoption in La Picasa basin.

Although land-use management in the region has been identified as negatively affecting the systemic functioning of the study area (Viglizzo *et al.*, 2010; Carreño, Frank and Viglizzo, 2011; Booman *et al.*, 2012; Nosetto *et al.*, 2015; Modernel *et al.*, 2016), the current socio-economic context favors short-term profit from unsustainable production systems (Carreño, Frank and Viglizzo, 2011), ignoring that these profits can be significantly outweighed by long-term costs to local communities and the government when floods continue causing disasters (Monty, Murti and Furuta, 2016).

Against this background, there is an urgent need to break the negative feedback loop that is triggered by harmful human impact. Best management practices with the potential to simultaneously fighting biodiversity loss and improving human well-being exist but are repeatedly neglected or not in place in the study area. To make their application reasonable it is important to understand the SES of the La Picasa basin and how it reacts to natural and anthropogenic impacts.

Applying the wise use of wetlands could hold a tremendous undiscovered potential for solving versatile problems in the La Picasa basin, which so far follows a purely engineered solution approach. Therefore, this thesis aims at paving the ground and creating a useful basis for facing the current problem of floods in the La Picasa basin with an integrative basin management approach based on functioning wetlands.

To make this multidisciplinary perspective possible, existing scientific studies from different research fields were analyzed to understand the natural functioning of the system since colonization of the Pampa, as well as where anthropogenic impacts cause environmental problems. Analyzing the role of wetlands in natural feedback loops is essential to understand which ESS play a significant role in the attempt to find nature-based solutions for the current problems of La Picasa basin.

In addition, this study identifies important stakeholder dynamics that play a vital role in future basin management schemes. With the results of these two analyses, different management approaches are developed, compared and evaluated according to their capability to provide sustainable basin management schemes as a first stepping stone for future scientific investigations and management decisions in La Picasa basin.

2 Characteristics of the Study Area

2.1 Climate

According to Köppen and Geiger's classification of climate zones, the study area "La Picasa" is defined to be part of the climate zone "Cfa" (Kottek *et al.*, 2006). The classification "C" implicates that the average temperature of the coldest month is in a range between 18°C and -3°C while the warmest month shows an average temperature above 10°C. In addition, the La Picasa basin is further situated in the sub-division "f", indicating a missing dry period. This means that the intra-annual precipitation average of the months shows no significant variability and therefore, we find year-round rainfalls in the study region (compare Table 1). In the temperate climate zones there is a third sub-differentiation according to threshold temperatures and the amount of time in a year they are present (Siegmund and Frankenberg 2018). La Picasa basin shows average temperatures of the warmest month above 22°C and therefore belongs to the "a" classification.

Based on the Thornthwaite classification, the climate of this ecoregion, the Argentinian Pampas, varies from sub-humid dry in the east to semi-arid in the west and is characterized by a potential evapotranspiration of 1,247mm while receiving a mean annual precipitation of 900mm (Pedraza, 2000). An irregular variability between inter-annual dry and wet periods, however, is a common phenomenon in that region (Paoli *et al.* 2005 as cited in Iriondo and Kröhling 2007).

Table 1: Climate characteristics in selected towns of the La Picasa Basin
(own elaboration based on data from https://en.climate-data.org/search/?)

	Rufino	Venado Tuerto	Laboulaye	Villa Rossi	Villa Saboya	Amenábar	San Gregorio
Köppen-Geiger climate classification	Cfa	Cfa	Cfa	Cfa	Cfa	Cfa	Cfa
Average annual temperature	16.4 °C	16.3 °C	16.8 °C	16.7 °C	16.2 °C	16.3 °C	16.1 °C
Total annual precipitation	771 mm	845 mm	769 mm	733 mm	768 mm	799 mm	837 mm
Wettest month	March 105 mm	March 107 mm	March 120 mm	March 111 mm	March 104 mm	March 104 mm	March 107 mm
Driest month	June 21 mm	June 24 mm	July 15 mm	August 15 mm	June 22 mm	June 22 mm	June 27 mm
Warmest month	January 24.2 °C	January 23.8 °C	January 24.6 °C	January 24.6 °C	January 24.2 °C	January 24.0 °C	January 23.7 °C
Coldest month	July 9.1 °C	July 9.5 °C	July 9.5 °C	July 9.2 °C	July 8.7 °C	July 9.2 °C	July 8.9 °C

Between 1986 and 2015, mean monthly precipitation values have fluctuated following dry and wet periods, which is represented in the accumulated monthly anomaly shown in Figure 2 and Figure 3. The problem of groundwater flooding increased since 2013-2014 as the study area is facing a wet period which is exacerbating this process.

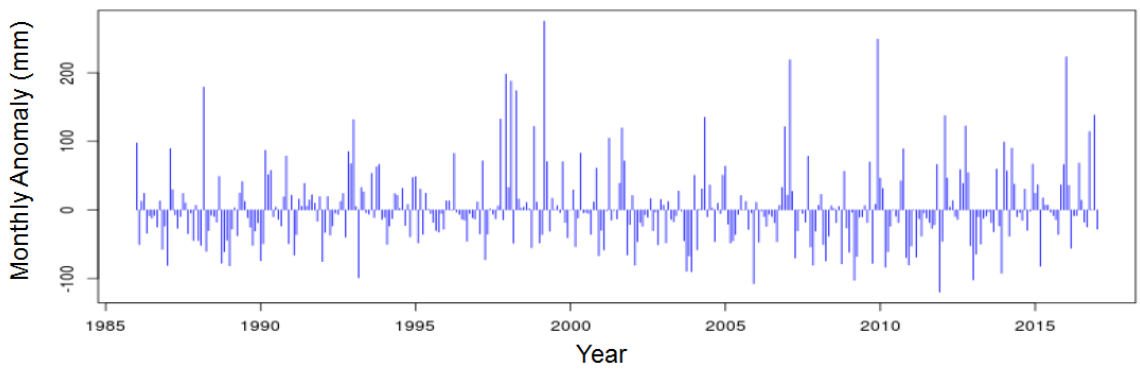


Figure 2: Monthly Anomaly in Laboulaye Station (1986-2015)
(adapted from Giordano et al. (2017))

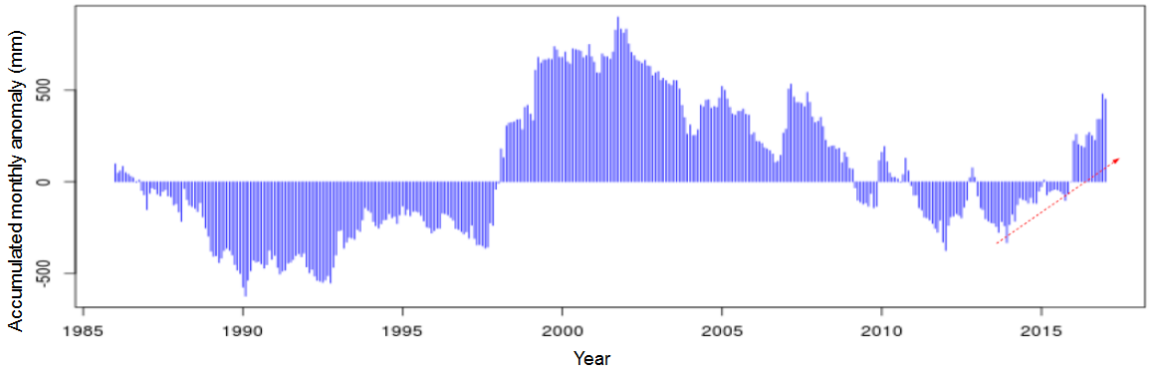


Figure 3 Accumulated monthly anomaly in Laboulaye station (1986-2015)
(adapted from Giordano et al. (2017))

The climatic, topographic and geomorphological characteristics of the region determine the processes of the hydrological cycle. The water balance is predominantly defined by vertical components such as rainfall, evapotranspiration and infiltration (Aradas and Thorne, 2001). Accordingly, after precipitation events, water infiltrates or evapotranspires faster in elevated areas and flows as interflow towards dells occupied by shallow lakes following depressions in the landscape (Iriondo & Drago 2004) from where it infiltrates or evaporates (Pedraza, 2000; Latrubesse and Brea, 2009). During humid periods, these shallow lakes are fed from the water table rising almost to the terrain surface (Pedraza, 2000; Tanco and Kruse, 2001; Latrubesse and Brea, 2009; Rosenstein *et al.*, 2009; Bertram and Chiacchiera, 2013).

Characteristic of the study area are also drainage systems that have been built to foster the movement of excess water to lagoons (Aradas and Thorne, 2001). Nevertheless, if the amount of water exceeds the capacity of these lagoons, it overflows and creates run-off fluxes (Paoli, Dondeynaz and Carmona-Moreno, 2015).

Lotic and lentic water bodies can be found in the study area (Iriondo and Drago 2004). Typical examples for lotic water bodies are transient marshes, also called “bañados”, which are non-permanent wetlands that can be found in depressed areas of the landscape and which are regularly flooded due to extreme precipitation events (Iriondo and Drago 2004). In contrast, lentic water bodies, most of them endorheic lakes such as La Picasa (Iriondo and Kröhling, 2007), are permanent water bodies that fluctuate according to the intra- or interannual variations in rainfall (Iriondo and Drago 2004).

2.2 The Pampa Ecoregion

The Pampa Ecoregion comprises an extensive plain of 398,966km², located in the eastern center of Argentina in the five agricultural provinces: the southern half of Entre Ríos, southeast of Córdoba and south of Santa Fe, northeast of La Pampa, almost the entire province of Buenos Aires, except for the

extreme south (Matteucci, 2012). Because of its extension, the Pampa Ecoregion constitutes the most important prairie ecosystem in Argentina (Matteucci, 2012).

For decades already, there is a discussion going on whether the treeless grass pampa, which today is predominantly used for agriculture, has always been a steppe landscape or lost its forest vegetation through anthropogenic influence (Schultz 2000). While some argue that at least the northeastern Pampa belongs climatically to the humid subtropics and probably only lost its forest cover through anthropogenic impacts (Schultz 2000), others would explain the original tree-lessness of the pampa by a combination of phylogenetic constraints, biogeographical accidents, droughts, frost, waterlogging, wildfire, damage to woody plants by indigenous large herbivores and edaphic factors adverse to trees (Tinley, 1982; O'Connor and Bredenkamp, 2004; Mucina and Rutherford, 2006; Wakeling *et al.*, 2012; Mills *et al.*, 2013 as cited in Milewski and Mills 2015).

Table 2: Estimation of the number of vascular plants, birds and mammals species inhabiting in the Pampas of Argentina (based on Bilenca and Miñarro, 2004a)

Biodiversity of the Pampas		
Vascular plants	Birds	Mammals
1600 (374 grass species)	300-400	70

The Pampa in Argentina has a noticeable and unique biodiversity with thousands of species of vascular plants, including almost 400 different grass species (compare Table 2) (Bilenca and Miñarro, 2004a). The particular climatic conditions of the Pampas allow the unusual coexistence of many species with C_3 and C_4 metabolisms (Bilenca and Miñarro, 2004a) and in some subtropical grassland areas, the species richness of grasses and legumes is as high as the vegetation of some tropical forests (Nabinger *et al.* 2000 as cited in Bilenca and Miñarro 2004). In addition, there are about 300-400 bird species among which 60 are strict grassland dwellers. Moreover, 70 species of mammals, including the Pampas deer (Ozotoceros bezoarticus), the most threatened mammal species of the region, can be found here.

2.3 Wetlands and Agricultural Land

The southeast of Córdoba province, where La Picasa basin is situated, used to be covered by hundreds of wetlands in a vast matrix of grasslands and savannas, but in the last few centuries this area has been widely transformed into agricultural land thereby making wetlands the last refuge for remaining wildlife (Brandolin, Ávalos and De Angelo, 2012). When after a gradual increase in precipitation the area occupied by wetlands increased, vast flooded regions were altered by the construction of artificial drainage channels, including crucial spots for the conservation of biodiversity (Brandolin, Ávalos and De Angelo, 2012). Several wetlands in the direct surrounding of La Picasa basin, such as the Saladillo wetlands, were recognized as biodiversity hotspots and even declared as “Important Bird Areas” in 2005 by Birdlife International (Di Giacomo, 2005). These wetlands that originally involved a complex network of interconnected ponds and shallow marshes, constitute the discharge area of all drainage systems in southern Córdoba (Blarasin *et al.*, 2005). However, this region also represents the most productive area for agricultural production and cattle ranching in Argentina, two activities acknowledged as leading causes of soil degradation and the replacement of natural environments (Bertonatti and Corcuera, 2000; Cabido and Zak, 2010). Consequently, wetlands are not only representing refuge for wildlife, but are also associated with the last remnants of natural grasslands and savannas, which are among the most endangered ecoregions of Argentina (Bertonatti and Corcuera, 2000).

The study area is located in the Rolling or Inland Pampa and is a rural area. As one of the most productive ecoregions in the world, it also represents the core of agricultural and farm production in Argentina (Latrubesse and Brea, 2009). Accordingly, today most of the area is destined for agriculture, especially annual crops such as wheat, soy, and maize in rotation with annual and perennial pastures such as oat, rye, alfalfa and grasses for livestock milk and meat production (Viglizzo and Frank, 2006).

Especially during the last two centuries, the Pampa ecoregion has undergone a sequence of changes: Once characterized by native grasslands, the region offered the perfect basis for a development in livestock activities (Nosetto *et al.*, 2012). Incorporating alfalfa and grain crops into the livestock farming systems was the start of a complete transformation of the landscape, during which, especially in the last two decades, livestock systems were completely replaced by annual crops with very little or no rotation throughout the production cycle (predominantly soybean, wheat, and maize) (Nosetto *et al.*, 2015). Only a minor proportion of land remains uncultivated, such as dense grasslands and herbaceous plants in flooded areas (compare Figure 4).

Today, the basin's land cover is characterized by a high percentage of non-gramineae and gramineae herbaceous crops, some spare areas of dense natural grasslands, some areas of dense herbaceous plants in temporarily flooded marshes, as well as some stationary water bodies and urban areas (FAO-LCCS, 2007), as shown in Figure 4.

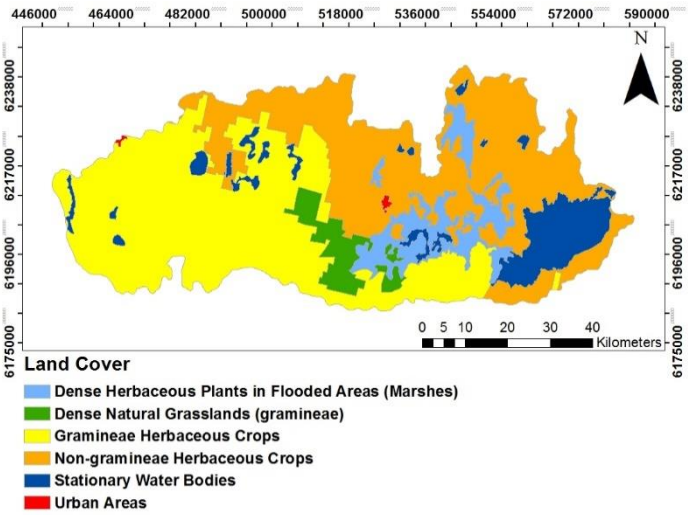


Figure 4: Todays Land Cover in the Study Area (own elaboration based on FAO-LCCS (2007))

2.4 Soils of the Pampa

Although fertile soils only make up 10% of Latin America's surface area (Jeffery et al., 2010; Gardi *et al.*, 2015), Argentina's soil resources make up the largest fertile area in the continent and have been the main support of the country's economic development (Moscatelli and Pazos, 2000). They enable long lasting periods of extensive harvests and made the country to be known as "The world barn" (Moscatelli and Pazos, 2000). Accordingly, common associations with Argentina used to be wide plains, everlasting dark and deep soils, meat of excellent quality and high crop yields (Moscatelli and Pazos, 2000). Especially for the humid Pampa these connotations are relatively true, where plains have developed in loess, a mineral-rich sediment deposited by wind, mixed with volcanic sediments (Gardi et al., 2015) and used to be originally covered by natural grasslands (Moscatelli and Pazos, 2000). The soils of the Pampa are rich in well-humidified organic matter and show an abundance of calcium carbonate as well as bases and salts (Gardi *et al.*, 2015). In most humid areas, like the study area, clay transformation can also take place which is more intense with the presence of sodium (Gardi *et al.*, 2015).

The La Picasa basin is part of the so-called 'Pampean Sand Sea' (Iriondo and Kröhling, 2007). Determined by a sequence of aeolian sedimentary processes (Petit-Maire *et al.* 1999 as cited in Iriondo and Kröhling 2007), the landscape is a large flat area with slopes lower than 0.4% (Latrubesse and Brea, 2009). Characterized by loess sediments, longitudinal relic sand dune fields (in directions S-N and SSW-NNE) and dells that resulted from deflation processes, this landscape is crisscrossed by numerous wetlands that usually formed in the dells as shown in Figure 5 (Aradas and Thorne, 2001; Iriondo and Kröhling, 2007).

In the central zone of La Picasa basin, one of these dells is a longitudinal flat low-lying stripe at the end of which the 'La Picasa' lagoon is located (Pedraza, 2000). In the higher parts of the landscape, dells are characterized by fine texture with limited drainage capacity while soils are deep, well-drained and their texture varies between loamy to loamy-sandy (Pedraza, 2000).

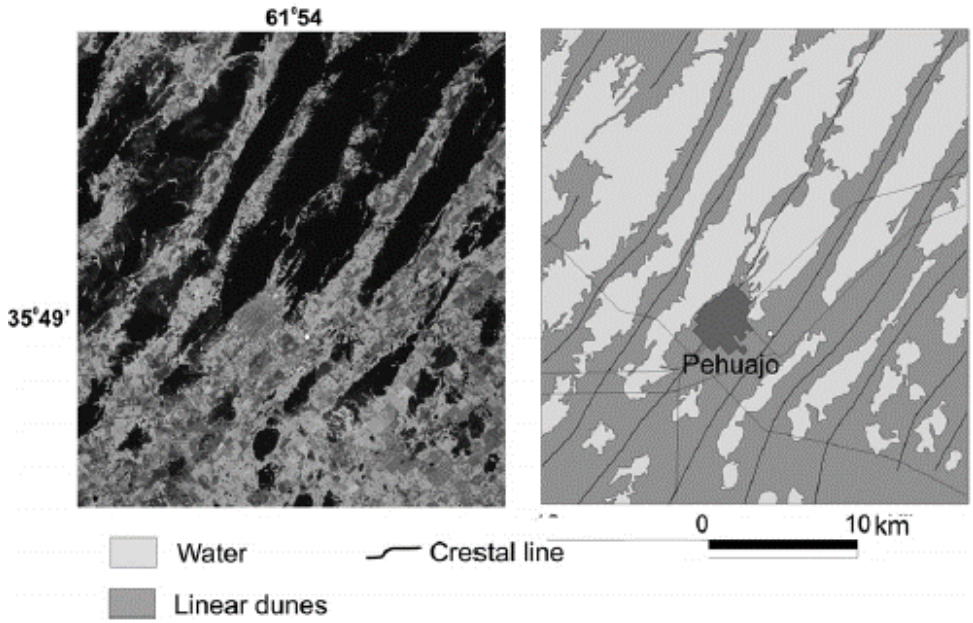


Figure 5 Longitudinal sand dunes and accumulation of water in dells (Source: Latrubesse & Brea (2009))

The soil pattern in the humid Pampa is dominated by extensive organic-rich Phaeozems that have developed on alluvial deposits and loess which can often be found on volcanic ash in in the Pampas in Argentina and Uruguay (Gardi *et al.*, 2015). These soils are fertile, rich in humus and have developed below extensive natural pastures (Gardi *et al.*, 2015). They mark the transition from dry climates in the south and west to more humid climates in the north (Gardi *et al.*, 2015).

According to the FAO WRB soil classification the most representative soils of the Pampa are Kastanozems and Phaeozems, although Solonchaks and Vertisols can also be found (IUSS Working Group WRB, 2014; Gardi *et al.*, 2015). The USDA soil classification states Mollisols as the predominant soil type in the Pampa ecoregion (United States Department of Agriculture, 1999). Mollisols commonly are very dark colored, base-rich, mineral soils of the steppes. Nearly all of these soils have a mollic epipedon, many have an argillic, natric or calcic, and few an albic horizon (United States Department of Agriculture, 1999).

2.5 Economy

The Argentinean Pampas are one of the main cereal and oilseed producing areas in the world thereby making a considerable contribution to the nutrition of humanity (Caride, Piñeiro and Paruelo, 2012; García *et al.*, 2017). Accordingly, the most important economic activity in this region is agricultural production and the processing of related agricultural goods (International Monetary Fund, 2016). This was made possible by several natural advantages, namely the high soil fertility, the high solar radiation and the flat terrain, which favors large-scale machine use and thus large-scale management (Caviglia, Sadras and Andrade, 2010; Monzon *et al.*, 2014). These advantages also make grasslands one of the most transformed biomes worldwide (Hannah *et al.* 1995; Hoekstra *et al.* 2005; Ellis and Ramankutty 2008 as cited in Caride, Piñeiro, and Paruelo 2012), because they often provide suitable circumstances for economic activities such as agricultural production.

In the study area the most important market crops are annual crops such as soybean, wheat, sunflower and maize (Baldi and Paruelo, 2008). The cultivation takes place by large enterprises on large scale farms using high-technology machinery which enables a capital intensive but work force extensive management (Caviglia, Sadras and Andrade, 2010). With this management approach of a highly commercialized and mechanized large-scale production, the costs of producing wheat and soybean have been reduced so far that the production of cereals became beneficial in comparison with the former widespread cattle production (Solbrig and Viglizzo, 1996; Solbrig, 1997; Bernardos *et al.*, 2001; Grau and Aide, 2008).

3 Problem Analysis and State of the Art

This thesis works with problems that, although identified on a local scale in the La Picasa basin, are part of a global prevailing development, causing challenges similar to the one in the study area all over the world. In the following, the specific problems in the La Picasa basin will be embedded into a more general conceptual framework, thereby allowing decision makers to put concerns about the study area into a broader context. In addition, the current state of the art related to ESS trade-offs of wetlands in La Picasa basin will be described.

3.1 Loss of Biosphere Integrity

The Millennium Ecosystem Assessment (2005) stated that in the last 50 years ecosystems have been degraded, destroyed or completely disappeared faster than ever before in the history of humankind, thereby increasing the risk of abrupt and irreversible damage to human well-being (Mooney *et al.*, 2005). As a major driving force of this development the study identified anthropogenic impacts in its various forms. Especially the demand for water, food, and natural resources, causes severe biodiversity loss and leads to changes in ESS (Mooney *et al.*, 2005). The Millennium Ecosystem Assessment also relates functioning ecosystems and the goods and services they deliver with human well-being (Mooney *et al.*, 2005). Since then, ESS became the centre of attention on global policy agendas and today are a major research objective of a vast number of scientific papers (Potschin-Young *et al.*, 2016).

The current high rates of ecosystem damage and extinction make global, regional and local solution approaches for the problem of rapidly decreasing biodiversity worldwide one of the most critical issues of natural resources management (Butchart *et al.*, 2010). It is widely believed that this negative development can be slowed down by efforts to protect the integrity of living systems (the biosphere), enhancing habitat quality, and improving connectivity between ecosystems (Mossman, Panter and Dolman, 2015; Gabel *et al.*, 2016; Pietsch, 2016; Field and Parrott, 2017; Landis, 2017). At the same time, it is also vital to maintain high agricultural productivity that is needed to feed a constantly growing world population (Landis, 2017). Further research is underway to improve the availability of reliable data as the 'control variables' for the planetary boundary of biodiversity loss.

In La Picasa basin, deep transformations caused by agricultural, residential, industrial and commercial land-uses have caused a situation in which the loss of biosphere integrity has passed sustainable limits and wetlands often represent the only refuge for remaining wildlife (Baldi and Paruelo, 2008; Faggi *et al.*, 2008; Brandolin, Ávalos and De Angelo, 2012)

3.2 Loss of Wetlands and related Problems for Human Well-being

Being one of the world's most important types of ecosystems, wetlands are also one of the most threatened habitats on earth (Hu *et al.*, 2017). From a biodiversity perspective, although only 1% of the earth's surface is covered by freshwater wetlands, these wetlands provide a home to >40% of the world's species and are therefore of vital importance to fight the loss of biodiversity on a global, regional and local scale (Mitra, Wassmann and Vlek, 2003). Although human well-being, especially of the populations living close to wetlands, is acknowledged to be strongly related to the ESS wetlands provide (Mooney *et al.*, 2005), they got heavily degraded on a global scale within the last decades (Mooney *et al.*, 2005; Douglas, 2015; Hu *et al.*, 2017). ESS act as a link between the social system and the ecosystem (Bennett *et al.*, 2005; Bennett, Peterson and Gordon, 2009) thereby creating a SES. The links between the natural ecosystem and the social system work in both directions in the way that ESS provide the social system with services for human well-being and reversely the social system interacts through ecological engineering, management and other anthropogenic impacts (Petrosillo, Aretano and Zurlini, 2015).

Wetland's key functions like biodiversity support, water quality improvement, flood abatement, and carbon sequestration are impaired when they get lost or degraded (Zedler and Kercher, 2005). Depending on the regional setting, climatic regimes and populations affected, the loss of functioning wetlands accompanied by a loss of the related ESS they offer, can have a tremendous impact on human well-being.

In La Picasa basin, especially the loss of ESS that regulate the hydrological cycle has tremendous consequences for human well-being on complex socio-economic levels (Scheijtman, 2006; Montico, Bonel and Rosenstein, 2008; Rosenstein *et al.*, 2009).

3.3 Specific Problems in La Picasa Basin

In flat continental landscapes like the study area, flooding is a natural process and a key component of the hydrological connectivity ensuring the water-mediated transportation of matter, energy and living organisms as well as ecological processes and features (Heiler *et al.*, 1995; Pringle, 2001). However, due to the reason that they also affect infrastructure and agricultural systems, flood events are commonly seen as hazard that has to be avoided because it potentially jeopardizes local economies, transportation networks and human life (Viglizzo, Frank and Carreño, 2006).

Photograph 1: Agricultural land affected by a flood in the study area (Wiedemeier, 2018)

In the La Picasa basin regular flooding events represent a regional problem for human well-being. Although natural cycles of dry and wet periods have always caused a variability in the water levels of lagoons and the groundwater, huge parts of the study area suffer from the increasing size of omnipresent lagoons (Rosenstein *et al.*, 2009). In the last 32 years the biggest lagoon in the study area "La Picasa" has undergone a 28-fold increase in its size from 1400 ha to 40000 ha (Rosenstein *et al.*, 2009), highlighting the significance and urgency to find solution approaches. This development raised questions about to which degree this increase in size of the lagoon is still a natural variability of the system and which proportion is accelerated through human actions.

The Argentinean Pampas have been a global hotspot of agricultural land use change since the 2000s (Piquer-Rodríguez *et al.*, 2018). Between 2000 and 2010, driven by high prices of soybean, the soybean area increased by 210% in Latin America, also replacing large parts of the cattle production, which used to be the pre-dominant land use form in the Pampa since the 16th century (Modernel *et al.*, 2016). The use of transgenic seeds, no-tillage techniques and agrochemicals became omnipresent in the La Picasa basin and a rotation between crops, wheat and soy primarily, or soy monocultures have been replacing the former rotation between crops and pastures (Filloy and Bellocq, 2007 as cited in Barral and Oscar, 2011). This development came at the expense of a broad variety of problems on a social, economic, environmental, and hydrological level.

The intensive agriculture performed in the study area, highly impacted the native ecosystems in the region from an environmental point of view (Carreño, Frank and Viglizzo, 2011). As farmland in Argentina expanded quickly, this development came at the expense of natural land and took place without a consideration of the related ecological costs (Carreño, Frank and Viglizzo, 2011). Especially

natural grasslands and wetlands were highly affected (Bilenca and Miñarro, 2004a; Booman *et al.*, 2012; Brandolin, Ávalos and De Angelo, 2012; Modernel *et al.*, 2016; Sica *et al.*, 2016). The agricultural expansion came at the expense of two million ha of native grassland, mostly in the Pampa (Modernel *et al.*, 2016) which is significant for the local biodiversity and functioning of the ecosystem. The creation of agricultural land was accompanied by a large-scale channelization process, which had effects on the water levels of shallow wetlands in the study area. In Córdoba studies have been conducted that indicate a 14.7% reduction of the flooded area where only a small number of channels was implemented, up to a greater reduction in the flooded area of 42.1% where most of the channelization occurs (Brandolin, Ávalos and De Angelo, 2012). By draining the landscape for the production of crops like soybean, the total area of wetlands in La Picasa basin decreased extremely thereby destroying the last remaining wildlife refuges in a landscape dominated by agriculture (Brandolin, Ávalos and De Angelo, 2012). The increase in agricultural production also resulted in major environmental trade-offs (Piquer-Rodríguez *et al.*, 2018) that are not fully understood yet. Once functioning grasslands and wetland ecosystems were able to deliver a broad variety of ESS, among which the service of flood risk mitigation would be significant nowadays but declined with the intensification of the farming systems.

Photograph 2: Wetland fallen dry in La Picasa basin (Wiedemeier, 2018)

Over the last decades, an increase in precipitation in combination with a decrease in evapotranspiration rates due to these land use changes, led the groundwater table to rise (Aradas and Thorne, 2001; Kuppel *et al.*, 2015; Nosetto *et al.*, 2015). From a hydrological perspective, the study area is a very flat and poorly drained region that, while most landscapes respond to extreme rainfalls with increased water outflows, has little capacity to do so (Kuppel *et al.*, 2015). Instead, the most common responses included an increase in water storage leading to rising water tables and floods, an increase in evaporative losses and, after reaching high levels of storage, increased liquid water outflows (Kuppel *et al.*, 2015). Today, the groundwater level reaches the surface in La Picasa basin and, in its interplay with surface water, has been identified as the main driver for groundwater flooding (Aradas and Thorne, 2001). Because these flat areas have different hydro-logical responses, evapotranspirative losses are strongly linked to flooded conditions as a regulatory feedback, while liquid water outflows remained negligible (Kuppel *et al.*, 2015). A broad range of evidence shows that the change in the land use pattern of the La Picasa basin has had an impact on the hydrological balance of the study area. Land-use plays a key role in the hydrology of the sub-humid plains (Nosetto *et al.*,

Photograph 3: Flooded railway in the principal lagoon La Picasa (Wiedemeier, 2018)

2015). There is a linkage between the expansion of grain production systems in the Pampas and raising groundwater level as well as flood frequency and severity (Nosetto *et al.*, 2015).

The consequences of the change in the productive system also cause social problems such as a concentration of land ownership and the migration of small farmers into cities (Joensen et al., 2005 as cited in Barral and Oscar, 2011) as well as the increase in soil and water contamination risk (Viglizzo et al., 2001). As agricultural areas are flooded, public infrastructure such as the national Route N°7 that connects Buenos Aires with Mendoza and Chile or a railway are cut-off by water masses, and even whole villages like the commune Aarón Castellanos are at risk to be entirely flooded (CARSFE, 2003; CARSFE, 2009). The whole region faces social problems as cities along the Route N°7 are suffering economic damage. Reversely, the cities along the alternative roads suffer from inadequate infrastructure and congestions. Many political problems arose, when the three involved provinces discussed solution approaches for how much water can flow into the principal lagoon and how much can be discharged via a water exit. The major channelization occurred in the province of Córdoba (Brandolin, Ávalos and De Angelo, 2012), while Santa Fe is suffering the major consequences and Buenos Aires refuses to take the water masses from upstream. The conflict between the three provinces finally resulted in bringing the action to the Argentinean Supreme Court of Justice (Corte Suprema de Justicia de la Nación, 2017). The bizarre situation that nobody wants the water, appears even stranger when considering that worldwide most agricultural regions suffer water shortages.

Photograph 4: Water gauge downstream north pumping station La Picasa (Wiedemeier, 2018)

Paradoxically, while the land cover change will most probably continue having impact on the hydrologic regime of the region, long-term eco-based solutions are not prioritized (Pereira *et al.*, 2014) so that most of the solution approaches today, focus on short-term construction-based solutions like build drainage pipes or channels to pump the overrun in water away (Brandolin, Ávalos and De Angelo, 2012). The three pillars on which the current solution approach builds up, are a water exit in the south of the lagoon La Picasa called “South Alternative”, internal construction works on pumping stations and channels, and another water exit in the north of the lagoon, called “North Alternative” (CARSFE, 2003). The objective of this solution is that the lagoon is kept in a save range between 98.5 and 102.5 m, which would allow using the Route N°7, the railway and having an additional storage capacity for periods with water excesses (CARSFE, 2003). However, eco-based solutions that build up on sound ESS functioning, bare high potential to be effective in various fields (Mooney *et al.*, 2005), including economic benefits as well as the optimization of various ESS.

3.4 Ecosystem Services Trade-Offs of Wetlands in La Picasa Basin - State of the Art

The loss of wetlands has been identified to be related to several problems in the study area of La Picasa basin primarily the increased risk of floods (Bullock and Acreman, 2003; Rosenstein *et al.*, 2009; Brandolin, Ávalos and De Angelo, 2012; Kumar *et al.*, 2017). Since wetlands have been the fastest component of the system to react to anthropogenic modifications and climatic variations in a discernible way, they were also perceived as an obvious stress-factor and comprehensively drained in the belief that these measures would cure the revealed symptoms of an increasing disaster risk (Booman *et al.*, 2012; Brandolin, Ávalos and De Angelo, 2012; Sica *et al.*, 2016). Unfortunately, the

current situation in La Picasa basin progressively illustrates that these anthropogenic impacts triggered the major components of the basin's water balance to change (Bullock and Acreman, 2003), thereby causing complex socio-economic and environmental problems (Scheijtman, 2006; Montico, Bonel and Rosenstein, 2008; Rosenstein *et al.*, 2009; Corte Suprema de Justicia de la Nación, 2017). The total magnitude of this development becomes obvious against the human impotence to cope with the increasing disaster risk related to floods caused by the expanding size of La Picasa lagoon.

Since it is widely recognized that wetlands provide a broad variety of different ESS (Mitra, Wassmann and Vlek, 2003; Mooney *et al.*, 2005; Brandolin, Ávalos and De Angelo, 2012; Van Loon-Steensma and Vellinga, 2013; Chen and Wong, 2016; Hu *et al.*, 2017; Odgaard *et al.*, 2017) and preliminary assessments indicate that the value of these ESS to agriculture, the primary income source of La Picasa basin, is enormous and often underappreciated (Power, 2010), using wetlands, including the variety of ESS they provide, for disaster risk reduction and vulnerability mitigation suggests itself (Kumar *et al.*, 2017).

Several studies exist that investigate within the frame of ESS trade-offs between specific ESS categories (compare Figure 6). In the context of Latin American countries, Argentina was one of the early pioneers in ESS research, likely motivated by the extensive conversion of fertile, natural grasslands and forests to agricultural land that occurred in the 1990s and the importance of this agricultural expansion to the national economy (Balvanera *et al.*, 2012).

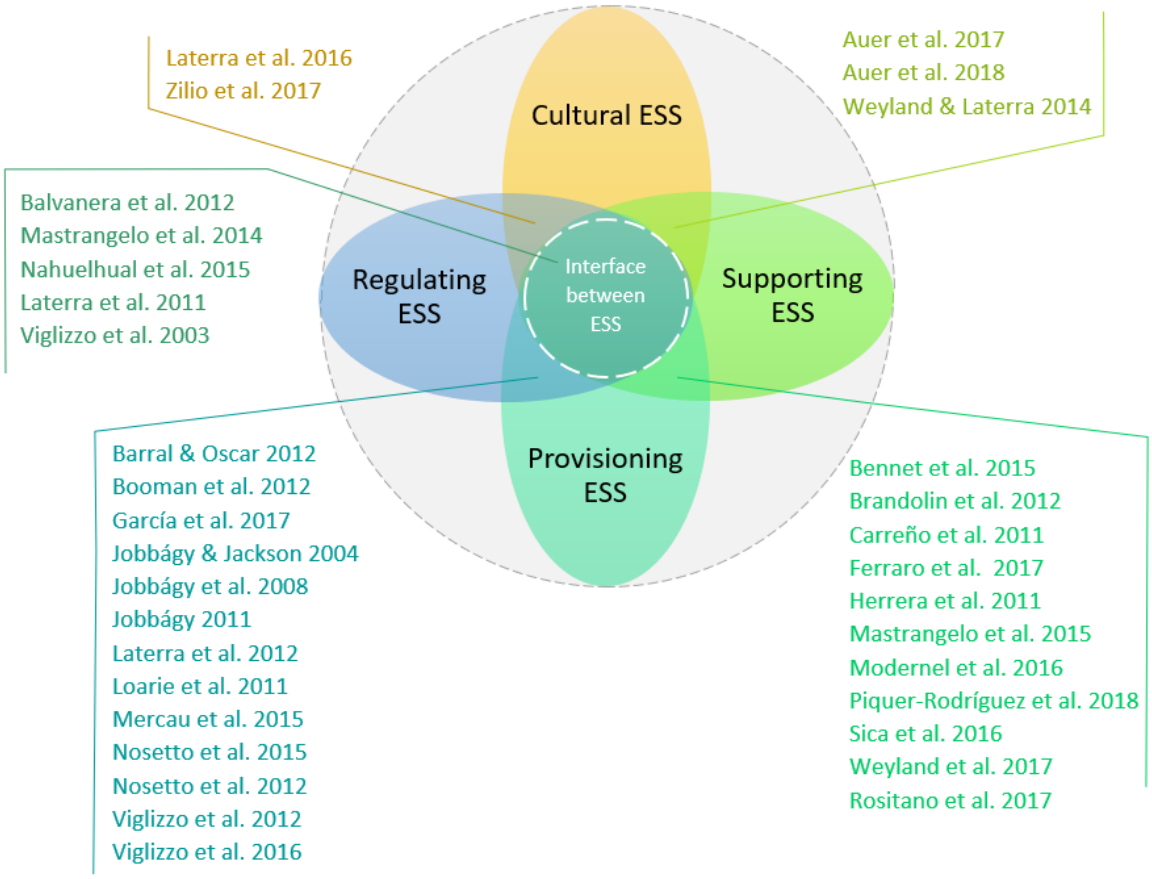


Figure 6: Research on ESS trade-offs in the Argentinean Pampas (own elaboration)

Accordingly, most research on ESS trade-offs is related to the provisioning ESS 'agricultural production' and how it increases or decreases in relation with other ESS. Numerous studies investigated the trade-offs between agricultural production and the effects it has on the regulating ESS 'hydrological

regulation' and 'flood protection'. Most works investigated the modifications of the size of water bodies or the water consumption of vegetations and how changes in these factors are affecting the water balance of the region (Jobbágy and Jackson, 2004; Jobbágy *et al.*, 2008; Barral and Oscar, 2011; Viglizzo *et al.*, 2011; Loarie *et al.*, 2011; Jobbágy, 2011; Booman *et al.*, 2012; Laterra, Orúe and Booman, 2012; Nosetto *et al.*, 2012, 2015; Mercau *et al.*, 2015; Viglizzo *et al.*, 2016) . In general, it was found that increases in provisioning services, especially agricultural production, decrease the supply of regulating services (Carreño, Frank and Viglizzo, 2011). Nevertheless, not one single study had a clear focus on investigating the potential that ESS of wetlands hold towards reducing the frequency and magnitude of floods.

Besides the trade-offs between agricultural intensification and the preservation of regulating services, its effects on biodiversity have also extensively been assessed (Grau and Aide, 2008). Most studies focusing on this trade-off highlight the importance of biodiversity for human well-being as a supporting ESS that enables the overall functioning of ecosystems (Carreño, Frank and Viglizzo, 2011; Herrera and Laterra, 2011; Brandolin, Ávalos and De Angelo, 2012; Rositano *et al.*, 2012; Bennett *et al.*, 2015; Mastrangelo *et al.*, 2015; Modernel *et al.*, 2016; Sica *et al.*, 2016; Weyland, Barral and Laterra, 2017; Ferraro and Gagliostro, 2017; Piquer-Rodríguez *et al.*, 2018). Few studies set a research focus on the potential of wetlands to provide diverse habitats as a support for an increasingly biodiverse flora and fauna in the Pampas, and none of the reviewed papers bridges the gap between functioning and biodiverse wetlands and a reduced risk of floods.

Little scientific work has focused on the trade-offs related to cultural ESS. Most research done in this field is dealing with the cultural ESS 'tourism and recreation' and often deals with the trade-offs between a monotonous agricultural landscape resulting from intensified production and low biodiversity and a landscape's ability to provide recreational ESS for its population or tourists (Weyland and Laterra, 2014; Auer, Maceira and Nahuelhual, 2017; Auer, Nahuelhual and Maceira, 2018). Only one study emphasizes the additional role that water ecosystems could play in diminishing the risk of local water challenges in the context of climate change (Zilio *et al.*, 2017). Another study states that policies based exclusively on ESS supply might not only fail at detecting priority conservation areas for the well-being of human societies, but may also increase their vulnerability by neglecting areas of currently low, but highly valued ESS supply and suggests to consider system's social mechanisms, which can enhance or reduce ESS demand to make policies more effective (Laterra *et al.*, 2016).

Besides the investigation about bi-directional trade-offs between ESS, several studies also analyzed how ESS in general can be mapped (Nahuelhual *et al.*, 2015), evaluated (Laterra, Jobbagy and Paruelo, 2011), embedded in concepts and methods for landscape multifunctionality (Mastrangelo *et al.*, 2014) and applied in environmental assessments for agricultural areas (Viglizzo *et al.*, 2003). Although compensations for the protection of ESS (PES) in the form of subsidies was incorporated into federal law on land-use planning in 2007 (Ley Nacional 26.331), Argentina is the only Latin American country, with no formal PES programs implemented (Balvanera *et al.*, 2012).

Scientific research investigating within the borders of La Picasa basin is either driven by technical questions aiming to provide a basis for engineered solutions, an ecological interest in the regions highly biodiverse landscape and its potential for the protection of native species, or social questions related to the perception of floods and how society deals with the increased disaster risk (compare Figure 7).

Already in the year 2000, the OCRED-2 hydrologic mathematical model was applied to the system of La Picasa lagoon (Pedraza, 2000). The continuous model was based on kinematic wave equations and was made to evaluate the risk of overflow of the principal lagoon La Picasa for water resources management purposes (Pedraza, 2000). The study describes the general physical characteristics of the system, the model applied and its implementation, calibration and operation (Pedraza, 2000). Almost

20 years ago, this study already found that periodically occurring floods cause severe damage to the infrastructure and great losses to social-economical activities (Pedraza, 2000).

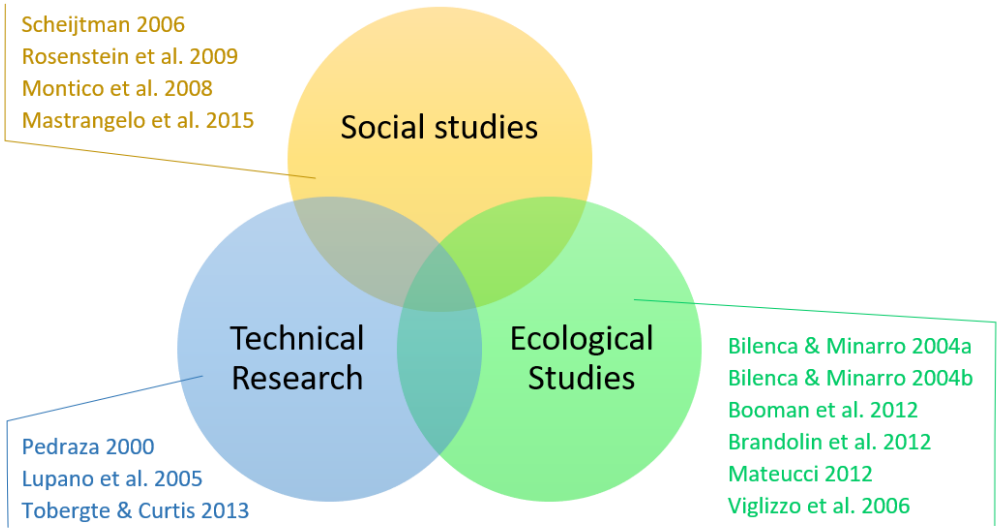


Figure 7: Research foci in La Picasa basin (own elaboration)

In projects distributed over a timespan of several years, the surface water resources of Santa Fe province were mapped, using the Digital Surface Water Resources Atlas of Argentina, the SIG-250 and sixteen Landsat ETM images (Lupano *et al.*, 2005; Tobergte and Curtis, 2013). By presenting analogical and digital cartographies, providing information related to rivers, water bodies, watersheds boundaries, main roads and urban settlements these studies also highlight the indefinite amount of drainage channels in the region of the La Picasa lagoon (Lupano *et al.*, 2005).

A distinct and more ecological focus was set with the identification of valuable grassland areas, among which the La Picasa basin was identified to represent an important area for the protection of biodiversity and native grass species of the Argentinean Pampa (Bilenca and Miñarro, 2004b). A related study further investigated and described adequate conservation strategies for identified areas and highlights that conservation actions should involve the recreational sector and strive to develop an integrated concept for the close by ecological reserve 'La Salada lagoon' and the natural area 'Los Médanos' (Bilenca and Miñarro, 2004a). Grassland conservation, consequently was found to go hand in hand with wetland conservation efforts.

La Picasa basin was also described within the frame of ecoregions (Viglizzo, Frank and Carreño, 2006; Matteucci, 2012) and identified as an endorheic basin with numerous temporal lagoons (Matteucci, 2012). Its environmental condition was analyzed in relation to the evolution of surface area dedicated to annual crops in the distinct ecoregions of the Pampa highlighting the ecological costs of agricultural expansion (Viglizzo, Frank and Carreño, 2006).

Another scientific research study was guided by the idea that in La Picasa basin neither disasters nor risks are conceived as socially constructed processes (Scheijtman, 2006). The study highlights that seeing disasters as isolated and fortuitous events and unmanageable products of a capricious and arbitrary nature seriously limits the design of public policies and prevents proper management (Scheijtman, 2006). Similarly, the idea to treat the whole basin as a unit should be strengthened to enable an integrated water resources management that considers the basin's natural, ecosystemic and above all, human and social environment (Scheijtman, 2006). Besides, the study investigated about the water management policy, the interdependence between the various jurisdictions involved, the

obstacles between the different levels of government and the lack of coherence in public management, related to the bias in dealing with complex issues (Scheijtman, 2006).

The effects of floods in La Picasa basin were evaluated in two studies based on stakeholder perceptions with a focus on communities and farmers (Montico, Bonel and Rosenstein, 2008; Rosenstein *et al.*, 2009). While the first study analyzed and interpreted the perception of 'environmental disasters' and necessary solutions to avoid them among all members of the affected communities (Rosenstein *et al.*, 2009), the second study investigated how local farmers in specific conceived the entity of the threat to their productive systems and which techniques they implemented as a response (Montico, Bonel and Rosenstein, 2008). There is a general consensus on the definition of floods as a problem, expressed through the priority actors give to the inundations and related complications (Rosenstein *et al.*, 2009).

It was found that floods have had –and still have- a strong impact on everyday life, even though not all actors notice the same symptoms of the problem (Rosenstein *et al.*, 2009). Especially the farmers in the basin of La Picasa (Santa Fe) were found to be severely affected by the inundations (Montico, Bonel and Rosenstein, 2008). Since they do not implement adequate prevention for the magnitude of the threat, the actors were extremely vulnerable to the impacts of floods and therefore incapable to manage successful protection strategies (Montico, Bonel and Rosenstein, 2008). Both studies conclude that the awareness of the risk of floods has not yet attained enough importance as to lead to changes in practices (Montico, Bonel and Rosenstein, 2008; Rosenstein *et al.*, 2009).

Despite the fact that, the participation of public stakeholders is becoming more and more important for environmental decision-making processes, because managers need to understand who is affected by their decisions and who bares the power to influence their outcomes (Reed, et al., 2009), stakeholders were found to be insufficiently involved in the definition of collective strategies (Rosenstein *et al.*, 2009). Farmers in Aarón Castellanos and Diego de Alvear even had to try and search individual solutions due to the lack of commitment shown by the community (Rosenstein *et al.*, 2009). They do rather trust in a great environmental capacity for restoring the previous levels of productivity, than adapting their actions to the threat of floods (Montico, Bonel and Rosenstein, 2008) while in Rufino, the preeminence of the conflict has reinforced the lack of social organization (Rosenstein *et al.*, 2009).

Surprisingly, research that focusses on the role that wetlands could play in reducing the risk of floods in the study area, the Pampas in general and whole Argentina barely exists. The only research related to this field of investigations is either focusing on the loss of wetlands due to agricultural expansion and the related loss of biodiversity (Booman *et al.*, 2012; Brandolin, Ávalos and De Angelo, 2012; Sica *et al.*, 2016) or on exploring the ability of wetlands to provide ESS (Bullock and Acreman, 2003). Nevertheless, in La Picasa basin, floods were identified as the major problem (Rosenstein *et al.*, 2009) and several studies demand a higher consideration of social mechanisms to facilitate the inclusion of relevant ESS management into policies to reduce the areas vulnerability to floods (Mastrangelo *et al.*, 2015; Laterra *et al.*, 2016).

In fact, the identified problems in La Picasa basin occur at the interface where the social part encounters the environmental part of the system and vice versa. To grasp the functioning of this interaction, it is helpful to embed ESS trade-offs into SES theory that works on the interface between social dynamics and ecological processes (Bousquet *et al.*, 2015). Applying this theory and defining systems as SES, helps emphasizing the integrated concept of the 'humans-in-nature' perspective (Zurlini, Petrosillo and Cataldi, 2008) and enables clearing interdependencies between the social and ecological part of systems.

In La Picasa basin and the Argentinean Pampas, only few research studies focus on embedding ESS research in SES theory, even though the utilization of these two perspectives combined, was found to enable an superior understanding of the consequences of land-use and land-cover changes to the society (Mastrangelo *et al.*, 2015). While the agricultural expansion and intensification has stimulated the utilization of ESS approaches, yet an increasing trend of environmental degradation and social conflicts due to agricultural practices continues to be unabated (Mastrangelo *et al.*, 2015). The application of SES frameworks could foster operationalizing the concept of ESS and using them as a management tool in different situations (Halliday *et al.*, 2011).

All in all, it can be said that using wetlands in La Picasa basin for reducing the risk of floods, has not been part of scientific projects so far and the role they could play is not satisfactory understood. Consequently, investigations focusing on the role wetlands hold in the systemic functioning of the study area, the ESS they provide and related trade-offs, could hold a tremendous potential to support sustainable solution approaches. The current absence of scientific research that connects the concept of ESS with SES theory and the lack of involving stakeholders, opens a possibility to contribute a new perspective to the on-going debate of floods in La Picasa basin.

3.5 Research Questions

Against the scientific research background found in the state of the art, the following research questions were defined to fill the identified research gap by understanding the role of wetlands in ESS trade-offs in La Picasa basin:

1) **Which role do wetlands play in the socio-ecological system of the Pampas, and La Picasa basin in specific?**
    a. Which role have wetlands played in the historic development of the SES starting with the colonization of the Pampa?
    b. What have been important historic turning-points in the development of the SES and how have they been influenced by wetlands?
    c. Which role have wetlands performed in maintaining the socio-ecological system in an equilibrium?
    d. Which ESS trade-offs are relevant for the study area?
2) **How are important stakeholder groups interacting in La Picasa basin?**
    a. Which stakeholders are involved in the socio-ecological system?
    b. How can stakeholders in the system be categorized according to their expediency to be involved in solution approaches?
    c. Which relationships between stakeholders provide opportunities or restrictions for the conservation of wetlands and their ESS?
3) **How could a more sustainable management approach integrating wetlands look like?**
    a. Which specific problems in the study area are related to ESS trade-offs?
    b. How do they affect each other through feedback loops?
    c. Which function do wetlands have in this process?
    d. Which management practices could inverse the negative feedback loops identified?
    e. Which advantages or disadvantages have nature-based management approaches, in specific the restoration of wetlands, in comparison to pure infrastructural or mixed approaches?

The outcome of this study should serve as a basis for decision makers to find management solutions for the urgent and extensive problems caused by the increasing wetland area and at the same time fighting biodiversity loss and improving human well-being.

4 Objectives

The general objective of this master's thesis is to apply up-to-date scientific methods from the field of sustainable natural resources management to the specific case of the selected study region La Picasa basin and investigate the role wetlands play in ESS trade-offs. This thesis therefore generally aims at generating interdisciplinary and multiscale knowledge, not only about possible solution approaches, but also about local stakeholders, existing experts' networks, the necessary research development process itself and the existent ESS and trade-offs of the study area.

Table 3: Objectives of the master's thesis (own elaboration)

1) Understand the role that wetlands play in the SES of La Picasa basin

a) Understand the role of wetlands in the historic development of the socio-ecological system, starting with the colonization of the Pampa.
b) Identify important historic turning-points in the development of the socio-ecological system and how wetlands influenced them.
c) Understand which role wetlands play in maintaining the socio-ecological system in an equilibrium and which ESS trade-offs are relevant for the study area.

2) Analyze important stakeholder dynamics.

a) Identify stakeholders involved in the socio-ecological system and understand what they are responsible for.
b) Categorize stakeholders in the system according to their expediency to be involved in solution approaches.
c) Analyze relationships between stakeholders to be aware of opportunities and restrictions for the conservation of wetlands and their ESS

3) Assess more sustainable management approaches integrating wetlands.

a) Understand which specific problems are related to ESS trade-offs, how they affect each other through feedback loops and which function wetlands have in this process
b) Derive management practices that could inverse negative feedback loops.
c) Assess which advantages or disadvantages nature-based management approaches, and in specific the restoration of wetlands, have in comparison to purely infrastructural or mixed approaches.

In specific, this study aims to achieve three major objectives (compare Table 3). The first objective has a natural scientific focus and aims to (1) understand the role that wetlands have played in the SES of La Picasa basin and how it reacts to changing environmental and anthropogenic impacts. To achieve this objective, it is necessary to (a) understand the role of wetlands in the historic development of the SES, starting with the colonization of the Pampa and to (b) identify important historic turning-points in the development of the SES and how wetlands influenced them. In addition, it is vital to (c) understand which role wetlands play in maintaining the SES in an equilibrium and which ESS trade-offs are relevant for the study area. The time scale for the first objective stretches from the past, starting with the colonization of the Pampas, to the current status today.

The second objective has a strong managerial focus and aims to (2) analyze important stakeholder dynamics that are a fundamental input for any future project that aims to strengthen the role of wetlands in the SES. To accomplish this objective, it is important to (a) identify stakeholders involved in the SES and understand what they are responsible for; to (b) categorize stakeholders in the system according to their expediency to be involved in solution approaches; and to (c) analyze relationships

between stakeholders to be aware of opportunities and restrictions for the conservation of wetlands and their ESS. As this objective has a strong focus on information needed for an applied management, the time scale for this part is mainly determined for the present with small excursion to the past to explain current relationships.

As a third objective, with an emphasis on bringing natural science and management approaches together, this study aims to provide (3) suggestions for more sustainable management approaches integrating wetlands to deliver a basis for the development of future solutions. To realize this objective, it is beneficial to (a) understand which specific problems are related to ESS trade-offs, how they affect each other through feedback loops and which function wetlands have in this; to (b) derive management practices that could inverse negative feedback loops between ESS trade-offs and to (c) assess which advantages or disadvantages nature-based management approaches, and in specific the restoration of wetlands, have in comparison to pure infrastructural or mixed approaches. This objective focusses on a time scale from today, using the current situation as a basis, and stretches out to the future by developing potential solution approaches.

5 Methodology

5.1 Delimitation of the Study Area

The study area chosen for this thesis corresponds to the hydrological basin La Picasa that covers southeast Córdoba, south Santa Fe and northwest Buenos Aires provinces (see Figure 8). Accordingly, it crosses political borders and its boundaries accentuate the fact that the basin is defined by natural

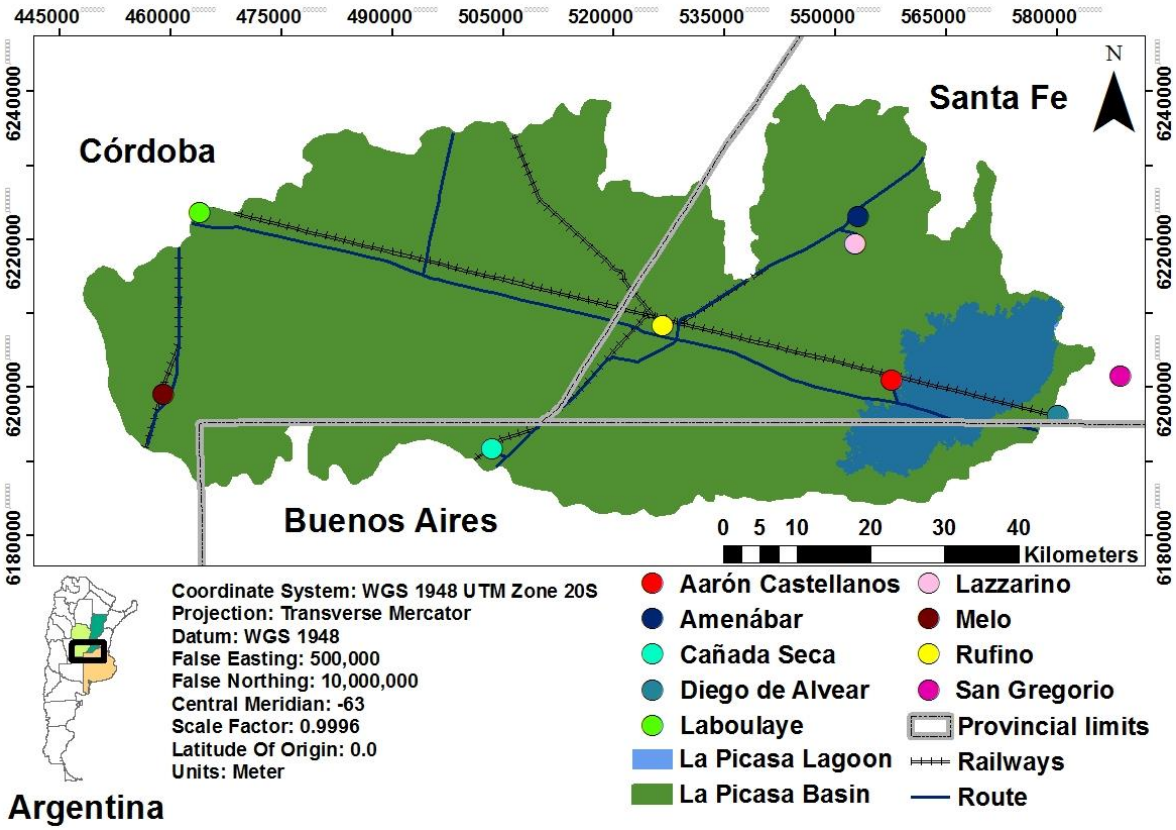


Figure 8: Delimitation of the study area – Natural and governmental boundaries (Source: own elaboration based on SsRH (2017))

factors instead of man-made limits. Nevertheless, the study area does not represent a purely natural system, as it is also highly influenced by social systems through diverse interaction mechanisms such as agricultural production, politics, the drainage of wetlands, the existence of urban environments and infrastructure.

To cope with the resulting complex socio-ecological research requirements, the scope of this thesis was slightly adapted to the methodological approaches chosen for each step in the analysis, taking into account a holistic frame of the situation. In this regard, its different parts were adequately scoped according to their research foci without losing the overall objective to investigate the role wetlands play for ESS trade-offs in La Picasa basin. For instance, the natural, social and governmental boundaries of the study area were flexibly considered as shown in Figure 9.

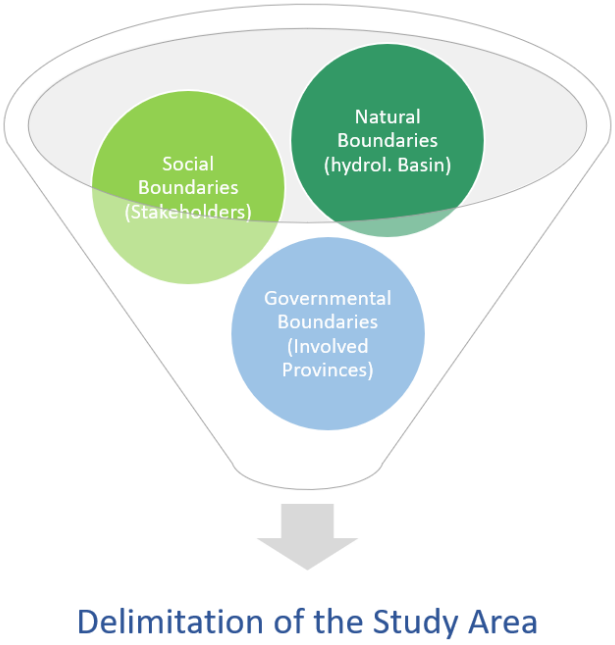


Figure 9: Three foci to delimitate the study area (own elaboration)

In the analysis of the historic development of the study area, the investigation process was oriented towards describing the changes in time within the natural boundaries of the hydrological basin La Picasa. Since it is assumed to be a representative basin of this ecoregion and due to a lack of specific data about its historic circumstances, the results were based on literature about the overall development of the whole Pampas.

The second step in the analysis highlighted social dynamics and, besides the natural boundaries of the basin, also emphasized five distinct social levels of stakeholder interaction, ranging from local to international (compare Figure 10). Although all stakeholders are related to La Picasa basin, their spheres of control and impact often stretch out over its natural boundaries. In order to representatively cover their different viewpoints, the interviews were conducted with local, regional, provincial and national stakeholder groups. The international stakeholders were not consulted because in this early stage of research, they are not strictly related to the current problem situation, but they could represent important future project partners.

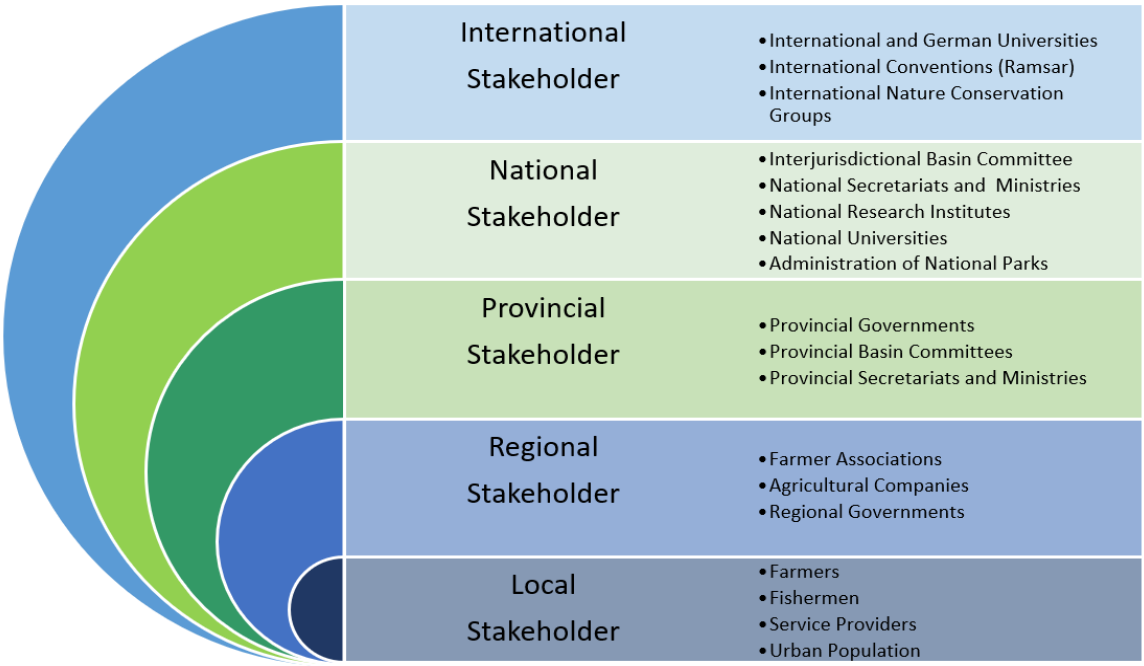


Figure 10: Stakeholder levels in La Picasa basin – Social boundaries (own elaboration)

The third step aimed at developing concrete management approaches for the hydrological basin La Picasa because it resulted to be a key representative basin to find a solution for the region. It does not only face typical problems and ESS trade-offs, but also experiences them in a superior dimension due to its geographical characteristics. Every raindrop not evaporated or transpired ends up in wetlands and in the long-term the La Picasa lagoon, which is the natural sink of this endorheic basin. Therefore, anthropogenic modifications of the water balance become more visible through the increase in water levels of this lagoon than in surrounding basins.

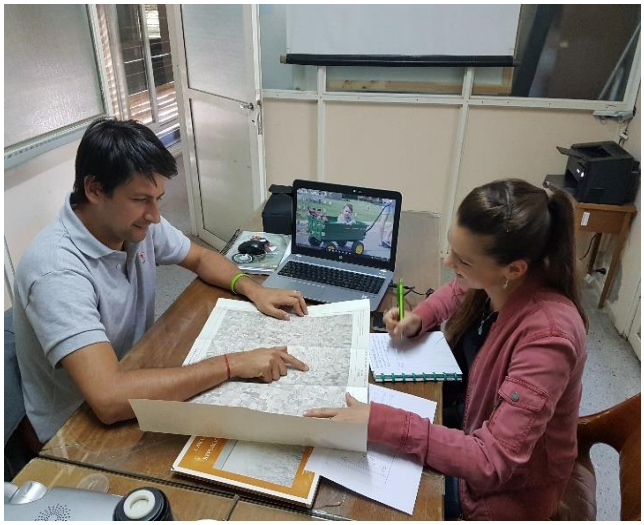
The apparent correlations between anthropogenic modifications of wetlands in La Picasa basin and diminishing benefits from their ESS make the study area interesting for the research scope of this thesis. The current problems are revealing the dependency of human well-being on functioning ecosystems and suggest closer examinations of ESS and their trade-offs. Therefore, results obtained from scientific investigations in La Picasa basin could also be employed for similar cases in the surrounding basins. The obvious problems occurring around La Picasa lagoon are an incentive for projects as well as unconventional solution approaches and lift La Picasa basin in a key role for future investigations on more sustainable agricultural production methods in the Argentinean Pampas.

5.2 Data Collection

To meet the defined objectives, information addressing the defined research questions was extracted from an intensive literature review. The topics covered, main foci, and the structure of this literature review are described in detail in Chapter 3 Problem Analysis and State of the Art. Search criteria for the inclusion of scientific papers were that their contents are closely related to the study area La Picasa basin or the Pampa ecoregion in general, that they either describe the natural factors for development, the anthropogenic factors, or both sides in combination and that they have a relation to ESS and their trade-offs. All of the included studies were peer-reviewed.

5.2.1 Pre-Interviews

This purely academic research approach was complemented with semi-structured expert interviews of important stakeholders of the region. After arriving in the host institution in Córdoba, Argentina, a set of pre-interviews (compare Photograph 5) was conducted to achieve a first overview about the in-situ circumstances.



Photograph 5: Pre-Interview with Pablo Bolatti in INTA, Marcos Juarez (Wiedemeier, 2018)

These pre-interviews helped understanding current relevant topics, collecting contact data from involved stakeholders and enabled the design of a suitable question catalogue for the main-interviews. Furthermore, they delivered valuable information about on-going processes before travelling to the study area and talking to directly involved stakeholders.

In the pre-interviews a total number of 13 stakeholders was interviewed in an unstructured format. The Interviews were conducted either in individual interviews between the interviewer and interviewee only, or in group interviews with up to three participants plus the interviewer. Their function and the location, date and time of the pre-interviews as well as a summary of their knowledge input can be found in Annex 1 and Annex 3.

Photograph 6: Interview with a group of local stakeholders in San Gregorio, La Picasa basin (Wiedemeier, 2018)

5.2.2 Main-Interviews

Once arrived in the study are La Picasa basin, a total number of 19 interviews was conducted, in which interviewees was interviewed contributed their knowledge, every day concerns, fears, problems and perceptions to this study. The interviews were semi-structured, qualitative interviews and followed a guiding question catalogue which can be found in Annex 4.

Photograph 7: Interview with Juan Carlos Bertoni in LH-CETA, Córdoba (Wiedemeier, 2018)

Like the pre-interviews, the main-interviews were also conducted either in individual interviews between the interviewer and interviewee only (compare Photograph 7), or in group interviews with up to eight participants plus the interviewer (compare Photograph 6).

This format of interviews in addition offered the possibility to discuss answers among the participants and resulted to have a strong work-shop character. A list indicates the consulted stakeholders, their function and the location, date and time of the interviews and can be found in Annex 2. The answers of all interview participants can be found in Annex 5.

5.3 Data Analysis

To investigate within the frame of the defined research questions, the methodology applied in this study followed three major steps (compare Figure 11).

The first step concentrated on the role wetlands play in the historic development of the SES in the study area and aimed at creating a timeline indicating important turning points based on interdependencies between climatic cycles and land-use schemes. Derived from that, distinct equilibrium states of the system were defined and related to ESS that affect those states through trade-offs.

The second step focused on analyzing important stakeholder dynamics in the study area that create opportunities or restrictions for the conservation of wetlands. It followed the objective to identify stakeholders involved in the SES in La Picasa basin and to become aware of their responsibilities as well as their expedience for future projects. In addition, helpful and challenging relationships within the stakeholder network were analyzed.

A clear understanding of the systemic behavior of the study area in conjunction with recognized stakeholder dynamics allowed to identify more sustainable future land-use and management approaches. Derived from the previous two steps, relevant problems in the study area were defined based on stakeholder perceptions and linked to ESS trade-offs and feedback loops between them.

Finally, possible management approaches were discussed to inverse feedback loops with negative effects for human well-being in the study area, and the benefits and disadvantages of nature-based, infrastructure-based and hybrid management approaches were compared.

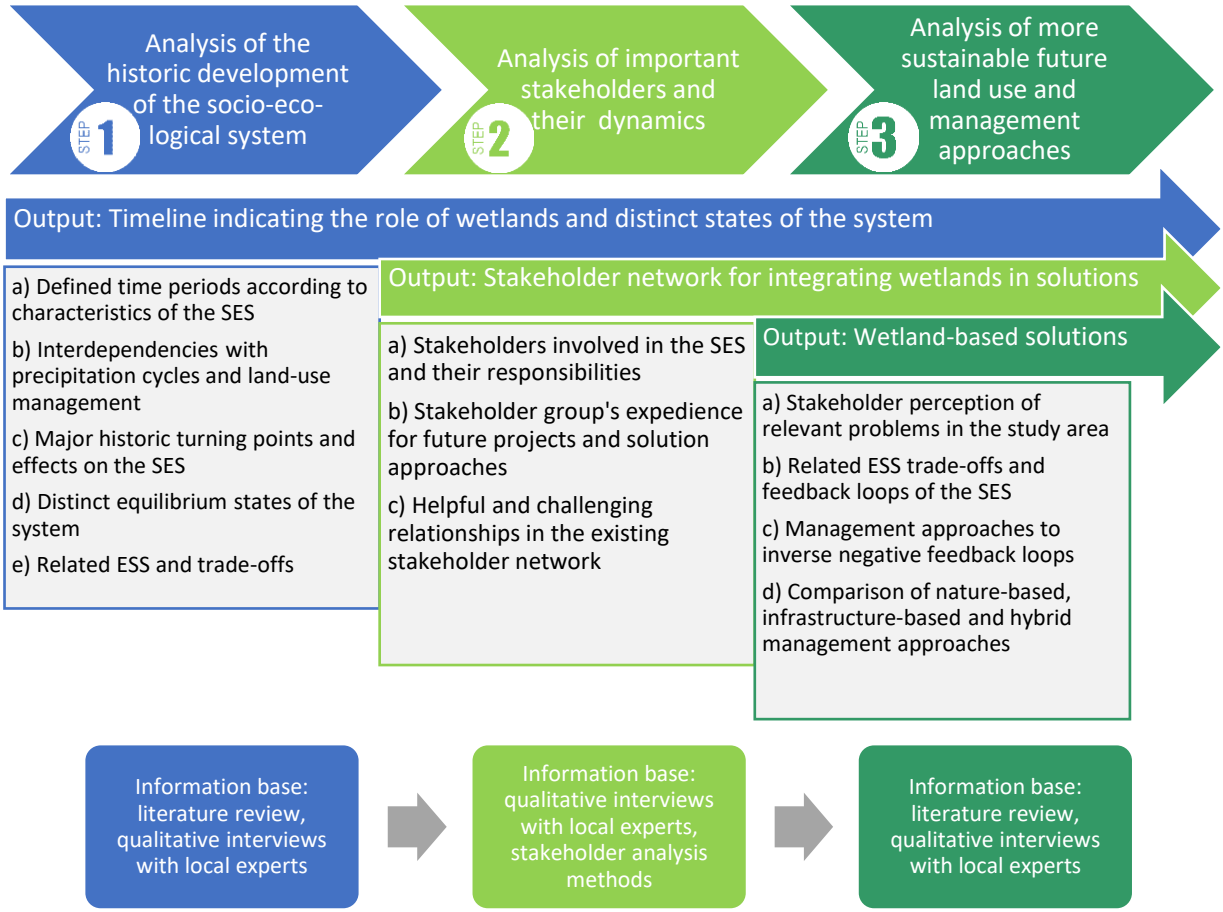


Figure 11: Methodological Steps (own elaboration)

5.3.1 Analysis of the Historic Development of the Study Area

In a first step, the historic development of the SES in La Picasa basin was described to achieve an understanding of the role wetlands play in the natural status, the changes and major turning points the system faced as well as in current systemic characteristics that determine it today. In addition, the predominant ESS and related systemic feedback loops were analyzed and investigated how they changed over time. This part of the thesis was based on data collected through the extensive literature review, which was additionally supported by information gathered in the stakeholder interviews. The main focus of this part was put on the historic development of the Pampa's SES. Major turning points in history were described, both caused by natural cycles and anthropogenic impacts on the system like how immigration, the agricultural revolution, and the construction of drainage channels affected the SES since colonization of the area.

The design of the timeline, visualizing the historic development of the study area from the beginning of significant agricultural production until today, aimed to explain the interrelations between changing land-use systems, climatic cycles and water related problems the region faced from 1870-2018.

The timeline was created indicating a chronological sequence of time periods with uniform circumstances and major turning points that led the SES of the study area to change. A specific focus was put on the interrelations between land-use, evapotranspiration rates, precipitation rates and how their interplay shaped the production patterns within the SES.

With the help of information extracted from an extensive literature, time sequences of consistent characteristic production schemes and related states of the SES were defined. The timeline was subdivided into six major periods: 1) The pre-agricultural system before 1870, 2) the agricultural development from 1870-1920, 3) a period of overexploitation of natural resources from 1921-1940, 4) the dust-bowl period between 1941 and 1960, 5) the agricultural expansion between 1961 and 1990, and finally 6) the predominant soybean monocultures from 1991 until today (2018).

A number of scientific papers investigated the predominant land-use schemes for the defined time sequences (Bernardos *et al.*, 2001; Viglizzo *et al.*, 2001; Nosetto, Jobbágy and Paruelo, 2005; Baldi and Paruelo, 2008; Bolatti, Andreucci and Escolá, 2015; Ghida Daza, 2016) and were used to extract information about the composition of the land-use for the corresponding decades. Land-use was expressed in terms of the relative area (%) of cropland (composed of soybean, maize and wheat), perennial pastures (characterized by alfalfa) and natural grasslands (native grasses of the Pampa ecoregion) with respect to the total area devoted to farming activities.

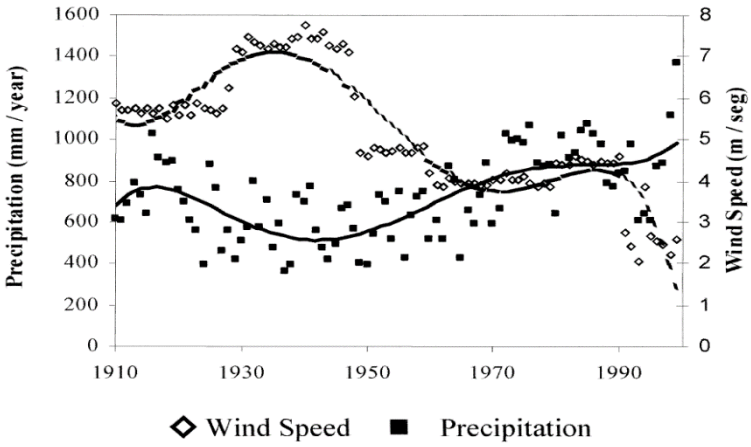


Figure 12: Historical changes in rainfall and wind intensity (Source: Bernardos, 2001)

To be able to formulate assumptions about, if the interplay of land-use schemes, corresponding evapotranspiration rates, and rainfall events could have been a crucial factor determining the water-related problems in these sequences, the defined time periods were coupled with further data sets. The first one is a table indicating the general evapotranspiration (ETo) trend of land-use schemes in comparison to the natural system, which represents the reference state before 1870. This trend is visualized in a qualitative way, due to a lack of evapotranspiration data dating back to the 1870s. However, since several interview partners made the assumption that evapotranspiration rates play a significant role in the systemic functioning of the study area (Interview 1, Villa Uria (2018); Interview 16-18, Jobbagy (2018); Interview 19, Bertoni (2018), see Annex 5), the general trend of evapotranspiration was developed from literature-based information about the land-use situation of corresponding time-periods, information on wind speed and precipitation data from 1910-2001 (compare Figure 12) generated with the EPIC model (Bernardos *et al.*, 2001) and the knowledge input from various stakeholder interviews.

To be able to relate this to water excesses, a second data set was based on data from a ground station in Pergamino, in a distance approximately 120 km from the study area that recorded precipitation data of the study region from 1931-2015. After a pre-processing of the data, the monthly precipitation and the monthly average precipitation was calculated for each month back to July 1931. By comparing the monthly precipitation with the monthly average precipitation, the monthly anomaly was computed and accumulated. Finally, a graph indicating the accumulated monthly anomaly in precipitation (in mm) was created.

Using data from the same ground station, the potential evapotranspiration rates of the study area from 1967-2015 were assessed. The resulting numbers were linked to literature-based land-use data

for the time periods 1961-1990 (Viglizzo *et al.*, 2001) and 1991-2018 (Bernardos *et al.*, 2001). It distinguishes between native grasslands in the pampas ecoregion, pasturelands dominated by alfalfa and cropland composed of the three major crops in the region, soybean, maize and wheat (compare Table 4). Evapotranspiration was calculated as water evaporated from soils plus water transpired by plants.

Table 4: Land-use for the periods 1960-1990 and 1990-2018 (based on Viglizzo, 2001 and Bernardos, 2001)

Land-use	Agricultural Expansion 1961-1990	Soybean Monocultures 1991-2018
grasslands	23%	~8%
pasturelands	34%	~31%
croplands	43%	~61%

Due to the fact that soybean and maize play a vital role in the composition of cropland since the late 1960s and because the production of these crops is limited to a six-month period per year, it is important to consider a time period of bare soils when calculating the potential crop evapotranspiration. The consideration of areas with bare soils was based on the area dedicated to soybean and maize crops (Bolatti, Andreucci and Escolá, 2015), and their proportion of the total cropland (Ghida Daza, 2016) as can be seen in Figure 13.

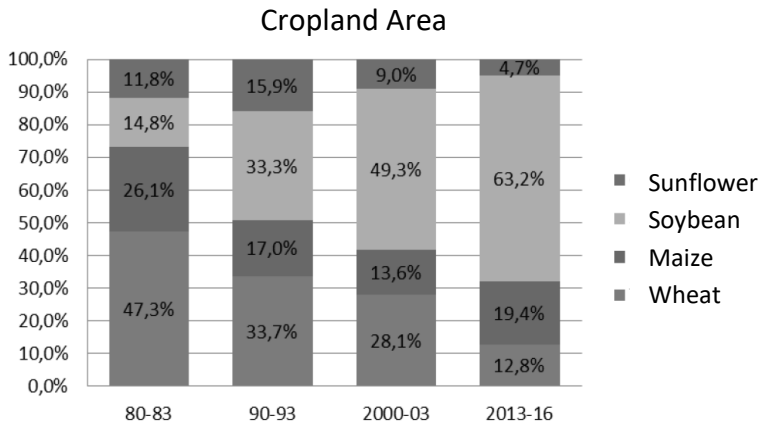


Figure 13: Cropland area dedicated to sunflower, soybean, maize and wheat crops from 1980-2016 (Source: Ghida Daza, 2016)

To finally calculate the potential crop evapotranspiration, the potential evapotranspiration was multiplied with the mean crop coefficients (Kc) of native grasslands (Besteiro, 2014), alfalfa for pasturelands (Mauricio, 2013), and an average between the Kc of soybean, maize and wheat for croplands (Andriani, 2017) in accordance to the area these crops cover, considering bare soils with a Kc value of 0,2 (Nosetto *et al.*, 2015).

All these illustrations together allowed linking dominant patterns of the defined time sequences with occurring climatic cycles and effects of fluctuating evapotranspiration from corresponding land-use schemes. Four important turning points in the historic development of the SES were derived from this analysis and distinct equilibrium states of the SES were described. All this information allowed drawing first conclusions on the question, which ESS are vital to be included in the following analysis steps and which major trade-offs between them could play a role in the attempt to investigate measures to reduce floods in the study area.

5.3.2 Analysis of Stakeholder Dynamics in the Study Area

Step two focused on the identification, categorization and analysis of important stakeholders, how they interact in the SES in La Picasa basin and how their dynamics create opportunities or restrictions for the conservation of wetlands. For the identification of stakeholders, the snowball sampling method was used which allowed identifying important players of an already existing network by starting with one member of the network only. Functioning as a door opener, this person recommended further important players, who again recommend additional actors, until the point was reached, where further

suggested stakeholders were already mentioned and registered before and the circle closed (Patton, 2002).

To relate stakeholder theory with ESS and their trade-offs, the stakeholder analysis in this thesis used the following definition to define relevant stakeholders: "Stakeholders refer to persons, organizations or groups with interest in the way particular ecosystem services are used, enjoyed or managed" (Groot *et al.*, 2011).

Once the stakeholder groups were identified, two methods, were used to classify them into categories. The first approach is an analytical approach, the so called 'rainbow diagram', as can be seen in Figure 14, developed by Chevalier and Buckles in 2008 (Reed, et al., 2009) and is coming from a natural resources management perspective. It classifies stakeholders in accordance to the degree they are affected by or affect an issue. By allocating the identified stakeholders according to the degree they affect, are affected by, or both simultaneously in the categories 1 (least), 2 (moderate), and 3 (most) an overview could be gained about the position of stakeholders within the rainbow diagram. The assignment of stakeholders into the categories was done with the help of information gathered in the qualitative stakeholder interviews.

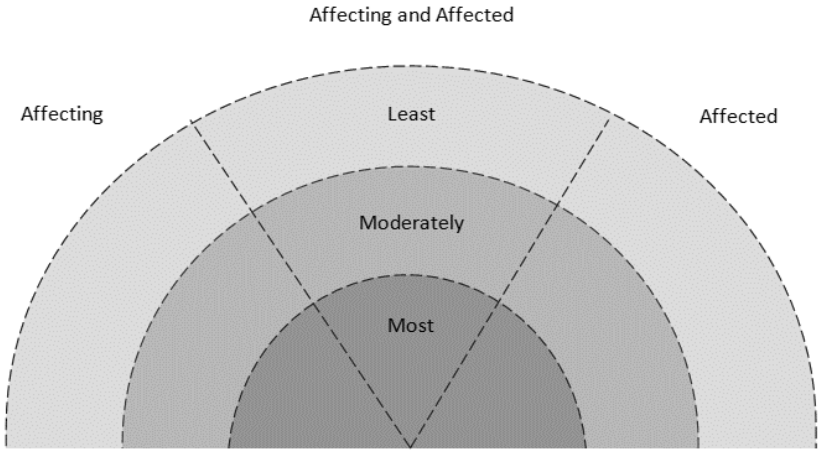


Figure 14: Rainbow diagram
(based on Chevalier and Buckles (2008) as cited in Reed et al. 2009)

In complex systems, such as the SES of La Picasa basin, the focus of stakeholder analyses, often lies on the ability to influence stakeholders in accordance to their power and interest in an issue. Therefore, another popular method for stakeholder analysis was applied, which uses the power-interest grid of Eden and Ackerman (1998) to analyze the relative position of the stakeholders on two dimensions: (1) The stakeholders' interest in an issue or activity, and (2) the stakeholders' power to influence the outcomes of the issue or activity. Stakeholders with both a high level of interest in an issue and high power to influence its outcome are considered key players that managers have to face and satisfy in order to be successful (see Figure 15).

Those stakeholders with both a low level of interest in an issue and low power to influence its outcome conversely require only minimal attention. All stakeholders with either a high level of interest or power should be kept informed or satisfied while stakeholders with both a low level of interest and power only require minimal effort (Boddy, 2008). Slightly adapting this approach to a natural resources management context, stakeholders were classified into four categories called "Key players", "Context setters", "Subjects", and "Crowd". Stakeholder with a high level of interest and power were classified as "Key players". Stakeholders with a low level of interest and power were classified as the "Crowd".

Stakeholders with a high level of power but a low level of interest were classified as "Context setters" and stakeholders with a low level of power but a high level of interest were classified as "Subjects" (Reed, *et al.*, 2009).

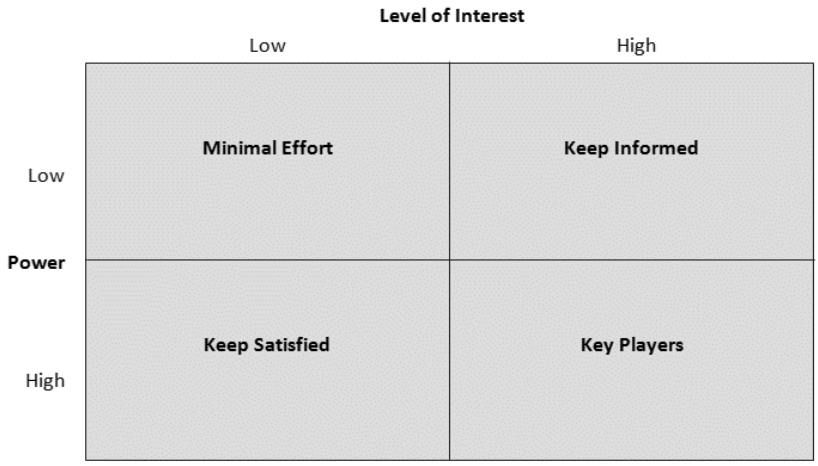


Figure 15: Stakeholder mapping - The power-interest matrix (based on Boddy, 2008)

How the stakeholders interact and are connected, which relationship they have and how the dynamics of their network function, was visualized and described based on the qualitative interviews with local experts and observations obtained during the field trip to the study area.

5.3.3 Analysis of more Sustainable Future Land-use and Management Approaches in the Study Area

In a third step, this study developed suggestions for more suitable land-use and management approaches that consider the role wetlands could play in disaster risk reduction. To achieve this, it was first assessed which specific problems in the study area are related to ESS trade-offs and how they affect each other through feedback loops. The specific problems the research area faces were extracted from the interviews conducted with local stakeholders and can be reviewed in detail in Annex 9. Although, during the interviews, stakeholders were not directly asked for ESS and their trade-offs, all interviewees directly or indirectly mentioned ESS trade-offs in relation with the problems they identified in La Picasa basin.

Only those ESS trade-offs were considered that were perceived by the consulted interview partners. The definition and typology of ESS in this thesis was based on the Millennium Ecosystem Assessment (2005) and distinguishes between provisioning, regulating, cultural and supporting ESS (Reid *et al.*, 2005). ESS can co-vary positively or negatively (Groot *et al.*, 2011). Consequently, trade-offs between ESS can occur, when there is a decrease in the provision of one specific ESS as a consequence of an increase in the provision of another ESS (Rodríguez *et al.*, 2006). According to these definitions and in line with the results of previous analysis steps, three major trade-offs between ESS in the study area were defined.

All interviewees mentioned that there is a fundamental deficiency in understanding the systemic functioning of the study area (compare Annex 9). Therefore, the problems related to the identified ESS trade-offs that got extracted from the interviews, were further analyzed on how they are interrelated and affect each other based on information from the interviewees and scientific literature. Feedback loops were associated with the three major ESS trade-offs, to be able to derive information on the role they perform in the systemic functioning of La Picasa basin. The term feedback loops in this thesis refers to the idea that a system component can itself be influenced indirectly by the changes it has

induced (Sundkvist, Milestad and Jansson, 2005). Negative feedback loops can therefore act as control devices, counterbalance change and have a stabilizing effect, while positive feedback loops reinforce change and amplify rather than reverse change (Allaby, 1994 as cited in Sundkvist, Milestad and Jansson, 2005).

To assess which management practices could inverse the negative feedback loops identified, management strategies and policies were discussed that were directly declared as needed for a sustainable solution for problems in La Picasa basin in the stakeholder interviews (compare Annex 9). To complement this internal perspective with a more scientific one, the current state of the art of several management approaches that were mentioned in the interviews was reviewed.

The identified solution approaches got further categorized into nature-based and infrastructure-based solution approaches. Nature-based solutions in this context were defined as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Monty, Murti and Furuta, 2016). Infrastructure-based solutions refer to the engineered infrastructure developed to reduce the risk of flooding events by the construction of artificial drainage systems of flooded areas (Collins, 2005; Maldonado *et al*., 2005; Booman *et al.,* 2012; Brandolin *et al.,* 2012; Brandolin & Avalos, 2012). Hybrid approaches meanwhile are referred to as the fusion of both, nature-based and infrastructure-based approaches.

To describe how nature-based solutions perform in comparison to infrastructure-based solutions and if their coexistence provides synergies or creates problems, the distinct approaches got compared with respect to three comparison factors. The first factor is related to how the three solution approaches improve or impair ESS for human well-being and divided into provisioning, regulating and supporting ESS. The second factor refers to the effect the three solution approaches cause with respect to disaster risk reduction and is separated in the three typical variables of DRR which are "frequency and magnitude", "degree of exposure" and "vulnerability" (Monty, Murti and Furuta, 2016) of the SES to floods. The third comparison factor refers to the effectiveness of the solution approaches in terms of the time needed until the system responds to applied measures ("Response"), the overall costs of the solution approaches ("Costs") and how measurable the successful implementation of the approaches is ("Measurability). The performance of the three solution approaches was evaluated in a qualitative way, using plusses (+) and minuses (-) for indicating the degree of improvement or impairment of ESS and DRR for human well-being or zeros (o) for no changes in the short-, medium- and long-term.

6 Results

The following sub-chapters present the results obtained from the three analysis steps conducted.

6.1 Historic Development of the Land-use in the Pampas SES

The historic development of the SES in the study area was divided into six distinct time periods (<1870, 1870-1920, 1921-1940, 1941-1960,1961-1990, 1991-2018) according to representative significant combinations of weather (rainfall and winds), land-use (land allocated to natural grassland, pastureland and cropland) and anthropogenic impacts (such as agronomic practices, the introduction of new technology or seeds and infrastructural modifications of the landscape). The time sequences were analyzed with a focus on the development of the hydrological regulation of the SES and how it was impacted by anthropogenic operations and based on an extensive literature review. An overview of the time sequences and interdependencies with land-use changes and evapotranspiration rates can be found in Figure 17 and Figure 18.

6.1.1 Pre-agricultural System before 1870

The formation of a SES in the Argentinean Pampa that is of relevance for the current problem situation, began with the colonization of the area. For the first immigrants, arriving in Argentina before 1870, the country had a large advantage over other 'underdeveloped' countries, because its development did not start with populations pressing against limited resources but a land surplus (Melville Watkins, 1963 as cited in Solberg, 1982). Indeed, Argentina contained one of the world's richest agricultural areas – the Pampas (Solberg, 1982). Originally covered by hundreds of wetlands in a vast matrix of grasslands and savannas (Brandolin, Ávalos and De Angelo, 2012), the Pampas and their grasslands provide feed for 42 million heads of cattle and 14 million sheep today (Modernel *et al.*, 2016). In addition, the biome provides habitat for 4000 native plant species, 300 species of birds, 29 species of mammals, 49 species of reptiles and 35 species of amphibians (Modernel *et al.*, 2016) Moreover, the soils of this region stock 5% of the soil organic carbon on 3% of Latin America's area (Modernel *et al.*, 2016).

When first settlers started cultivating spots of the landscape, they created a patchwork of agricultural crops and alfalfa within vast areas dominated by natural grasses (Interview 16-18, Jobbágy (2018), see Annex 5). Because the minor plots of agricultural area did not weigh enough to influence the overall water balance, before 1870 the SES was mainly determined by ecosystemic mechanisms, such as evapotranspiration rates that kept the system in a hydrological balance. Wetlands played an important role in the hydrological cycle, because besides their provision of various ESS (Brandolin, Ávalos and De Angelo, 2012), they also provided the capacity to reduce floods and recharge groundwater (Bullock and Acreman, 2003).

6.1.2 Agricultural Development from 1870-1920.

The first significant agricultural development in the Pampas did not begin until the 1870s, and while it already accelerated in the 1890s, it did not last longer than until the 1920s that Argentina had risen to the rank of leading global agricultural exporters (Solberg, 1982). Since Argentina's population was relatively small with approximately nine million inhabitants in 1921, agricultural products primarily flew to the export markets and Argentina became the world's largest corn and beef exporter and was ranging between position two and three in wheat exports (Solberg, 1982).

This phenomenal growth was enabled through policies encouraging massive foreign investment and immigration. The promotion of immigration to populate Argentina's empty grasslands and to provide labor force essential for the further agricultural development, resulted in millions of immigrants arriving to work the soils of the Pampas and to transform them into breadbaskets of the world between 1870 and 1930 (Solberg, 1982). The Argentinean government kept the doors wide open for any group

of immigrants, especially Southern Europeans, precisely when Southern and Eastern European migration reached its zenith shortly before World War I. Consequently, ambitious migrants peopled the Pampas who were not accustomed to living standards as high as those common in Northern Europe and who were willing to enter agriculture as sharecroppers or renters rather than landowners (Solberg, 1982).

While the Volga Germans and Jews were exceptions in the general pattern of massive rural immigration and became landowners and formed communities, most Southern Europeans did not. Therefore, the prevailing social and political system in the pampas did not fundamentally change with immigration (Solberg, 1982). Although immigrants contributed greatly to agrarian protest movements, the pressure groups of the Pampas failed in taking over the control of agrarian economic policy from the dominant political groups. The Pampas farmers remained primarily tenants and peripheral groups in the larger national frameworks (Solberg, 1982).

6.1.3 Overexploitation of Natural Resources from 1921-1940

Between 1920 and 1950 another agricultural expansion wave took place and came at the expense of natural resources such as forests, wetlands and grasslands (Viglizzo and Frank, 2006). Land-use change, and low forage grazing regimes were predominantly associated with negative effects on ESS provision, because they reduced the soil organic carbon stocks and species biodiversity while increasing soil erosion (Modernel *et al.*, 2016). The loss of wetlands already had the first impact on human well-being in this period, because the disappearance of their highly diverse ecosystems caused the loss of important goods and services (Sica *et al.*, 2016), too. Overgrazing, overcropping and non-suitable tillage technologies triggered the SES to pass a critical ecological threshold (Viglizzo and Frank, 2006) for its self-regulation. In combination with dry and windy weather condition (Viglizzo and Frank, 2006) and an increasing evapotranspiration "reaching its peak in the 1950s, with the alfalfa depending production system" (Interview 16-18, Jobbágy (2018), see Annex 5), the SES faced a disequilibrium in the hydrological balance which resulted in a dust-bowl period in the following years (Viglizzo and Frank, 2006).

6.1.4 Dust-Bowl Period between 1941 and 1960

Long periods of droughts and strong winds (Bernardos *et al.*, 2001) affected the fragile structure of soils in the Pampas and made wind-erosion a major concern in the 1940s and 1950s. The accumulative effects of land misuse and non-appropriate soil management in the previous decades resulted in a big ecological collapse – the Pampean "dust-bowl" (Covas, 1962; Covas and Glave, 1988 as cited in Bernardos *et al.*, 2001).

Between the 1940s and 1960s, the region suffered the catastrophic consequences of an extensive erosion that degraded arable lands, caused a rapid decay of soil productivity, successive crops failure, and a massive death of livestock (Bernardos *et al.*, 2001; Viglizzo and Frank, 2006). Many farmers were confronted with bankruptcy and were leaving the Pampas to migrate to the surrounding cities (Viglizzo and Frank, 2006). During the 1930s and 1940s, the population of the Pampas diminished by almost 50% due to such environmental perturbation (Covas, 1989 as cited in Bernardos *et al.*, 2001).

6.1.5 Agricultural Expansion between 1961 and 1990

Improved rainfall conditions enabled the conversion of abandoned lands into grazing plots and cropland in the second half of the century, while simultaneously episodes of repeated flooding events affected the area especially in the highly productive lowlands (Viglizzo and Frank, 2006). Water removal was hindered because of the configurations to the slopes of naturally occurring dunes, a lack of infrastructure that favored its accumulation and high cultivation rates that dramatically increased the severity of floods during such humid periods (Viglizzo and Frank, 2006). Consequently, the ecological catastrophes that the region faced during the 20th century were outcomes of a set of

complex interactions between the geological configuration, climate variability and anthropogenic impacts. Presumably, over cropping had surpassed critical ecological thresholds again and after triggering the dust-bowl, it was also responsible for the flooding events experienced in this period (Viglizzo and Frank, 2006).

Because an increase in precipitation since the mid-1970s enlarged the area occupied by wetlands, artificial drainage channels were constructed in vast flooded regions, including critical areas for the conservation of biodiversity (Brandolin, Ávalos and De Angelo, 2012). Besides the mitigation of floods, the channelization in Córdoba also favored further agricultural expansion at the expense of wetlands, thereby destroying wildlife refuges (Brandolin, Ávalos and De Angelo, 2012).

Soybeans were first introduced in Argentina at the beginnings of the 1970s and primarily cultivated in the Pampa ecoregion due to its suitability for large scale, capital intensive production (Gutierrez, 1997). Its cultivation experienced an explosive growth, because the summer crop fit perfectly into the agroecological characteristics of the region and could be produced in rotation with winter crops like wheat in the same year (Gutierrez, 1997). Argentina became the fourth largest soybean producer in the world, exporting the good almost entirely and thereby made soybeans the main source of external currency (Gutierrez, 1997). This soy-boom resulted from an avid external market, the withdrawal of cattle exports, and national policies fostering the incorporation of soybeans in the SES (Gutierrez, 1997). Furthermore, the productivity of agriculture in the Pampas was boosted through the increasing application of external inputs, modern technology and management practices (Viglizzo *et al.*, 2010). The promotion of soybeans by transnational enterprises which offered the whole technological package led to a better rentability in comparison with any other agricultural activity (Gutierrez, 1997).

An important part of this modern technology package was the introduction of no-tillage machinery and corresponding management practices. After the experiences with the dust-bowl period between 1950 and 1960, the newly introduced no-tillage technology, besides other benefits, also followed the objective to conserve humidity in the soils (HGCA, 2012). Within only eighteen years, the overall area devoted to soybeans in the Pampas developed from no cultivated soybeans in 1970 to almost four million hectares total area in 1988, while the area under cattle production continuously declined (Gutierrez, 1997).

6.1.6 Soybean Monocultures from 1991 until today

The dominance of soybeans in the study area since the 1990s is valid until today. Considering the agricultural potential of the Pampas, it is surprising that only few main crops, such as soybean, wheat, maize, sorghum, and sunflowers account for most of the planted surface and production (Hall *et al.* 1992 as cited in Solbrig 1997).

Although the strong influence of vegetation shaping the hydrological cycle is increasingly recognized, the effects of land-use changes in very flat areas, like the Pampas, are less understood (Nosetto *et al.*, 2015). Land-use has a key role in the hydrology of the Pampas, supporting the linkage of groundwater level raises as well as flood frequency and severity with the expansion of grain production systems (Nosetto *et al.*, 2015). Relating higher water-table levels and flooding risks to the land-use change that occurred in the Pampas, lifts the importance of natural ecosystems to another level.

It is widely recognized that wetlands play a significant part in the hydrological cycle and therefore they have become important elements in water management policies (Bullock and Acreman, 2003; Verma and Negandhi, 2011). Many examples show that wetlands have the capacity to reduce floods, recharge groundwater, or augment low flows, when managed properly (Bullock and Acreman, 2003; Kumar *et al.*, 2017). Most landscapes respond to extreme precipitation with increased surface water outflows, but flat and poorly drained regions like the Pampas, have little capacity to do so (Kuppel *et al.*, 2015).

Therefore they face an increased water storage resulting in rising water tables and floods (Interview 8-9, Tricarico (2018), see Annex 5), an increased evaporative water loss after this storage reached elevated levels, and finally increased water outflows (Kuppel *et al.*, 2015). A distinction has to be made between 'slow floods' lasting several years when the water table is brought to the surface, because of precipitation in groundwater connected systems and 'fast floods' triggered by surface water accumulation over weeks or months, typical of poor surface groundwater connectivity or when exceptionally strong rainfalls overwhelm infiltration capacity (Kuppel *et al.*, 2015). Evapotranspirative losses in the Pampas are strongly linked to flooded conditions as a regulatory feedback, while liquid water outflows remained negligible (Kuppel *et al.*, 2015).

6.1.7 Historical Development of Evapotranspiration in the Pampas

Regarding the water balance of the SES, land-use schemes have an immense influence on the hydrological cycle (Viglizzo and Frank, 2006; Nosetto *et al.*, 2009, 2012; Bollatti, 2014; Kuppel *et al.*, 2015; Mercau *et al.*, 2015). With the beginning of anthropogenic impacts through land-use decisions and soil management since the 1870s, evapotranspiration rates of the system got heavily modified (Nosetto *et al.*, 2009; Kuppel *et al.*, 2015; Mercau *et al.*, 2015).

Because precipitation and evapotranspiration records do not date back longer than to the years 1931 and 1967, a general trend in the evapotranspiration was developed based on knowledge-input from the interviews with local experts and supported by actual evapotranspiration data of the time period for which it was available (compare Figure 17). This trendline follows the logic that ignoring the variability of rainfalls and wind intensity, the predominant land-use patterns and related evapotranspiration rates of the defined time sequences had a major impact on the water balance of the SES.

The reference state was defined as the pre-agricultural state of the SES before 1870. It was characterized by vast grass- and wetlands and functioning ecosystems with a diversity of species adapted to the prevailing climatic conditions. ESS were able to keep the SES in a balanced state, with various mechanisms mitigating the interactions of precipitation and evapotranspiration rates through natural vegetation. Almost 400 distinct grass species could be found in the Pampas (Bilenca and Miñarro, 2004a) before agricultural land-use came at the expense of vast grassland areas.

When the land cover changed corresponding to the agricultural development beginning in the 1870s and reaching its peak in the 1920s, "the according evapotranspiration diagram, ignoring the variability of rainfalls, would show an increase in evapotranspiration until the 1920s" (Interview 16-18, Jobbágy (2018), see Annex 5) because more and more land got converted into pastures mainly composed of alfalfa. Since "alfalfa became about 50% or more of the area around the 1950s, (it caused) a higher evapotranspiration (and) probably dried down the system" (Interview 16-18, Jobbágy (2018), see Annex 5). In connection with the extremely low accumulated monthly anomaly in precipitation that was obtained from the ground station in Pergamino, it is probable that the dominant land-use form of the Pampas in that period, triggered a feedback with negative effects for the SES, resulting in a "dust-bowl".

As a result of these dry conditions and the crop failures reported, the evapotranspiration rates started falling in the 1940s. This trend got even accelerated "in the 1980s and 1990s with the beginning of no-tillage technologies and the intensive cultivation of crops (like soybean) that have a lower water consumption" (Interview 16-18, Jobbágy (2018), see Annex 5). Since the region simultaneously also faced an increasing trend in precipitation, the SES suffered from repeated flooding events affecting productive areas. Today, it is common practice in the study area that soybean, wheat and maize get combined in rotation cycles with two cultivation periods throughout a year (Bollatti, 2014). Various options exist for the combination of crops but, unfortunately, more than 80% of the land-use account

for a soil management with bare soils in winter and soybean or maize crops in summer (Bolatti, Andreucci and Escolá, 2015). Consequently, the summed up annual water consume of most rotation options is below the mean annual precipitation of 900mm (Pedraza, 2000). The consequence is water excesses that accumulate over the years and lead to flooding events (compare Table 5).

Table 5: Water consumption of distinct agricultural management strategies and resulting water balances (Own elaboration based on Bollatti, 2014)

Water consumption of distinct agricultural management strategies										
	Option 1		Option 2		Option 3		Option 4		Option 5	
Crops	Bare soils (in winter)	1° Soybean (in summer)	Bare soils (in winter)	1° Maize (in summer)	Cover crop (wheat) (in winter)	1° Soybean (in summer)	Wheat (in summer)	2° Soybean (in winter)	Wheat (in summer)	2° Maize (in winter)
Annual water consumption (mm)	161	500	161	667	281	500	350	437	350	533
Total	**661**		**828**		**781**		**787**		**883**	

Annual hydrological balance of distict agricultural management strategies										
	Option 1		Option 2		Option 3		Option 4		Option 5	
Crops	Bare soils (in winter)	1° Soybean (in summer)	Bare soils (in winter)	1° Maize (in summer)	Cover crop (wheat) (in winter)	1° Soybean (in summer)	Wheat (in summer)	2° Soybean (in winter)	Wheat (in summer)	2° Maize (in winter)
La Niña Year (750 mm)	89		-78		-31		-37		-133	
Ordinary year (900 mm)	239		72		119		113		17	
El Niño Year (1100 mm)	439		272		319		313		217	

The described general trend of the behavior of evapotranspiration rates can be supported by actual data acquired from the ground station in Pergamino for the time period from 1967 to 2015. Within this time, the general trendline assumes a decreasing tendency of evapotranspiration rates in accordance to an increase in area dedicated to crops with a lower total annual evapotranspiration. The actual calculation of this period shows a slight decrease in the potential reference evapotranspiration (see Figure 16). The potential crop evapotranspiration that takes into consideration the predominant crops and their specific evapotranspiration rates, generally follows the behavior of the potential reference evapotranspiration but the difference between both lines increases with the years, as more and more cropland is dedicated to soybean and maize which are mainly produced with 6-months periods of bare soils. The difference between potential reference evapotranspiration and potential crop evapotranspiration, as can be seen in figure 16, increased with the introduction of soybean in the early 1970s and thereby veers away steadily from the potential amount of water that could leave the system through evapotranspiration.

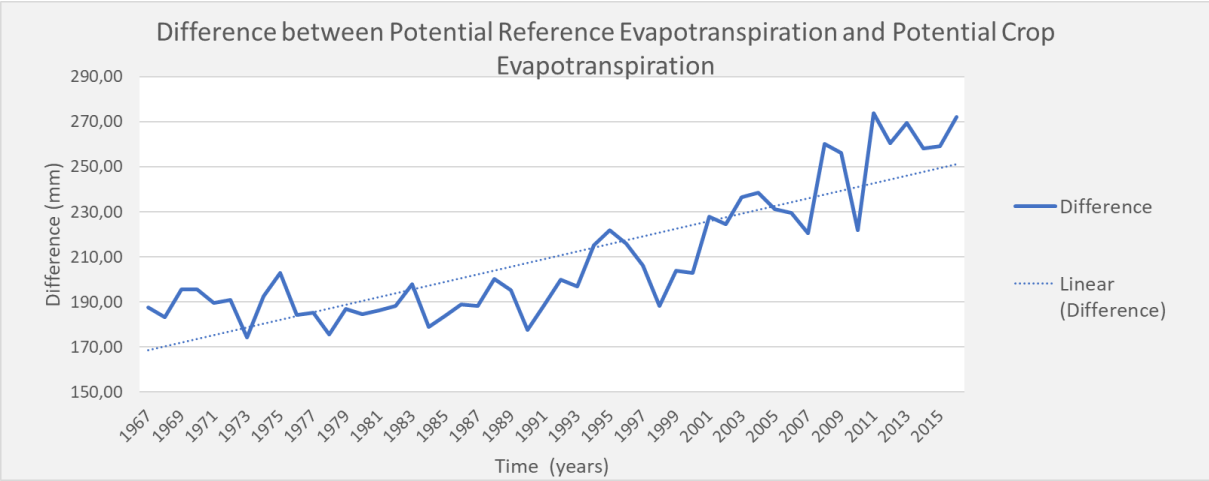


Figure 16: Difference between potential reference evapotranspiration and potential crop evapotranspiration (own elaboration based on data from Pergamino ground station)

Figure 17: Timeline Infographic (a)

Timeline

1870-1920: Agricultural Development

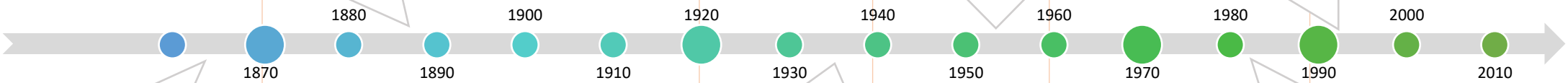
Beginning of significant agricultural development (mainly cattle, wheat and maize), in 1920 Argentina has developed to a leading global agricultural exporter, this economic boom was enabled through policies encouraging massive foreign investment and immigration, evapotranspiration rates are increasing due to more and more land converted into pastures (alfalfa, natural grasses and agriculture)

1941-1960: Dust-Bowl Period

Many farmers suffered from the extremely dry and windy weather conditions, high cattle mortality, and crop failure often resulted in bankruptcy and led to many farmers leaving the Pampas and migrating to surrounding cities, high evapotranspiration rates due to the productive system in connection with low precipitation rates due to natural climatic cycles

1991-2018: Soybean Monocultures

Rotation of three major annual crops (soybeans, wheat, maize), massive drainage of the area to get rid of excess water, evapotranspiration rates below precipitation rates, almost no natural areas left (such as wetlands), loss of biodiversity, drastic increase of groundwater levels and flooding events, increased disaster risk



Before 1870: Pre-Agricultural System

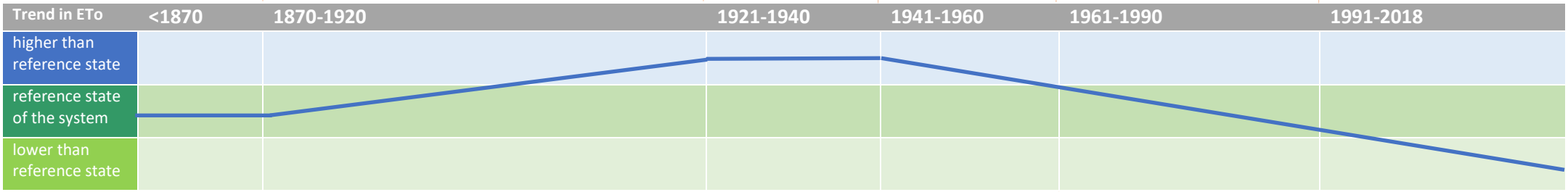
Abundance of natural resources and land, hundreds of wetlands in a vast matrix of grasslands and savannas, rich and fertile agricultural areas, first settlers cultivating spots of pasture (alfalfa) and agriculture, SES mainly determined by ecosystemic mechanisms, evapotranspiration rates of the SES can keep the system in a hydrological balance

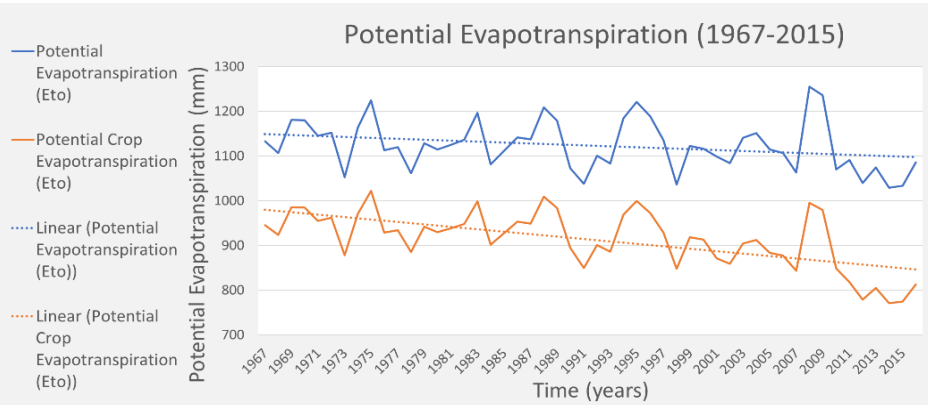
1921-1940: Overexploitation of NR

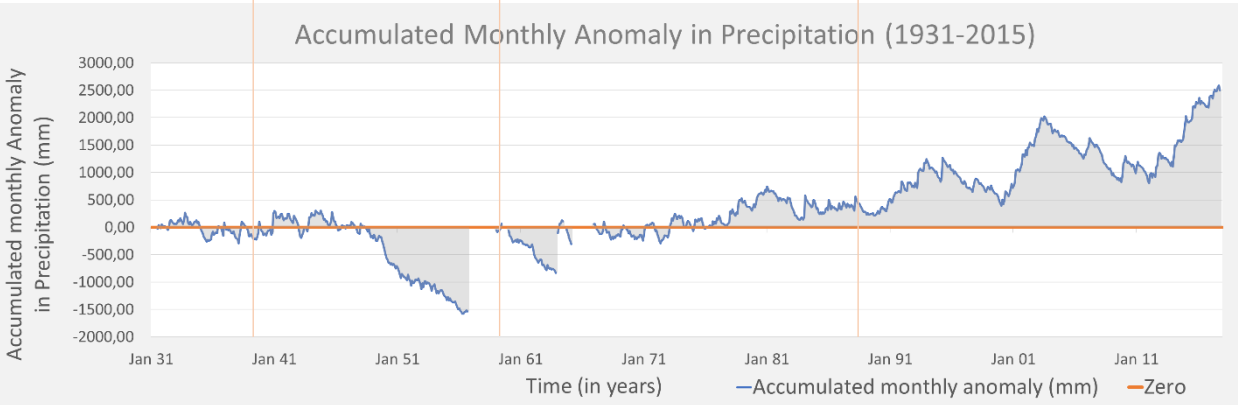
The period of further agricultural expansion came at the expense of natural resources such as forests, wetlands and grasslands, overgrazing, overcropping and non-suitable tillage technologies in combination with dry and windy weather condition caused the SES to pass a critical ecological threshold resulting in a dust-bowl period, evapotranspiration rates were not able to keep the system in a hydrological balance anymore

1961-1990: Agricultural Expansion

Due to improved rainfall conditions abandoned land was transformed into grazing plots and cropland, high cultivation rates, introduction of no-tillage technology with the objective to conserve soil structure and humidity, economic incentives for crop-production, land-use change, the evapotranspiration rates of more and more cropland decrease, repeated flooding events affect productive areas, construction of drainage channels

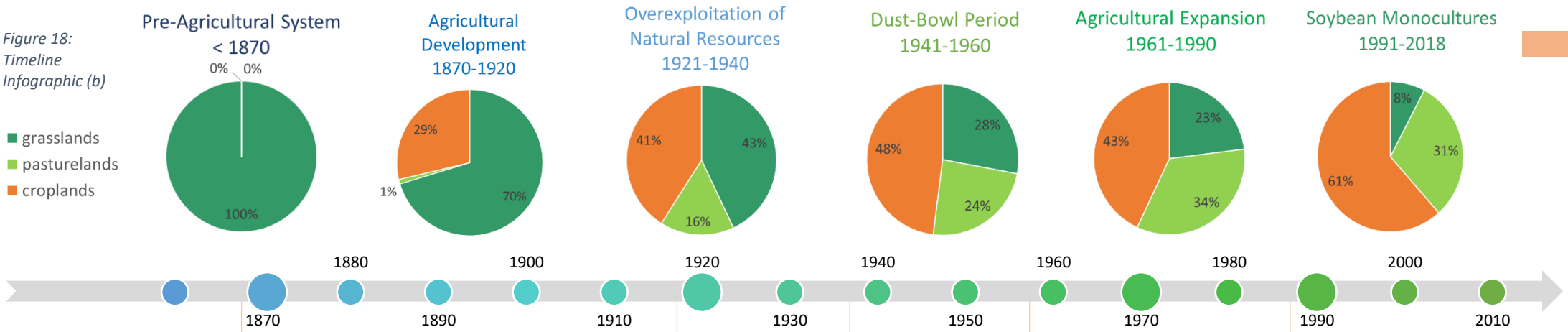


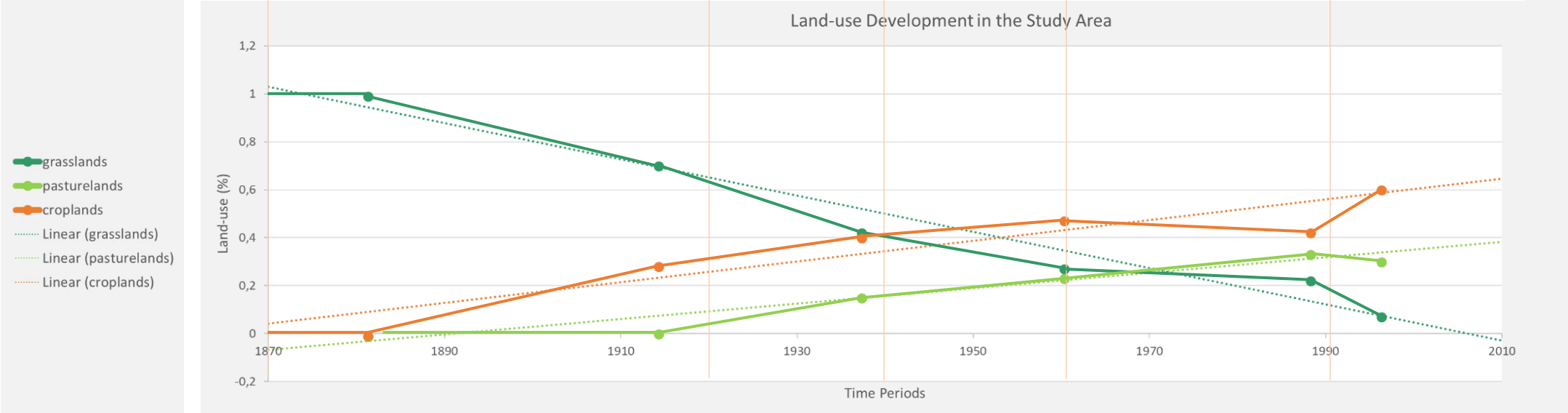




Potential Evapotranspiration (1967-2015) and Accumulated Monthly Anomaly in Precipitation (1931-2015); own elaborations both based on data from Pergamino ground station

Figure 18: Timeline Infographic (b)





Land-use Development in the Study Area

Land-use in time period under investigation	Pre-Agricultural System < 1870		Agricultural Development 1870-1920		Overexploitation of Natural Resources 1921-1940		Dust-Bowl Period 1941-1960		Agricultural Expansion 1961-1990			Soybean Monocultures 1991-2018	
Sources*	Bernardos et al. 2001	**Viglizzo et al. 2001**	Bernardos et al. 2001	**Viglizzo et al. 2001**	**Viglizzo et al. 2001**	Bernardos et al. 2001	Bernardos et al. 2001	**Viglizzo et al. 2001**	Bernardos et al. 2001	**Viglizzo et al. 2001**	Baldi & Paruelo 2008	**Bernardos et al. 2001**	Baldi & Paruelo 2008
Data for the year(s)	**1880**	**1881**	**1907**	**1914**	**1937**	**1938**	**1960**	**1960**	**1988**	**1988**	**1985-1990**	**1996**	**2000-2004**
grasslands	100%	100%	~60%	71%	43%	~40%	~25%	28%	~18%	23%	~30%	~8%	~25%
pasturelands	0%	0%	~35%	1%	16%	~25%	~42%	24%	~26%	34%		~31%	
croplands	0%	0%	~5%	29%	41%	~35%	~33%	48%	~56%	43%	~70%	~61%	~75%

*Sources in bold letters represent the data used in the above figure. They got chosen according to accurateness and completeness of all land cover types

6.1.8 Important Turning Points in the Historic Development of the Pampas SES

Four major turning points were derived from the analysis of the historic development of the SES that were crucial to transform the functioning of the system from one state into another one (compare Figure 19). The first turning point that caused a notable change of the system, is the beginning of significant agriculture in the 1870s, which transformed the study area's natural system of vast steppes with natural grass- and wetlands into a SES, in which humans considerably shaped their environment for agricultural purposes.

The second turning point results from the agricultural boom in the 1920s that caused a massive overexploitation of natural resources and a rapidly proceeding land-use change with high evapotranspiration rates. It also caused the loss of natural grass- and wetlands and their regulating ESS. Consequently, human impact on the SES passed critical ecological threshold and resulted in a dust-bowl period.

When improved rainfall conditions caused a further expansion of agricultural land, the introduction of soybeans in the 1970s caused a complete change of the conventional production schemes and therefore was identified as the third turning point. An augmented modification of evapotranspiration rates that went down drastically, caused the SES to switch from extremely dry conditions to wet conditions that allowed an intensive agricultural use again.

The 1990s represent the start of significantly higher rainfall rates that made the SES change from beneficial conditions for intensive agricultural use towards extremely humid conditions causing groundwater flooding of highly productive areas and an increase in water levels of the principal lagoon la Picasa related with a loss of infra-structure and threats for the local communities.

Figure 19: Major turning points of the historic development of the study area (own elaboration)

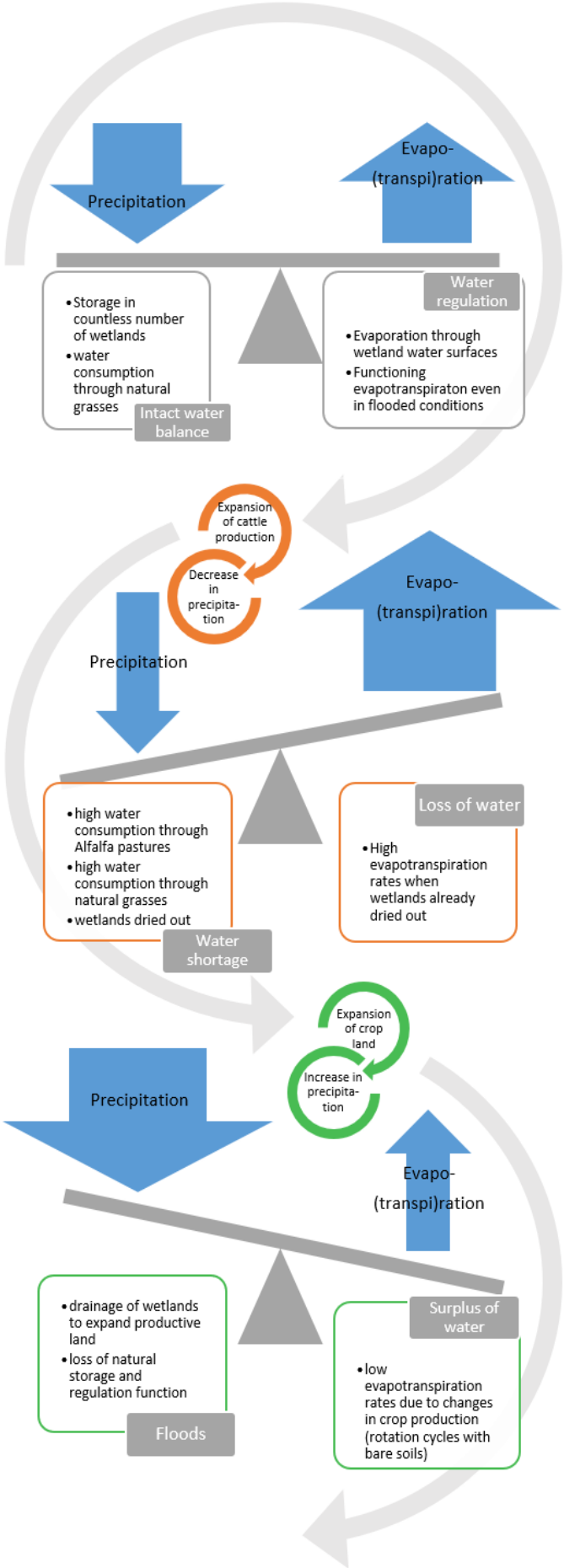


Figure 20: States of the SES in La Picasa basin and major feedback loops (own elaboration)

6.2 Distinct Equilibrium States of the SES

Derived from the SES's reactions to changes in climatic conditions and to changes in land-use management schemes with corresponding modifications in evapo(transpi)ration rates, distinct systemic states of the study area could be observed with differing characteristics, feedback mechanisms and water-related problems such as floods and droughts.

Although further research is required to quantify the degree of influence each component has in determining the SES's behavior, the analysis of distinct equilibrium states helps understanding the systemic functioning of the study area as a consequence of changing variables.

Since the overall water balance in the study area is dominated by the vertical components precipitation and evapotranspiration, while the lateral movement of water is very small or negligible (Aradas and Thorne, 2001) these two vertical components were taken as main elements determining the state of the SES with respect to the water balance. Precipitation and evapo(transpi)ration rates vary according to changing climatic conditions or land-use schemes and are influential factors that can cause the system to switch from one state into another.

The previous analysis of the historic development of the SES in the study area allows the compilation of three distinct systemic states (compare Figure 20).

The first state is the reference state of the system and refers to the natural situation before anthropogenic impacts became the determining factor which shaped the SES to large parts. Although the system faced natural variations in climatic conditions that varied with the wet and dry periods caused by El-Niño- and La-Niña-Events, the system was able to balance different water inputs through precipitation by functioning eco-systems and their services. A vast matrix of wetlands, grasslands and steppes with a variety of natural factors could regulate the water balance. While a countless number of

small lagoons and wetlands stored water masses and enabled evaporation on their water surfaces, they also supplied a diverse habitat for natural grass species, which, adapted to distinct climatic conditions, consumed and evapotranspirated water even under water-logged conditions. The systemic feedback mechanisms were mainly driven by ESS and kept the system in a balance thereby avoiding water-related problems.

The second state of the system refers to the extremely dry period in the 1950s. Obviously the state of the SES switched from a humid environment with good conditions for cattle production and the growing of pastures such as alfalfa, which has a high water consumption, into a completely different state. Although land-use changes in the study area already took place before the system experienced this drastic change, natural feedback loops handling precipitation and evapo(transpi)ration, were capable to buffer the effects of land-use changes away, until they fell together with a period of low precipitation rates. When the lack of rainfall added up on the high water consume and evapotranspiration rates of the pre-dominant pastures of that time period, it finally resulted in an extreme water shortage. Many farmers went bankrupt and crop failure resulted in lowering overall evapotranspiration rates. Nevertheless, the system remained in this state, until increasing precipitation rates terminated it a few years later.

The sufficient input of water into the SES was able to counteract the evapotranspiration rates, which continued being high after enough rainfall allowed continuing business as usual, and kept the system in a balance. It even allowed the further expansion of range lands and pasture lands. With the introduction of soybeans and the land-use change towards annual crops as the pre-dominant land cover, the evapotranspiration rates decreased drastically. Together with an overall increase in precipitation rates that the study area faced since the 1990s, and the drainage of wetlands related to the agricultural expansion, the system switched into an over-dimensionally humid state. Once effective regulatory feedback mechanisms, like evaporation and evapotranspiration through functioning ecosystems, became impossible because most of the wetlands were drained and most natural grasslands were replaced by croplands. The study area consequently started suffering from floods and until today never was able to reverse these negative feedback loops back into a more balanced state.

The process was even accelerated through the implementation of grey infrastructure that fails to solve the problem of floods and created unwanted feedback mechanisms that are not fully understood today and cause the water levels of the principal lagoon La Picasa to stay high even in drier climatic circumstances (Interview 1, Villa Uria (2018); Interview 5-7, Milardovich (2018); Interview 8-9, Tricarico (2018); Interview 10-15, Más (2018); Interview 19, Bertoni (2018), see Annex 5).

6.2.1 Relevant ESS and Trade-offs

The major feedback mechanisms that were identified in the SES are driven by the vertical components precipitation and evapo(transpi)ration. ESS delivered by the natural part of the system held the capacity to mitigate and buffer extreme climatic conditions and over a long period of time were able to keep the system in a balance. Crucial ESS for keeping this special landscape in a stable state thereby enabling human well-being are the water regulation and flood protection functions of natural wetlands involving diverse grasslands.

They heavily depend on a biodiverse mixture of species, which support these essential functions with many small-scale feedback loops within the bigger and more obvious balancing of water masses. The ESS delivered by natural areas such as wetlands in the system stand in direct competition with agricultural production that the fertile soils of La Picasa basin make highly lucrative. Consequently, the most important ESS trade-offs with respect to characteristics and current problems in the study area but also with respect to past states of the SES occur between agricultural production (provisioning ESS)

and hydrological regulation (regulating ESS), supported by habitat quality related to biodiversity (supporting ESS). The major ESS trade-offs occurred between the provisioning and regulating ESS although the increase in provisioning services also impacted the supporting ESS (compare Figure 21).

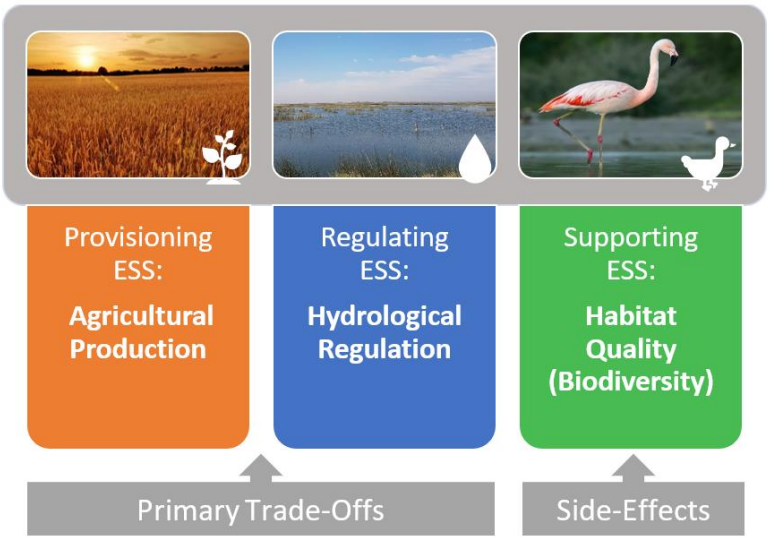


Figure 21: Identified vital ESS and their trade-offs (own elaboration)

When the development of the ESS agricultural production, hydrological regulation and habitat quality gets heavily simplified and broken down to a general trend (compare Figure 22), it could be said that already before 1870 the first agricultural production took place and since then steadily increased until today at the expense of a decreasing hydrological regulation and the side effect of a decreasing habitat quality and related biodiversity.

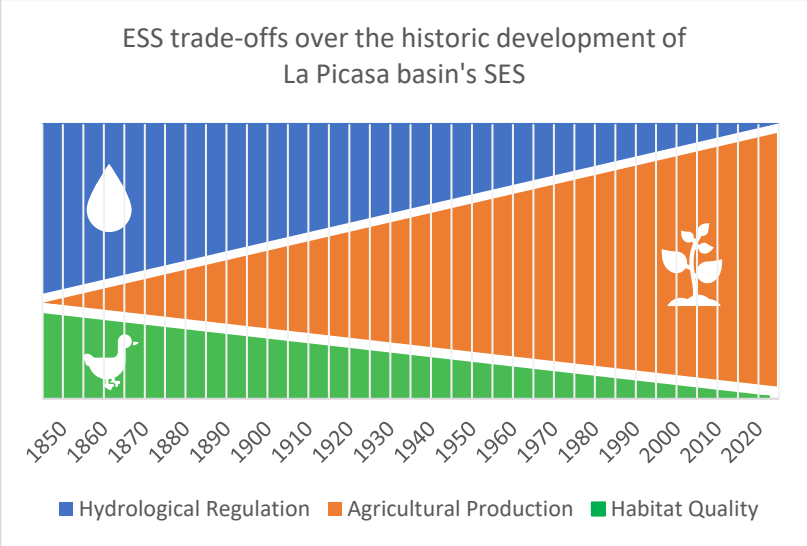


Figure 22: Simplification of general ESS trade-offs in La Picasa basin (own elaboration)

If the current problems in the study area are directly related to the decrease in the hydrological regulation function of ecosystems in the study area, cannot be answered here because it requires much more information and research to be able to make a defendable statement, but the analysis of the historic development of La Picasa basin's SES, its turning points and feedback loops, suggests that a direct connection between the loss of ESS and the current problems in the study area is possible and worth to be considered in future solution approaches.

6.3 Stakeholder Analysis

6.3.1 Identification of Stakeholders

As a result of the conducted semi-structed and qualitative interviews with local experts, a total number of 45 potential stakeholders for a future project about La Picasa basin and the related problems were identified. Among them are current stakeholders, composed of private persons but also companies and institutions, as well as potential future stakeholders and project partners. A detailed list of all stakeholder institutions, their area of profession, representatives and their contact data can be found in Annex 6.

To obtain a manageable amount of involved parties for the following analysis, the identified 45 stakeholders got condensed into seven stakeholder groups and 22 sub-groups, according to their characteristics and area of profession (see Table 6).

Table 6: Stakeholder grouping (own elaboration)

Stakeholder Grouping	
Stakeholder Groups	Stakeholder Sub-Groups
A: Basin Committees	1 Interjurisdictional Basin Committee 2 Provincial Basin Committee
B: Governmental Stakeholder	3 National Government 4 Provincial Governments 5 Regional Governments
C: Research Institutes	6 Agricultural Research Institutes 7 Water Resources Research Institutes 8 Environmental Research Institutes
D: Universities	9 Directly Involved Universities 10 Potentially Involved Universities
E: Nature Conservation Stakeholders	11 International Nature Conservation Groups 12 National Nature Conservation Groups
F: Agricultural Stakeholders	13 Farmer Associations 14 Tenants 15 Landlords 16 Owners that farm 17 Agricultural Companies 18 Dairy farmers/Ranchers
G: Local Stakeholders	19 Fishermen 20 Tourism Related Stakeholders 21 Service Providers 22 Urban Population

6.3.2 Categorization of Stakeholder

Once these stakeholder groups were identified, it was important to know which of them are affecting the SES of the study area, which are affected, and which are both affecting and affected. The following categorization of stakeholders was done with the help of the conducted interviews and a detailed justification of it can be reviewed in detail in Annex 7. The categorization of stakeholders applying the rainbow diagram approach, showed the following results presented in Figure 23. The term 'affecting' in this context refers to actions that have a direct negative impact on the water balance of the SES while the term 'affected' refers to the experience of direct or indirect trade-offs that occur as a result of disturbances in the water balance.

From 22 stakeholder subgroups, nine were categorized as only affecting the system, eight as both affecting the system and being affected from it and five as only being affected from it. More than 70%

of all stakeholder groups were categorized as affecting and being affected in a “high” or “moderate” degree, while six stakeholder subgroups were put in the category “low”.

Stakeholder groups were related to all combinations of classifications, however, while eight subgroups are purely affecting the system and do not directly perceive the consequences of their acting, five are affected by the consequences without having an impact.

While it seems logical that research institutes, universities and nature conservation groups (C6, C7, C8, E11 and E12) that are not directly situated in the study area, are not directly affected by changes of the system, it appears a bit odd that two agricultural players that should suffer from ESS trade-offs, are categorized as not being affected, while all other agricultural stakeholders are categorized as being affected. This is due to the fact that large agricultural areas in La Picasa basin are rented and the corresponding tenants (F14), usually wealthy, have short-term contracts for large areas in the study region. This allows them to abandon the rented land as soon as they suffer trade-offs and meanwhile they exploit the land as much as possible to gain the highest economic return. This makes them a highly influential group of players in the system. The corresponding landlords (F15) of these lands usually live far away in cities and only want to spend as little time and effort as possible while earning the lease. So far, they are not considering the decreasing value of their land, when exposed to exploitative agricultural management practices.

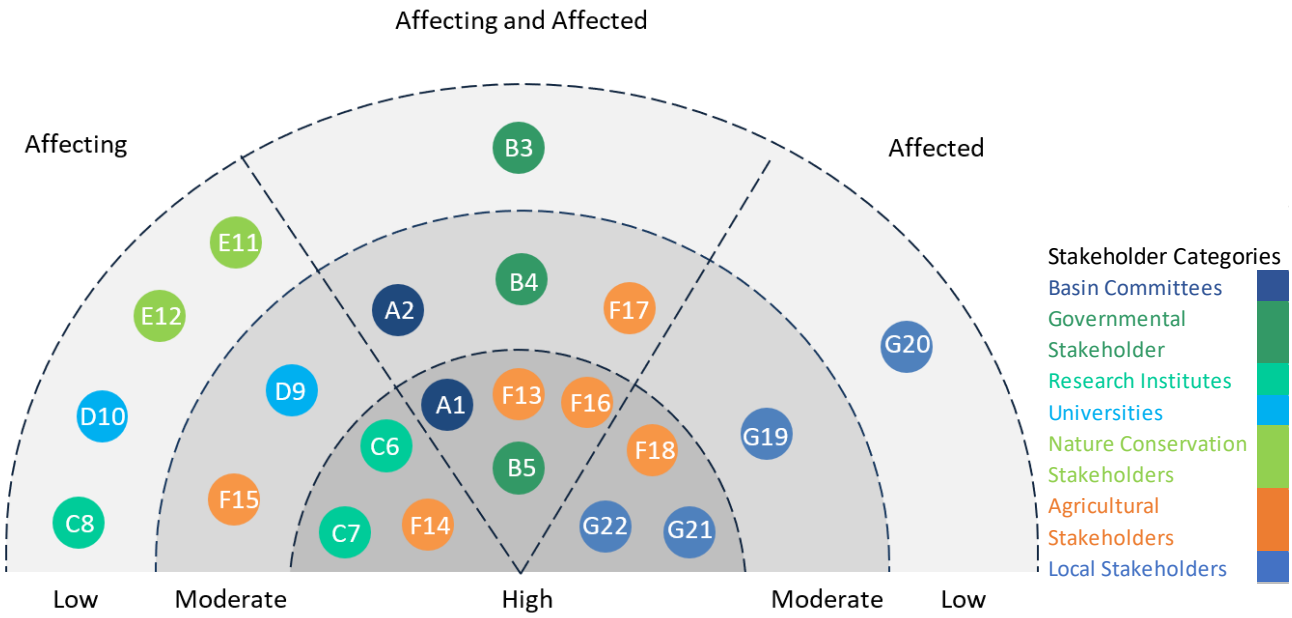


Figure 23: Stakeholder categorized according to the rainbow-diagram approach (own elaboration)

The landlords represent the opposite to the remaining small dairy farms or ranches (F18), whose land management with perennial pastures is not negatively affecting the problematic situation in the study area, but which are usually farming land stripes due to the conditions of soils close to the areas most affected by floods. Because they are often small farms, they are also lacking the economic resources to mitigate the effects of floods. All other agricultural stakeholders are usually affecting the system but do also suffer the consequences of the impacts and are often aware of the feedbacks their actions cause but cannot escape the economic and political forces that drive their management actions.

It is a bit surprising that the basin committees and governmental stakeholder groups are not all categorized as highly affecting the system. This is due to the fact that the three provincial basin committees (A2) as well as the interjurisdictional basin committee (A1) are all lacking adequate control mechanisms to effectively implement strategies or measures and, in addition, suffer from disagreement and tensions between the provincial governments (B4). The national government (B3) whereas has the power to pass laws, but so far shows little interest in solving the problems in a top-down approach and rather devolves the power and responsibilities to the provincial governments, which are not able to agree on a solution approach.

Most local stakeholders that are not involved in the predominant agricultural sector (G19, G20, G21), are not directly affecting the water balance through their actions, but to large extends suffer the consequences of the floods. Every trade-good from Chile, Mendoza or San Luis had to go through the study area to reach Buenos Aires before the Route N°7 was cut-off. Technicians, gas station owners or any other service providers (G21) who offered their services to 3000-4000 trucks each day, toady do not see one single truck passing the village. Besides the loss of land and property, the population of the small villages (G22) surrounding La Picasa are highly affected by the floods because they changed the economic conditions in the area extremely and caused complex socio-economic problems. Some of the villages are cut-off from once neighboring towns, where many inhabitants have friends and relatives. Sleepy villages are suddenly confronted with a vast number of traffic and children who visited the school in the next village are now in a position where they cannot visit the secondary school or must live separated from their families.

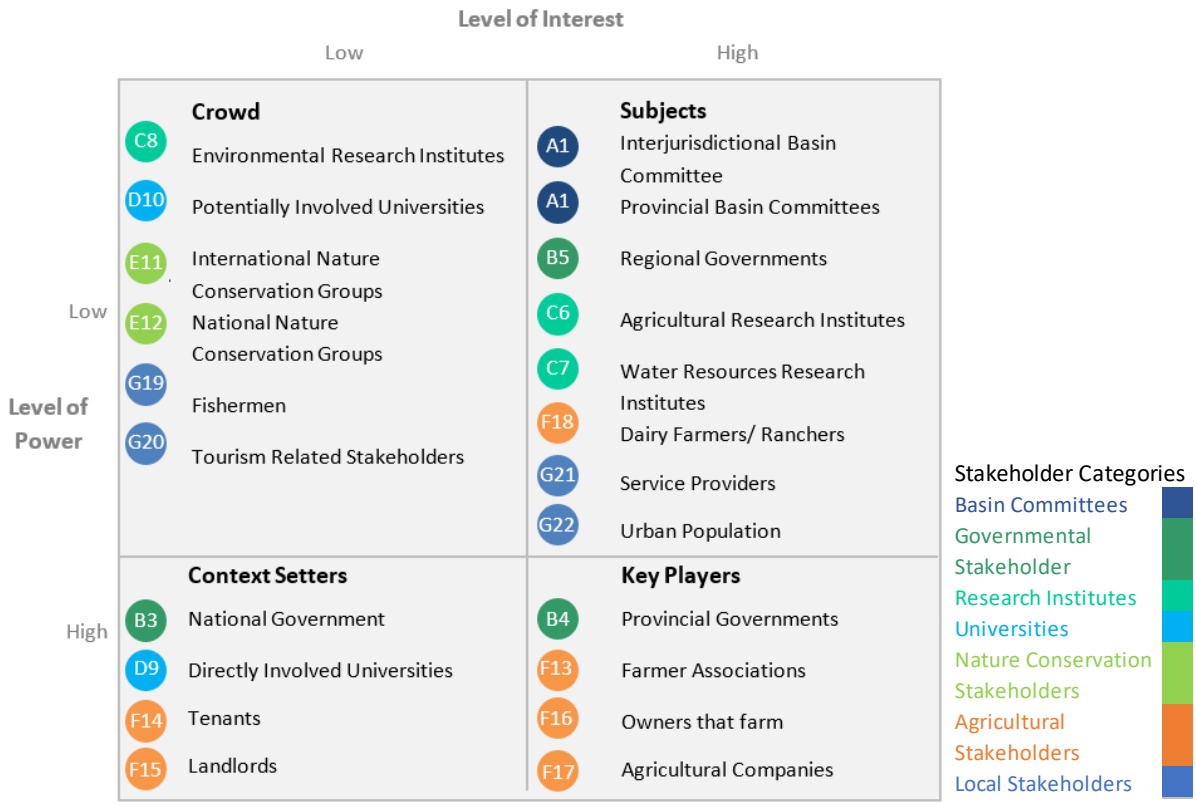


Figure 24: Stakeholder mapping of stakeholders in La Picasa basin (own elaboration)

Meanwhile, stakeholder groups, like fishermen (G19) or stakeholders working with the tourism sector (G20) are barely benefitting from the changes of the system that unintentionally created a wildlife spot. Most of them are former farmers that lost their land and are trying to compensate these

economic losses. However, due to a lack of promotion for tourism in the bigger cities, where potential target groups live, touristic activities in the region are negligible small and do not significantly affect the system today.

Although affecting and affected stakeholder groups got identified, it is also important to know which involved parties have the ability to influence the current socio-ecological situation and this highly depends on their interest in this subject and the power they hold. Hence, another popular method for stakeholder analyses was applied, which uses the power-interest grid of Eden and Ackerman (1998) and slightly adapts it to the natural resources management context. The stakeholder sub-groups got classified into four categories which are called "Key players", "Context setters", "Subjects", and "Crowd" as can be seen in Figure 24. A detailed justification of this categorization can be found in Annex 8.

Stakeholders with a high level of interest and power were classified as "Key players" that should be actively groomed while the ones with a low level of interest and power were classified as the "Crowd" representing little need to consider them in detail. Stakeholders with a high level of power but a low level of interest were classified as "Context setters" and have to be well monitored and managed as they can be significant risk or success factors. Players with a low level of power but a high level of interest were classified as "Subjects" and can be supportive for a project but often lack the capacity for impact, when not forming influential alliances. They are often the marginal stakeholders that development projects seek to empower.

Four key players could be allocated to the 3rd quadrant of the power-interest matrix representing the stakeholder groups with the highest power and interest in a future project about La Picasa basin. They are the ones that are able to influence the future development of the study area and therefore have to be actively groomed, carefully managed, and kept in mind when working on possible solution approaches for floods in the study area.

The four identified key players are the provincial governments (B4), farmer associations (F13), owners that farm their land themselves (F16) and agricultural companies which often are "mega owners" (F17). Due to the fact that the pre-dominant economic activity in the study area is agriculture, it is not surprising that three of the four key players (F13, F16 and F17) belong to the sub-group "agricultural stakeholders". As the current problems were identified to be closely linked to unsustainable agricultural land-use patterns, these three agricultural key players hold a high potential to change the cause of the current problems. The provincial governments (B4) are necessary to set the organizational and legal frame for their future actions and to establish a stable cooperation between the three provinces with agreements on crucial questions regarding the water balance.

In the 2nd quadrant of the power-interest matrix, another four stakeholder sub-groups were positioned as context setters which have a high level of power but a low level of interest and therefore have to be carefully observed and well managed. Since their influence is high, they bare a significant risk to affect the development of a future project about La Picasa basin to a high degree as soon as their interest increases. This also bares an opportunity when influential context setters can be convinced to support a more sustainable development in the study area.

The four context setters identified are the national government (B3), directly involved universities (D9), tenants (F14) and landlords (F15) that do not farm the land themselves but rent it. While the national government could directly shape the future of the La Picasa basin through laws or through legal regulations, universities directly involved in a project could indirectly shape the future of La Picasa basin through setting the main focus of their research and management objectives on more sustainable and holistic approaches. While some agricultural stakeholder groups like owners that farm themselves (F16), farmer associations (F13) and agricultural companies (F17) have a high interest in

avoiding ESS trade-offs because they are directly affected by them, tenants (F14) and landlords (F15) are risk factors in this context as they have a low interest in sustainable management practices and do not suffer the consequences.

A number of eight stakeholder sub-groups were positioned in the 4th quadrant of the power-interest matrix thereby representing the "subjects" who have a high interest in the development of the study area and wish to be well informed. Often "subjects" are marginal stakeholders that development projects seek to empower, and that are able to achieve some influence when building alliances. This case is especially valid for two of the seven stakeholder sub-groups categorized in this quadrant which are the dairy farmers or ranchers (F18) and the service providers (G21) that are not directly working with agriculture. Both are marginal groups that hold the potential to shape a more sustainable future of the study area but lack the power to have an impact today.

The urban population (G22) has a high interest in finding a solution for the flooding problems as they are directly threatened to lose property or suffer socio-economic problems but so far, their voices remain unheard or do not cause significant changes in the system. The interjurisdictional basin committee (A1), the provincial basin committees (A2) and the regional governments are all highly interested in finding solutions for the current problems but still lack the power to implement control mechanisms and to take decisions autonomously. Agricultural and water resources research institutes (C6 and C7) are highly interested in the problem creating processes happening in the study area but can only indirectly shape the future development of the region through investigations and scientific approaches to handle the current problems.

The stakeholder sub-groups which are positioned in the 1st quadrant of the power-interest matrix, are called the "Crowd" as they have a low influence and interest. Although a number of six stakeholder groups could be categorized in this class, they only require minimal effort as they are only marginally interested in the development of the study area and do also influence the current situation to a minimal degree. The stakeholder groups found in this category are almost all related to possible alternative economic activities such as nature conservation for touristic uses including touristic infrastructure, as well as recreational activities like fishing or enjoying wildlife for the local population. While environmental research institutes (C8), international or national nature conservation groups (E11 and E12) could be interested in the area due to its potential for wildlife observations and studies, so far, they are not represented among the current active stakeholders.

Nevertheless, arousing these stakeholder group's interest could represent an opportunity as it could create a demand for touristic infrastructure and create another economic sector in the area. Such a development would also lift the low interest and power of fisherman (G19) and stakeholders working with the tourism sector (G20). It could also create an interest for other universities (D10) that are not involved in the solution-finding process so far, to participate in a future project and support more sustainable management approaches. Nevertheless, today these groups represent only marginal stakeholders whose management requires only minimum effort.

6.3.3 Stakeholder Dynamics

The identified involved parties are currently organized in an existing network which is highly interconnected among the stakeholder groups as can be seen in Figure 25, in which orange lines indicate nodes between stakeholders that are defined by personal recommendations of experts, existing working contacts, or already implemented cooperations. All stakeholder groups are interconnected with each other and not one stands isolated from the others. Personal contacts between representatives of the stakeholder institutions exist, which can represent a meaningful resource and input for a future project about La Picasa basin.

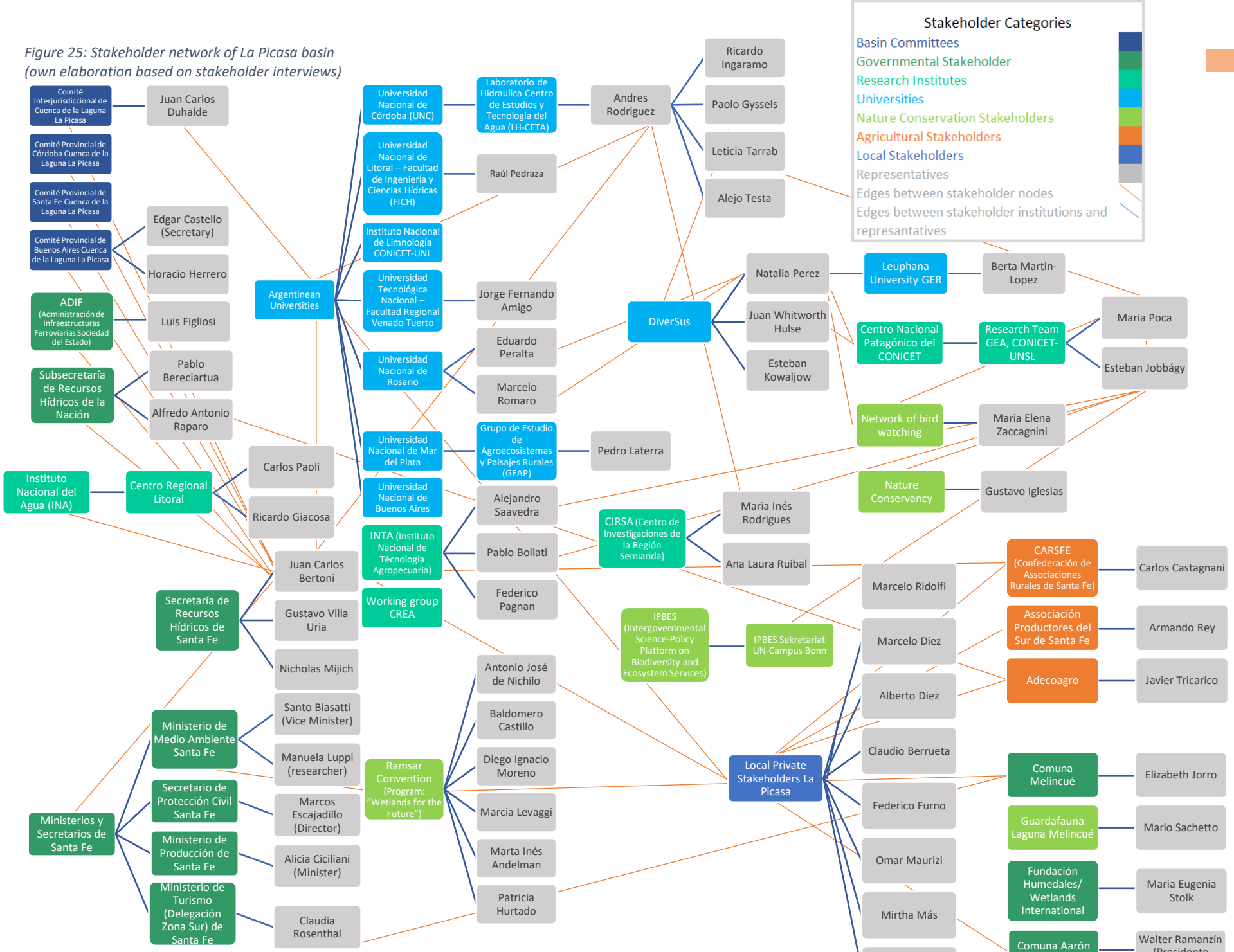
It is also beneficial that many governmental and scientific stakeholders are involved in the stakeholder network, because they can be included in executing a future project work. Unfortunately, the three provinces in charge are facing many conflicts due to fundamental disagreements about possible solution approaches and a lack of inter-provincial cooperation and support. This is also one of the major reasons why the interjurisdictional basin committee fails in establishing a sustainable framework for the use of water in the La Picasa basin. One representative from the hydrological secretary of Santa Fe, Juan Carlos Bertoni, is standing out due to his high degree of interconnection within the existing network of stakeholders. He can be a crucial partner for a future project about La Picasa basin and is professionally able and personally very interested in starting a work on potential solution approaches.

The dominant stakeholder group in the region consisting of agricultural actors, is well organized and connected among themselves and has good relations with governmental institutions as the Argentinean economy is depending on agricultural production, but has a tremendous lack of connections with other sectors. This creates a unilateral perspective on the current problems due to a limited consideration of solution approaches. Nevertheless, the agricultural stakeholders have an organizational infrastructure and represent important stakeholders for a future project.

The urban population in the affected villages of the study area is adversely affected by this imbalance of representation of interests. Their concerns and experiences are not heard although, in comparison to the agricultural sector, they are threatened to not only lose productive land but all their property and live subsistence. These local stakeholders must carry the biggest burden of consequences caused by the floods. Because they are highly affected and suffer from the complex socio-economic-ecological problem, they could also be the ones who are interested in forming alliances to be able to change common management practices in the region. Nature conservation stakeholders are currently not well-included in the discussion of alternatives for the problems in the study area. In fact, more ecological future scenarios are often perceived as risky because they decrease the ability to control flood events through infrastructural measures. Since no importance is given to the preservation of natural habitats which also represent recreational areas in many cases, most stakeholders related to a touristic use of the region are neglected as well.

It can be concluded that the only well-represented interest group within the current process of solution-findings is the agricultural stakeholder group, because they are already well-organized internally and are represented by alliances, associations and committees, while, due to the lack of an existing network structure, all other affected stakeholders remain unheard, are excluded from the process or lack the power to stand in for their perspectives and make their positions clear.

Figure 25: Stakeholder network of La Picasa basin (own elaboration based on stakeholder interviews)



6.4 Sustainable future Land-Use and Management Approaches

Throughout history, water and the production of food have been closely linked and water is recognized as a key driver of several provisioning, regulating and supporting ESS (García *et al.*, 2017). However, in the Pampas annual crops have displaces cultivated pastures and native grasslands (Viglizzo and Frank, 2006; Baldi and Paruelo, 2008) and the reciprocal influences of land-use and related environmental hazards such as floods, have hindered a harmonic combination between ecosystem conservation, human well-being and efficient farming in this highly productive region (Nosetto *et al.*, 2009, 2012; Viglizzo *et al.*, 2009; Kuppel *et al.*, 2015). As the agricultural use of these arable lands is expected to further intensify in response to global food demand and trade (Kuppel *et al.*, 2015), the understanding of linkages between agroecosystems, water cycles and the production of food is important for the health of the SES in La Picasa basin (Kuppel *et al.*, 2015; García *et al.*, 2017).

Sustainable future land-use and basin management approaches should therefore be based on a sound understanding of the systemic functioning of La Picasa basin. It is of major importance to understand how the occurring problems in the study area are interrelated and how they affect, accelerate or mitigate each other to develop careful land management strategies. Without adequate knowledge and understanding, undesirable trade-offs could occur, opportunities in optimizing synergies could be missed and dramatic or unintended changes in the provision of ESS could be experienced (Bennett, Peterson and Gordon, 2009).

Management and policy instruments applied in future projects should be addressed to specific feedback loops of the system to be effective. Only when the systemic feedback loops of ESS and their trade-offs are taken into consideration in future management approaches, nature-based solutions can be a realistic alternative for pure infrastructural projects. The results from the following analysis reveal valuable information on feedback loops, ESS and the predominant feedbacks that determine human well-being in the study area.

6.4.1 Identified Problems and related ESS

The analysis of the historic development of the SES in La Picasa basin and the correlation between extraordinary events, precipitation cycles and land-use schemes already allowed drawing first assumptions on the determining feedback loops between ESS trade-offs that are responsible for switching the equilibrium of the system from one into another state (compare chapter 6.2 Distinct Equilibrium States of the SES). The following results are the outcome of a more in-depth analysis of feedback loops between ESS and related trade-offs. With the help of knowledge input from local stakeholders, the assumptions derived from the previous analysis of the historic development of the SES in La Picasa basin could be further fortified.

The problems identified through stakeholder interviews are corresponding to the results of the study conducted by Rosenstein et al. (2009). Corresponding to their findings, a clear majority of interviewees mentioned floods as the fundamental problem of the recent years and relates them to exceptional economic losses and an associated unprecedented social crisis because communities around La Picasa lagoon highly depend on the income generated by the agricultural sector.

Also, in accordance with Rosenstein et al. (2009), the absence of a collective project and solution approach is seen as reflecting a general disorganization among responsible stakeholders associated with the inability of institutions and political organs at different levels (municipal, provincial and national) to negotiate agreements. The lack of stakeholder participation in the solution-finding process got linked to a common feeling of impotence expressed through a “Why participating if it is impossible to reach an agreement”- thinking and does, almost 10 years after the study of Rosenstein et al. (2009), still withstand in an unrestricted way.

The second priority theme is the agricultural production model which depends on the cultivation of soybean and is not only related to monocultures and ungracious conditions for the local biodiversity, but also to unemployment because the current model requires a low labor input. Despite these strongly negative attributes, changing the agricultural model remains unabated since, today as it was in 2009, the communities of La Picasa basin live on soy (Rosenstein *et al.*, 2009). The lack of industrialization that is also related to the absence of a collective future development project for the region, is associated with the lack of commitment from stakeholder groups and their incapacity to create better living-conditions.

The third priority issue identified in the study area is that of infrastructure, which was and still is highly affected by the effects of floods. Most stakeholders perceive the loss of critical infrastructure, such as the Route N°7 and the road and railway network in general, as disastrous. They cannot understand that political decision-makers seem to neglect and abandon the problems in La Picasa basin, while the cutting-off of major transportation roads such as Route N°7 have grave consequences for the now isolated communities around the principal lagoon.

Problems mentioned by stakeholders are manifold and interwoven in a complex manner, but in compliance with Rosenstein et al. (2009), the three major problems of the study area can still be defined as 1) floods, 2) an inadequate production model, and 3) the loss of critical infrastructure. Although most interviewees state climatic causes as part of the fundamental problem of floods, a general consensus in the belief that the occurring disasters are not exclusively a result of nature but rather are related to anthropogenic mismanagement and impacts was found (Interview 1, Villa Uria (2018); Interview 2, Raparo (2018); Interview 3, Ramanzín (2018); Interview 4, Diez (2018); Interview 5-7, Milardovich & Castagnani (2018); Interview 10-15, Duhalde, Más & Rey (2018); Interview 16-18, Poca & Jobbágy (2018); Interview 19, Bertoni (2018), see Annex 5).

By linking the set of problems which was identified by local stakeholders (compare a detailed justification in Annex 9) with the concept of ESS, allows a closer evaluation of relevant ESS trade-offs and feedback loops. The hydrological regulation function of natural wet- and diverse grasslands was previously assumed to be a crucial ESS for keeping the SES of the study area in a stable state, thereby enabling human well-being. It was thought to be heavily dependent on a biodiverse mixture of species, which support these essential functions with many small-scale feedback loops within the bigger and more obvious balancing of water masses.

Linking the mentioned problems perceived by local stakeholders with ESS revealed three major ESS trade-offs that are consistent with the previous assumptions made (see Table 7). The first trade-off occurs between two provisioning ESS and mainly refers to the historic replacement of cattle production systems along with vast pasture lands by the current monocultural production of agricultural crops. Stakeholders are aware that this land-use change had an impact on the hydrological cycle of the study area and know about the advantages that a more diverse agricultural production system holds (Interview 1, Villa Uria (2018); Interview 19, Bertoni (2018), see Annex 5).

The second trade-off appears between provisioning ESS and regulating ESS. The intensive production of crops had had an immense impact on the water balance of the system and the local stakeholders interviewed were aware of the reduced evapotranspiration capacity of the predominant crops and its impact on the hydrological regulation and flood protection services that ecosystems provides (Interview 1, Villa Uria (2018); Interview 2, Raparo (2018); Interview 5-7, Milardovich (2018); Interview 10-15, Furno, Más & Rey (2018), see Annex 5). The third trade-off was identified between provisioning and supporting ESS and refers to the negative relation between the expansion of agricultural land at the expense of habitat quality and biodiversity. Although the direct trade-off between agricultural production and the loss of habitats and biodiversity is not perceived as directly negatively affecting

human well-being, people are aware that intact habitats are the basis for a diverse composition of species that are well-adapted to a range of climatic conditions and even have the capability to continue evapotranspiration in water-logged conditions (Interview 1, Villa Uria (2018); Interview 3, Ramanzín (2018); Interview 4, Diez (2018); Interview 16-18, Jobbágy (2018); Interview 19, Bertoni (2018) see Annex 5.

Table 7: Identified trade-offs between ESS in La Picasa basin (own elaboration)

Trade-Offs between ESS	Provisioning vs. Provisioning ESS	Provisioning vs. Regulating ESS	Provisioning vs. Supporting ESS
Increase of ESS causes Decrease of ESS	Production of Agricultural Crops vs. Cattle Production (Pasture Lands)	Production of Agricultural Crops vs. Water regulation (Flood Protection)	Production of Agricultural Crops vs. Habitat Quality (Biodiversity)

Once the identified problems were related to ESS trade-offs, it became obvious that many problems are indirectly or directly created, accelerated or mitigated through others. In other words, feedback loops between the identified problems and their contribution to the three above mentioned ESS trade-offs exist and require further examination. Therefore, the existing feedback loops were visualized as can be seen in Figure 26 considering both the mentioned problems and related ESS and trade-offs.

6.4.2 Feedback Loops between Identified Problems

In the current situation in La Picasa basin, all feedback loops between identified problems (in the illustration represented through grey arrows) were detected to be positive feedback loops and therefore indicate that an intensification of one problem causes all other problems that are related to this specific problem, to perceive an augmentation, too (Allaby, 1994 as cited in Sundkvist, Milestad and Jansson, 2005). The general logic behind the illustration works from bottom up and starts with the two problems that were mentioned from many interviewees as being the major causes for the current problem situation in La Picasa basin. The first one is the increase in annual average precipitation rates, while the second one refers to the intensive agricultural production that leaves its characteristic mark upon the region. Both are highly affected by uncontrollable external factors.

While the increase in annual average precipitation rates since 1970 caused by a westward displacement of isohyets is widely recognized (Viglizzo *et al.*, 1995; Aradas and Thorne, 2001; Viglizzo and Frank, 2006; Venencio and García, 2011; Brandolin, Ávalos and De Angelo, 2012; Pereira *et al.*, 2014), it is only a general assumption that this phenomenon is driven by the miscellaneous effects of global climate change. This assumption is supported by the fact that observed trends in precipitation fields represent an important component of the global circulation system, which changed its position in a statistically provable manner during the last 35 years (Barros, Castañeda and Doyle, 2000).

Photograph 8: Flooded private land and property in La Picasa lagoon (Wiedemeier, 2018)

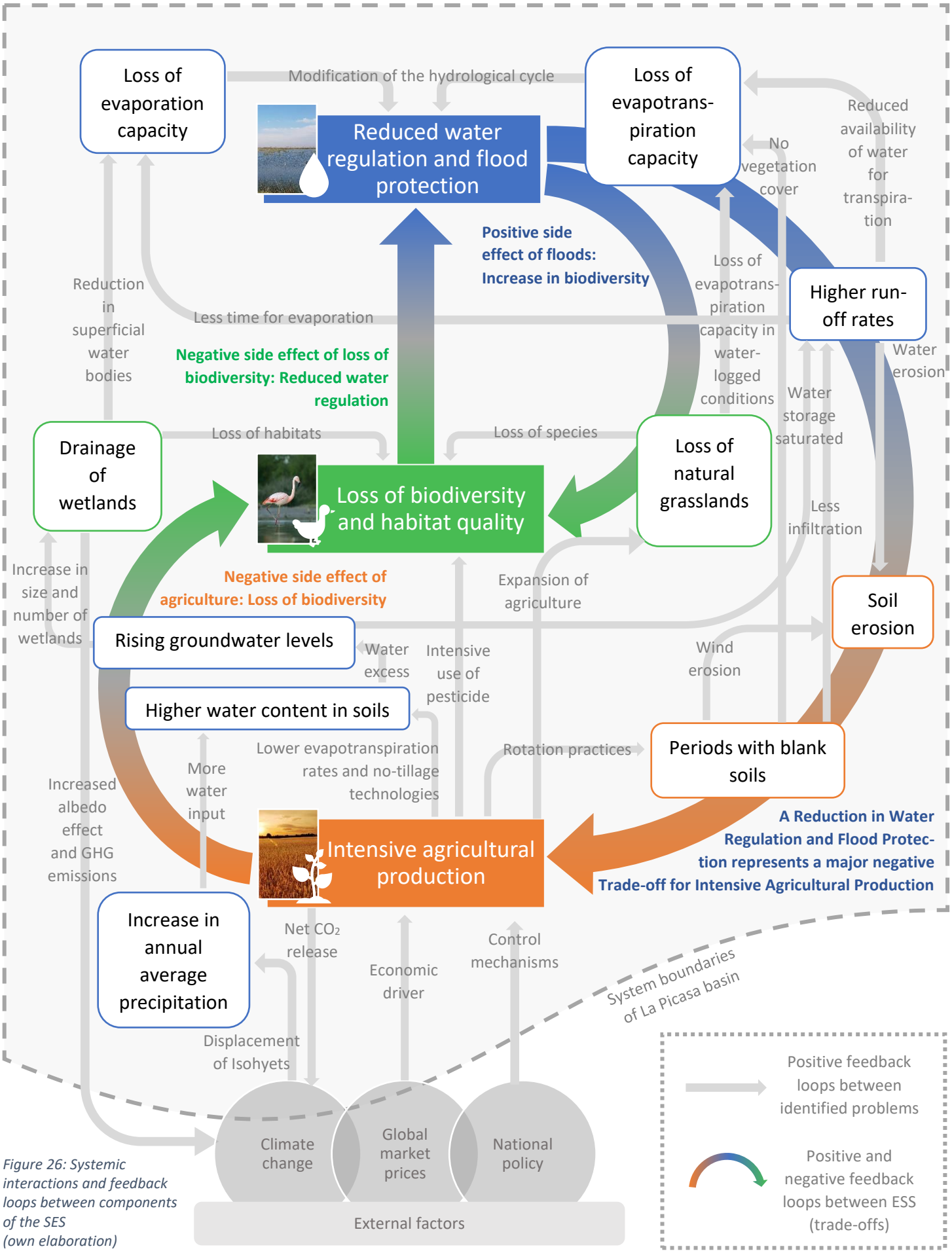


Figure 26: Systemic interactions and feedback loops between components of the SES (own elaboration)

For more than a century, the study area got transformed from wide natural grasslands with little human intervention (Viglizzo *et al.*, 2001) to livestock production systems that were initially based on natural grasslands and later on an incorporation of alfalfa pastures (Nosetto *et al.*, 2015). The current agricultural production system, which came with a widespread replacement of livestock systems by grain production systems (Nosetto *et al.*, 2015) at the same time came at the expense of natural grasslands (Bernardos *et al.*, 2001; Viglizzo *et al.*, 2001; Baldi and Paruelo, 2008; Brandolin, Ávalos and De Angelo, 2012).

This change in the productive model was highly affected by external factors such as global market prices and national policy, because it was motivated principally by the existence of an avid external market, the low profitability of the beef industry and a related retraction in cattle exports and high grain prices (Gutierrez, 1997; Viglizzo *et al.*, 2009). In addition, the promotional national policies, which fostered the incorporation of soybean and the promotion of this crop by transnational enterprises, which offered the whole technological package, drove the comparably higher rentability of crops to any other agricultural activity (Gutierrez, 1997). Today, only few main crops, such as soybeans, wheat and maize account for most of the planted surface and production in the study area (Hall et al. 1992 as cited in Solbrig 1997).

This development was supported by no-tillage technologies coupled to an increase in the use of pesticide packages (Bernardos *et al.*, 2001). With the change in tillage technologies, the number of tillage operations per fallow period decreased, and the amount of crop residue remaining on the soil surface increased (Bernardos *et al.*, 2001). Furthermore, the no-tillage technology is also able to conserve humidity in the soils (HGCA, 2012). No-tillage technologies were also related to the development of platy structures on soil surfaces in the Pampas (Sasal *et al.*, 2016). These platy structures alter drainage patterns, water infiltration into the soil and surface run-off rates (Sasal *et al.*, 2016).

It is common practice in the study area that soybean, wheat and maize get combined in rotation cycles with two cultivation periods throughout a year (Bollatti, 2014). These rotation practices are widely accepted to have a crucial influence on the hydrological cycle of the basin, because the summed up annual water consume and related evapotranspiration of most rotation options is below the mean annual precipitation of 900mm (Pedraza, 2000; Bollatti, 2014). In addition, pesticide packages cause long periods of blank fields with no living vegetation cover that further diminishes the annual evapotranspiration rates and in addition leads to an increase in pesticide contamination risk and loss of species and habitats (Viglizzo *et al.*, 2010).

Several interview partners connected the absence of vegetation on blank fields with increases run-off rates which, from their experience, result from the compaction of blank soils which creates an impermeable layer and lowers the infiltration of water into the soil (Interview 1, Villa Uria (2018), see Annex 5). This can be explained with the fact that under the cover of vegetation, the accumulation of organic matter and the moderation of a soil microclimate favor microbial activity and the creation of water stable soil aggregates (Li, Li and Lu, 2004). Therefore, it can be said that a vegetation cover favors factors that improve infiltration rates (Li, Li and Lu, 2004). A number of studies demonstrated that especially grasses can have a reducing effect on run-off and erosion and that perennial plants are generally more effective than annual plants (Pressland, 1982; Eldridge, 1992; Eldridge, 1993 as cited in Li, Li and Lu, 2004). Blank soils consequently also foster higher run-off rates, which again cause water erosion of fertile soils. Due to the soil being exposed to an increased volatilization through the changed surface environment, also wind erosion of highly fertile soils takes place (Swift, Izac and Van Noordwijk, 2004).

Many studies relate groundwater dynamics of the Pampas with surface water behavior (Aradas and Thorne, 2001; Nosetto *et al.*, 2009, 2015; Jobbágy, 2011; Kuppel *et al.*, 2015; Mercau *et al.*, 2015). As previously discussed, the current predominant land-use scheme of the region leads to higher water contents in soils and the water excess results in rising groundwater levels (Nosetto *et al.*, 2015; Interview 10-15, Rey (2018), see Annex 5) As soils are saturated with water, it is assumed that less water infiltrates and surface run-off rates increase. A number of interviewees mentioned that after precipitation events, the water reaches the principal lagoon La Picasa significantly faster than before and this can partly be explained by the connection between groundwater dynamics and surface water dynamics (Interview 10-15, Rey & Más (2018), see Annex 5). Nevertheless, leading ecohydrological experts in the region mentioned that little knowledge exists about the effects that determine run-off rates in the study area (Interview 16-18, Jobbágy (2018), see Annex 5).

Photograph 9: Artificial drainage canal in La Picasa basin (Wiedemeier, 2018)

Another major problem that the region faces and that was identified in many interviews, are artificial drainage canals that were constructed in vast flooded regions, including critical areas for the conservation of biodiversity as a response to rising groundwater levels, when an increase in precipitation in the mid-1970s enlarged the area occupied by wetlands (Brandolin, Ávalos and De Angelo, 2012). Besides the mitigation of floods, the channelization in Córdoba also favored further agricultural expansion at the expense of wetlands, thereby destroying wildlife refuges and biodiversity (Brandolin, Ávalos and De Angelo, 2012).

The rapid and widespread losses of freshwater marshes in the study area took place in a relatively short period of time (Booman *et al.*, 2012; Brandolin, Ávalos and De Angelo, 2012; Sica *et al.*, 2016) and have direct effects on the water cycle of the La Picasa basin, because they caused a reduction in the area of superficial water bodies. The surface of all small lagoons of the basin together is ten times bigger than the surface of the La Picasa lagoon (Interview 1, Villa Uria (2018), see Annex 5). Because the water balance in the study area is dominated by the vertical components precipitation, evapotranspiration and evaporation, (Aradas and Thorne, 2001) the motor which takes out the water from the system is the sun. The bigger the water surface, the more water leaves the system. Having all the water in one spot with less surface results in less water leaving the system (Interview 1, Villa Uria (2018); Interview 19, Bertoni (2018) see Annex 5).

The accumulation of water masses in the principal lagoon La Picasa is even accelerated by higher run-off rates because they diminish the time water needs to end up in the principal lagoon La Picasa after a precipitation event and thereby also reduces the evaporation of water while it transits the basin. Higher run-off rates also cause a reduced availability of water in soils that plants can use for transpiration and therefore affect both the evaporation and evapotranspiration factor of the basin's water balance. The loss of wetlands, in addition, had and still has an effect on important factors that are recognized to drive climate change. One of these factors is the land surface albedo and the area around La Picasa basin was identified to account for up to 16% of large albedo increases in South America (Loarie *et al.*, 2011). In comparison, the famous example of deforestation of the Amazon

including northern forested regions of the Cerrado only account for 17% of large albedo increases (Loarie *et al.*, 2011). The pure loss of wetlands was responsible for 7% of albedo increases (Loarie *et al.*, 2011).

Another factor driving climate change is the emission of greenhouse gases (GHG). Wetlands are widely known to store huge amounts of carbon dioxide (CO_2), although estimations show extreme variations (Mitra, Wassmann and Vlek, 2003). The drainage of wetlands together with agricultural expansion in the study area resulted in the emission of GHG (Viglizzo *et al.*, 2010).

Photograph 10: Wetland with local flora and fauna in the study area (Wiedemeier, 2018)

In the interplay between the loss of grasslands due to agricultural expansion and the drainage of wetlands, many habitats got degraded and species got lost (Interview 4, Diez (2018), see Annex 5). Besides the fact that freshwater wetlands, provide a home to >40% of the world's species and are therefore of vital importance to fight the loss of biodiversity on a global, regional and local scale (Mitra, Wassmann and Vlek, 2003), the loss of a biodiverse landscape also has direct effects on the water balance of La Picasa basin. Natural grasslands are composed of many different species and perfectly adapted to the hydrological characteristics of the study area. While agricultural crops stop consuming water when they get flooded, natural grasslands hold the capacity to continue evapotranspiration in water-logged conditions (Interview 16-18, Jobbágy (2018), see Annex 5).

In the end, all the described feedback mechanisms that start with the intensification of the agricultural production model, result in a loss of biodiversity and a massive anthropogenic modification of the natural hydrological cycle. The floods occurring in La Picasa basin are a result of these feedback loops and are driven by a reduction in the water regulation and flood protection ESS. These results are important to consider, because regulating ESS are critical for coping with and recovering from disasters (Renaud, Sudmeier-Rieux and Estrella, 2015) and supporting services can assist in the recovery process from a disaster (Monty, Murti and Furuta, 2016).

6.4.3 Feedback Loops between ESS and Trade-offs

Management decisions can create ESS trade-offs, which might change the type, magnitude and relative mix of services provided by ecosystems (Rodríguez *et al.*, 2006). Unfortunately, these trade-offs are not always apparent, and decision makers unknowingly may make decisions that diminish the value of some services while enhancing the value of others (Jessop *et al.*, 2015). It is recognized that trade-offs among ecological functions and services may be more common than expected, and that they may discourage “one size fits all” solution approaches (Viglizzo *et al.*, 2011). Nevertheless, the Ramsar

Convention (1971), the Convention on Biological Diversity (1993) and the Paris Agreement (2016), as well as global policy frameworks such as the Sendai Framework on Disaster Risk Reduction (2015) and the Sustainable Development Goals (2015), clearly recognize that nature-based solutions for reducing disaster risk are vital for a sustainable and secure world (Kumar *et al.*, 2017).

Since the provision of some services can be accompanied by the emergence of unexpected dis-services, effective management strategies to inverse trade-offs between ESS must analyze a myriad of potential tradeoffs (Viglizzo *et al.*, 2011). Therefore, restoration practitioners should prioritize services based on needs and opportunities given at local and watershed contexts (Jessop *et al.*, 2015).

When the three major ESS and their relations with each other get extracted from the overall feedback loops between identified problems, the occurring trade-offs between ESS in the study area crystallize out of many interrelations (compare Figure 27) and set a frame for prioritizing meaningful management strategies for La Picasa basin.

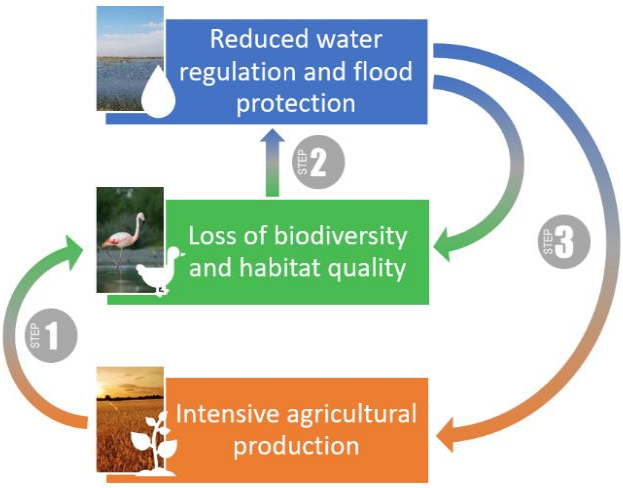


Figure 27: Feedback loops between ESS and trade-offs (own elaboration)

The general logic behind those ESS trade-offs, starts with the anthropogenic intensification of the provisioning ESS 'agricultural production'. The previously described feedback loops between related problems indicated that the increase in provisioning ESS leads to a decrease in the supporting ESS 'habitat quality' that is closely related to biodiversity. Nevertheless, for the stakeholders of the region, the loss of biodiversity is not perceived as a perdition that directly affects human-well-being.

Although people are aware that a lack of green infrastructure, such as functioning wet- and grasslands, influences the ESS 'hydrological regulation', which apparently is directly related to the major problem of the study area, they perceive the loss of biodiversity as a negative, but unavoidable side effect of intensive agricultural production rather than a cause of the present floods. The reduced capacity to provide the regulating ESS 'water regulation and flood protection', in contrast, is perceived as the determining factor for the complex socio-economic problem in the study region today.

Even though natural grass- and wetlands have highly been modified and affected by human intervention in the study area (Brandolin, Ávalos and De Angelo, 2012; Sica *et al.*, 2016), it is assumed that their ecosystems can be restored to provide a full suite of services (Jessop *et al.*, 2015) which are recognized by a broad number of authors to increase the proper functioning of the crucial ESS 'hydrological regulation' (Bullock and Acreman, 2003; Simonit, Cattaneo and Perrings, 2005; Zedler and Kercher, 2005; Malekmohammadi and Jahanishakib, 2017; Odgaard *et al.*, 2017). Especially wetlands provide many ESS such as water quality maintenance, carbon storage, flood abatement, and biodiversity support (Jessop *et al.*, 2015) that could benefit the study area. They are also the reason why the conservation and wise use of wetlands is increasingly acknowledged to be part of nature-based solution approaches reducing disaster risk (Kumar *et al.*, 2017). These Eco-DRR approaches involve the sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim of achieving a sustainable development and resilient community (Kumar *et al.*, 2017).

Unfortunately, the lacking consideration of manifold interrelations between all three ESS leads to a poor and incomplete understanding of the systemic functioning in the study area and, consequently,

current solution approaches are predominantly based on grey infrastructure like pumping stations, canals and water exits. At the moment, the key aspects of this approach are construction works focusing on three major focal points: The South Alternative water exit, connecting La Picasa lagoon through various pumping stations, canals and natural lagoons with the Salado river in Buenos Aires province, the North Alternative water exit following the same principle connecting the La Picasa lagoon with the Salado river but within the provincial boarders of Santa Fe and internal construction works focusing on the maintenance of pumping stations and canals and the finalization of reservoirs. Because Buenos Aires is only allowing to discharge a limited amount of water via the Salado river and, so far no agreement could be found to negotiate a higher allowed discharge amount, in a future project Santa Fe province will work on another option that aims at pumping water with canals to the Paraná river in approximately 250 km distance and overcoming several height meters. Although from a technical point of view this option is irrational and also costly from an economic point of view, the conflict between the three involved provinces makes this additional and more independent option necessary.

Against this background nature-based solution approaches seem to have a high potential to provide an entirely distinct perspective on the topic, thereby opening new possibilities of removing water from the system.

6.5 Management Needs

6.5.1 Identified Management Needs and potential Management Strategies to inverse Trade-offs between ESS

All interviewees mentioned 'management needs' that they consider relevant to find a solution for the problems that the study area faces (compare a detailed justification for the identification of problems, ESS trade-offs and management needs in Annex 9). The previously done analysis of ESS trade-offs and existing feedback loops, offers an adequate starting point, to prioritize management strategies according to the identified existing ESS trade-offs. Consequently, after a first review, the management needs that stakeholders expressed, were coupled with the identified ESS trade-offs as presented in in Figure 28.

It is an interesting result that even though infrastructure-based solutions are predominantly applied in the study area, interviewed stakeholders expressed the need for a vast number of nature-based solution approaches. They linked them to socio-economic and management requirements that must be fulfilled to create an enabling frame for these Eco-DRR approaches. When suggesting nature-based solutions, stakeholders particularly refered to the ESS trade-offs between an intensified agricultural production and its direct effects on habitat quality and biodiversity, as well as its indirect effects on hydrological regulation.

For trade-offs between the provisioning and supporting ESS (compare Step 1 in Figure 27) local stakeholders expressed the need for a more sustainable production model in the region that includes a diversification of the current land-use scheme, a strengthening of the dairy sector and a related creation of a market for alfalfa pastures. They also mentioned that soil covers with living crops throughout the year and an adaption of the rotation of crops to climatic conditions could help nature to provide the necessary ESS. PES could enable farmers to provide areas for the creation of ESS without facing a financial loss.

Athough these measures would indirectly foster an improvement in habitat quality and biodiversity of the study area, it becomes clear again that the primary focus of stakeholders and scientific research lies on the regulating ESS 'flood protection' while the protection of biodiversity is a necessary side-effect instead of a main objective. Accordingly most management needs mentioned in relation to the trade-off between provisioning and supporting ESS, indirectly also aim at improving the regulating ESS. For example, the strengthening of the dairy sector based on pastures like alfalfa, would benefit the

habitat quality and biodiversity of the region, because the land-use becomes more diverse, but primarily, it is known to increase evapotranspiration rates and therefore affect the water balance of La Picasa basin.

Hence, all mentioned nature-based management approaches have the primary objective to reduce the risk of occurring floods and can therefore be categorized as disaster risk reduction (DRR) measures. Management strategies suggested for facing the trade-off between supporting and regulating ESS (compare Step 2 in Figure 27) were related to a higher water consumption through natural components of the system. Fostering higher evapotranspiration rates through the restoration of wetlands that create water storages and the creation of nature protection areas and buffer zones were mentioned, as well as bio-drainage options related to the introduction of deep-rooting plants that drain the water levels in the soils down or even are able to make use of the groundwater aquifers.

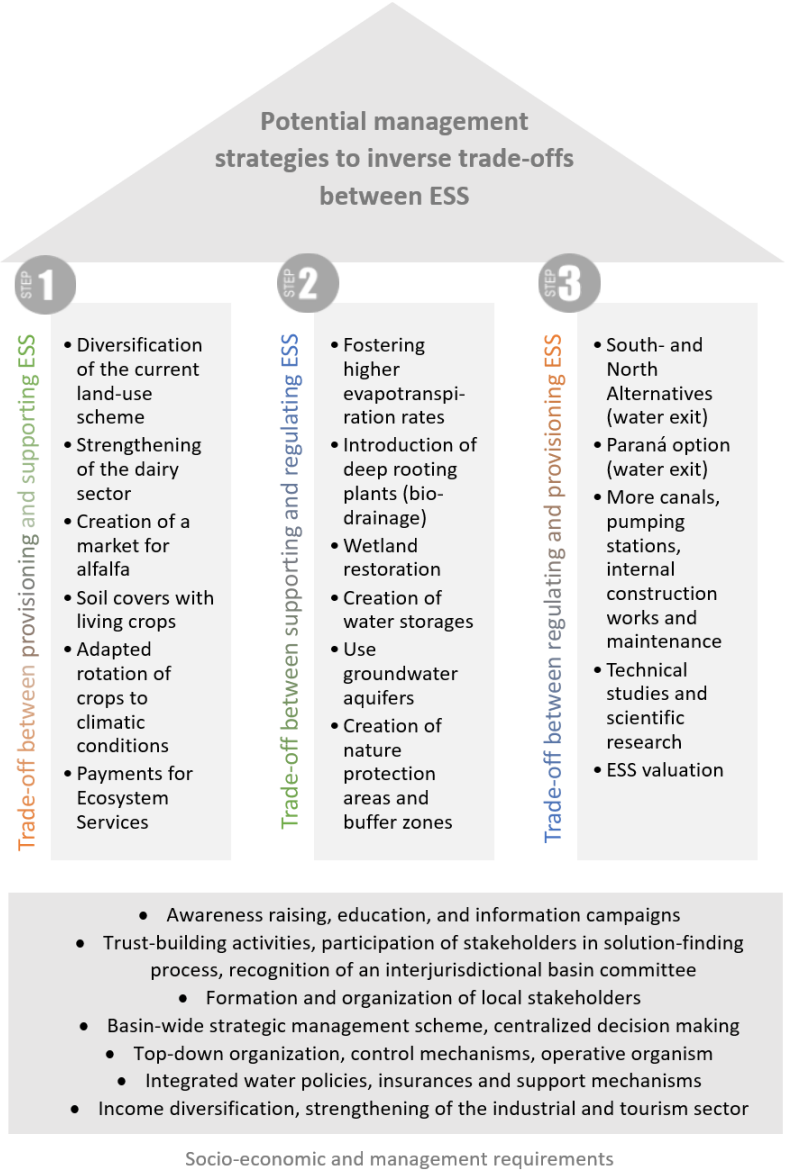


Figure 28: Potential management strategies to inverse trade-offs between ESS (own elaboration)

Various scientific authors have investigated in research fields, overlapping with the management strategies mentioned by stakeholders. Many studies suggest crop rotation systems at farm and landscape scales to increase the consumption of water in agricultural production systems, thereby increasing the ESS 'hydrological regulation' (Caviglia, Sadras and Andrade, 2010; Nosetto *et al.*, 2012). Especially intercropping has been proposed on a farm scale, referring to the use of multiple crops to extend the evapotranspiration period and increase water consumption (Caviglia, Sadras and Andrade, 2010; Monzon *et al.*, 2014). However, due to the reduced evapotranspiration in the transition between summer and winter crops, crop-rotation is considered to only have secondary effects on intra-annual water table fluctuations and therefore provides only limited possibilities for long-term solutions (Mercau *et al.*, 2015). To control groundwater levels on a landscape scale, a basin-wide land-use decision making has been recommended that would allow a heterogenous land-use through implementing a rotation system for the overall soybean land-cover combined with "pasture islands" (García *et al.*, 2017).

Also the transformation of the current farming system to other economic activities that integrate an ESS perspective to the production system have been subject of various scientific investigations. As a part of silvo-pastural systems combining forest species with cattle ranching, the coupling of the ESS 'hydrological regulation' and 'agricultural production' has been suggested in in areas of recharge and transit to local groundwater flows (Alconada Magliano *et al.*, 2009). The use of perrennial crops for pastures in dairy farming systems was recognized to be an effective measure to lower water table levels, because the deep root system of these crops allows to drain up water from greater depths (Nosetto *et al.*, 2015).

Although wetlands and their ESS providing hydrological regulation have received considerable attention from the scientific community (Bullock and Acreman, 2003; Monty, Murti and Furuta, 2016; Kumar *et al.*, 2017), still little evidence exists about the role of wetlands in flood control or groundwater recharge reduction (Maltby and Acreman, 2011). Although wetlands in the Pampas ecoregion have been recognized to be an important natural discharge system, functioning as a network of interconnected shallow marshes, most literature has focussed on wetlands' impacts on the ESS 'habitat quality' related to biodiversity rather than 'hydrological regulation' (Brandolin and Ávalos, 2012; Brandolin, Ávalos and De Angelo, 2012).

The use of native vegetation as natural water pumps is called "bio-drainage" and has been subject of a number of scientific works. Ecosystems consisting of native vegetation can have a controlling effect on the depth of water tables and related floods due to enhanced evapotranspiration in comparison to annual crops (Viglizzo, Frank and Carreño, 2006; Alconada Magliano *et al.*, 2009; Viglizzo *et al.*, 2009). Especially the definiton of different land-use zones, such as conservation zones for native grasslands providing hydrological regulation to reduce groundwater flooding risk, has been pointed out a lot in this context (Barral and Oscar, 2011).

Many scientist reviewed the bio-drainage capability of afforestations in flood-prone areas (mainly with Eucalyptus sp.) as a strategy to lower groundwater levels and surface runoff (Engel *et al.*, 2005; Farley, Jobbágy and Jackson, 2005). Especially the high evapotranspiration rates of tree-plantations in comparison with grasslands or crops (Nosetto *et al.*, 2012) made this option attractive. The mechanism that leads to a reduction of groundwater levels is a hydraulic gradient between the groundwater, the vadose zone moisture from surrounding grasslands or crop areas, and the area of tree plantations, which is created by the trees' higher capacity to consume water when the balance is becoming more positive (Engel *et al.*, 2005; Nosetto, Jobbágy and Paruelo, 2005).

Due to its capability to remove water excess through an increased drainage, especially in lowlands, afforestation was identified to be a suitable strategy for flood control (Díaz and Querner, 2005). Nevertheless, other scientfic works have also revealed undesirable trade-offs of bio-drainage approaches using afforestation. The increased drainage of water does not only alter the water balance, but also affects soluble salt fluxes and can lead to a salinization process in the surrounding of root-systems, thereby excluding fresh groundwater solutes (Jobbágy and Jackson, 2004). Moreover, in the characteristic recurring cycles of droughts and floods, the limited water availability caused through afforestation could be a major disadvantage intensifying water shortages in dry periods (Farley, Jobbágy and Jackson, 2005; Alconada Magliano *et al.*, 2009).

While local stakeholders seem to be aware of more nature-based alternatives, they do not see a future basin-wide management plan with a focal point on nature-based strategies as probable (Interview 10-15, Duhalde (2018), see Annex 5). The lack of understanding the study area's SES and relevant ESS, creates uncertainties among local stakeholders about the effectiveness and implementation process of Eco-DRR strategies and poses serious barriers to its adoption in La Picasa basin.

Infrastructure-based solution approaches are perceived as 'safer' alternatives, because they have an immediate effect, once implemented, and can be entirely planned to serve the needs of avoiding future flooding events (Interview 2, Raparo (2018); Interview 5-7, Castagnani & Milardovich (2018); Interview 10-15, Duhalde, Furno, Maurizi & Rey (2018); Interview 19, Bertoni (2018), see Annex 5). Therefore, most stakeholders mentioned infrastructure-based management strategies to overcome the trade-off between regulating and provisioning ESS (compare Step 3 in Figure 27). Especially the functioning of artificial water exits like the South- and North Alternative or the Paraná option were repeatedly discussed as necessary and require more canals, pumping stations, internal construction works and maintenance. Stakeholders expressed the need that this infrastructure should be based on technical and scientific studies which should also consider the evaluation of ESS.

The scientific community agrees that the construction of a network of artificial drainage channels has been prioritized and implemented in the Pampas with the aim to mitigate flood and to increase the size of suitable areas for agriculture (Maldonado, Natenzon and Cóccaro, 2005; Booman *et al.*, 2012; Brandolin and Ávalos, 2012; Brandolin, Ávalos and De Angelo, 2012). This development has been part of a governmental programs to drain extensive areas in southeast Córdoba province (Brandolin and Ávalos, 2012; Brandolin, Ávalos and De Angelo, 2012) and Buenos Aires province (Booman *et al.*, 2012). This channelization process was also related to the construction of numerous illegal canals constructed by private owners (Maldonado, Natenzon and Cóccaro, 2005). Despite the short-term effect of reduced flooded area, scientists agree that, in the long-term, a major drawback of the channelization process has been the loss of the ESS 'hydrological regulation' of endorrheic wetlands due to their direct drainage, which caused a decline in their abundance and size (Booman *et al.*, 2012; Brandolin, Ávalos and De Angelo, 2012).

Currently, the absence of a basin-wide management and control authority, together with the conflicts between the three involved provinces, sets a major limitation to any basin-wide management strategy, but is especially required for all nature-based strategies that have to come along with a strong planification among the players (Interview 19, Bertoni (2018), see Annex 5). Consequently, most stakeholders named a number of socio-economic or managerial requirements that are necessary to set a frame for a sustainable basin-wide management. They mentioned awareness, education and information campaigns, trust building activities and the participation of stakeholders in solution-finding process. In addition, they commented on the necessity of a legal recognition of the interjurisdictional basin committee, a top-down organization of the solution approach and centralized decision making, to enable a basin wide strategic management scheme.

Stakeholders also pointed out that integrated water policies, effective control mechanisms and an operative organism for La Picasa basin are needed to implement changes. The formation and organization of local stakeholders, as well as trust-building activities with them, could increase the support from the local population and result in an income diversification including the strengthening of the industrial and the tourism sector. In conjunction with insurances and financial support mechanisms in the case of flooding, these measures could decrease the high dependency of the study area on agricultural production.

6.5.2 Applicability of "Nature-based", "Infrastructure-based" and "Hybrid" Solution Approaches in La Picasa basin

Although stakeholders are aware of nature-based solutions, the lack of knowledge on such approaches, especially their effectiveness and implementation process, was also identified as one of the major barriers for their application in the study area La Picasa basin. Accordingly, among the needs for future management solutions expressed by local stakeholders, several approaches can be categorized as nature-based DRR solutions, while most of the current measures actually implemented, belong to engineered infrastructure-based solutions (compare Table 8).

Some of the nature-based solution approaches that were mentioned but are not in place yet, can be related to natural ecosystems, while others would intervene in modified ecosystems. Although all of these solution approaches are valid to affect the sensitive interactions and feedback loops of the study area, those nature-based solution approaches related to a more sustainable agricultural production require a large-scale basin wide application to noticeably affect the water balance of La Picasa basin. In addition, many of them depend on various external socio-economic factors that go beyond the decision-making capacity of responsible parties in the basin. These dependencies could hold the risk that their implementation could be volatile and unsteady with negative consequences for their effectiveness.

Those nature-based solution approaches related to natural ecosystems, meanwhile represent an opportunity to create a stable frame for Eco-DRR among the responsible decision-making parties of the basin. By declaring areas for nature-protection and wetland restoration, the pressures driving the loss and degradation of wetlands could be eliminated and therefore a further loss of ecological and economic values in these zones could be avoided or at least controlled. Although numerous wetlands of the study area are situated on private lands, payments for ESS could create a financial incentive to create an enabling context for the conservation of wetland ecosystems.

Table 8: Categorization of identified solution approaches into nature-based and infrastructure-based approaches (own elaboration)

Nature-based solution approaches	Infrastructure-based solution approaches
Related to natural ecosystems	South- and North Alternatives (water exists)
wetland restoration	Paraná option (water exit)
creation of protected natural areas and buffer zone	maintanance of engineered infrastructure
introduction of deep-rooting plants for bio-drainage	internal construction works
Payments for Ecosystem services	increasing the number of puming stations
Related to modified ecosystems	increasing the number of canals
diversification of the current land-use scheme	
strengthening of the dairy sector	
creation of a market for alfalfa	
soil covers with living crops	
adapted rotation of crops to climatic conditions	
fostering higher evapotranspiration rates	
creating water storages	
using the ground-water aquifer	

The conservation or restoration of wetlands can deliver considerable support or even substitute conventional grey infrastructure for water treatment, water supply, drought mitigation and flood control (Bertule *et al.*, 2014). In many case studies around the world, water quality and quantity regulation services provided by wetlands proved to be cost-competitive and more sustainable to those provided by infrastructure-based solutions, while providing a wide range of socio-economic co-benefits (Bertule *et al.*, 2014).

The natural ability of wetlands to filter effluents and absorb pollutants, contributes to water quality, while microorganisms in the sediments and vegetation in the soil help to break down many types of waste, eliminate pathogens and reduce the level of nutrients and pollution in the water (Groot *et al.*, 2011). Wetlands also play a key role in the natural regulation of water quantity during periods of droughts and floods (Interview 8-9, Tricarico (2018), see Annex 5) as they hold the ability to store large amounts of water, and release it slowly (Silva *et al.*, 2010). This allows them to “slow” flood water thereby minimizing the potential of flood damages to grey infrastructure and human lives downstream, while at the same time increasing resilience to storms (Bertule *et al.*, 2014).

In dry periods, contrariwise, they can function as “retention basins”, providing water to the system through slow release of the stored water (Bertule *et al.*, 2014). A restoration of the natural environmental flows through the conservation of wetlands can contribute to better biological control (Forslund *et al.*, 2009) while wetlands also reduce downstream transport of sediments by trapping sediments (Russi *et al.*, 2013).

Table 9: Water management benefits and co-benefits of wetland restoration/conservation (Adapted from Bertule et al. 2014)

Wetland restoration/conservation	
Water management benefits	Co-benefits
Water supply regulation (incl. drought mitigation) Flood mitigation Water purification and biological control Water temperature control	Biodiversity benefits (incl. pollination) Recreational, aesthetic value Livelihood income possibilities Climate change adaptation and mitigation (carbon storage and sequestration)

Beyond the primary benefits related to water quantity and quality regulation that wetlands provide, they also offer recreational value and support livelihoods through fisheries and tourism (Bertule *et al.*, 2014). Wetland restoration additionally enables the provision of habitats for a number of species (compare Table 9), thereby delivering high biodiversity benefits, and also plays an important role in climate change adaptation and mitigation through carbon storage capacities of wetlands (Russi *et al.*, 2013; Bertule *et al.*, 2014).

These benefits for water management in specific and broad-scale co-benefits are of significant importance for a sustainable future development of La Picasa basin, as they would provide a foundation not only for handling the problem of floods but also enable the integration of alternative economic activities besides the omnipresent agricultural production. This would allow a diversification of income generation as a first stepping stone for a more sustainable and resilient community in La Picasa basin.

As already found out during the interviews, the wetland restoration in the study area, like in other projects around the world, also involves trade-offs, between providing improved state of water related ESS and livelihood options for some, while potentially eliminating sources of income for others (Bertule *et al.*, 2014). In addition, creating larger areas of standing water, can form habitats for the spread of vector borne diseases (Forslund *et al.*, 2009). Yet, it was found that in the long-term, the majority of stakeholder groups usually benefits from wetland restoration efforts (Bertule *et al.*, 2014). Restoration costs of wetlands vary depending on the location and level of degradation and can be high, requiring physical restoration works, but also long-term management ensuring the, often slow, process of recovery (Russi *et al.*, 2013). Nevertheless, worldwide cases indicate that once restoration of wetlands and associated ESS succeeds, the economic and social benefits can be exceptionally high (Russi *et al.*, 2013).

6.5.3 Comparison of "Nature-based", "Infrastructure-based" and "Hybrid" Solution Approaches

The previous analysis steps of this thesis clearly identified a need to relate DRR to ESS trade-offs and developed solution approaches that have a more nature-based focus than the currently employed strategy based on grey infrastructure. Especially wetland conservation and restoration efforts hold numerous benefits (compare table 9) that were identified to be able to compete with conventional infrastructure-based approaches. Nevertheless, nature-based solutions are often most effective when they consist of a combination of ecosystem management approaches and engineered infrastructure, as their fusion benefits from complementarities between green and grey infrastructure to ensure effective risk reduction (Monty, Murti and Furuta, 2016). Consequently, it is important to know for responsible decision makers, how nature-based solutions perform in comparison to infrastructure-based solutions and if their coexistence provides synergies or creates problems.

The following comparison refers to nature-based solution approaches as wetland restoration or conservation strategies, to infrastructure-based solution approaches as strategies based on engineered grey infrastructure and to hybrid solutions as strategies implementing a combination of wetland restoration and conservation with conventional infrastructure-based approaches. The performance of these solution approaches got compared according to the degree they influence ESS,

how they affect DRR and how effective they are in the short-, medium- and long-term (compare Table 10).

To compare how the solution approaches influence ESS, they got evaluated according to the degree they improve or impair the provisioning ESS 'agricultural production', the regulating ESS 'hydrological regulation' and the supporting ESS 'habitat quality'. The reduced disaster risk was assessed based on changes in the frequency and magnitude of floods, the degree of exposure to floods and the vulnerability of the SES. The effectiveness of solution approaches was evaluated based on the time needed until the system responds to the initiated changes by a reduced risk of floods, the cost levels of related measures and how difficult it is to measure the results of initiated changes to prove their effectiveness.

Table 10: Comparison of different solution approaches to solve the problem of floods in La Picasa basin considering its performances with respect to ESS, DRR and effectiveness (own elaboration)

Comparison of different solution approaches to solve the problem of floods in La Picasa basin			Performance of Solution Approaches								
			Nature-based soultion approaches			Infrastructure-based solution approaches			Hybrid solution approaches		
			short-term	medium-term	long term	short-term	medium-term	long term	short-term	medium-term	long term
com-parison factors	ESS	Provisioning (Agricultural Production)	-	+	+ +	+ + +	+ +	+	+ +	+ +	+ + +
		Regulating (hydrological regulation)	+	+ +	+ + +	- - -	- -	-	+ +	+ +	+ + +
		Supporting (habitat quality)	+ +	+ + +	+ + +	- - -	- -	-	+	+ +	+ + +
	DRR	Frequency and magnitude of floods	+	+ +	+ + +	+ +	+	o	+ +	+ +	+ + +
		degree of exposure to floods	+	+ +	+ + +	+ +	+	o	+ +	+ +	+ + +
		vulnerability of the SES	+	+ +	+ + +	+ +	+	o	+ +	+ +	+ + +
	Effective-ness	Response	long-term			short-term			short-term		
		Costs	low			high			medium		
		Measurability	difficult			easy			medium		
	Legend										
	+	a slight improvement for human well-being				-	a slight impairment for human well-being				
	+ +	a medium improvement for human well-being				- -	a medium impairment for human well-being				
	+ + +	a strong improvement for human well-being				- - -	a strong impairment for human-wellbing				
						o	neither improvement nor impairment for human well-being				

Performance of Nature-based Solutions

The implementation of protected areas for wetland restoration or conservation requires as a principal input that parts of the area, now used for agricultural production purposes, are dedicated to this objective. Although the soil quality of most drained wetlands does not allow for the production of crops, their dedication for wetland restoration efforts including buffer zones, would most probably result in a decrease in the provisioning ESS agricultural production in the short-term. In correspondence with the increasing functionality of the regulating ESS 'hydrological regulation', however, also agricultural production areas would benefit from the reduced risk of getting flooded in the medium- and long-term, as areas currently lost for production purposes could be recovered.

Although, it will probably need some time until the hydrological regulation function of wetlands is fully or to large parts recovered, already in the short-term, the restoration of currently drained wetlands will have an effect on the total water surface of La Picasa basin and therefore affect the water balance by increasing evaporation rates. The supporting ESS 'habitat quality' will benefit in the short-term from spots of natural areas forming wildlife refuge within a landscape highly affected by agricultural land-uses, and even more in the medium- and long term, when wetland ecosystems recovered their complex and multi-level biological interactions between species.

The performance of nature-based solutions in terms of DRR coincides with the functioning of the hydrological regulation mechanisms of wetland ecosystems, because they have the ability to decrease the frequency and magnitude of floods. Nevertheless, the exposure to them also relates to the implementation of buffer zones and protected areas that avoid agricultural lands as well as private property to get flooded. As respective ESS increase over time, so does the overall risk of disaster and the vulnerability of the SES decline, making the system increasingly resilient.

Nature-based solution approaches in general require some time until they fully unfold their potential and wetland restoration and conservation usually reach the provisioning maximum of benefits in the long-term. Although the costs for restoring or conserving wetlands can be high depending on their degradation, in comparison to the costs of conventional infrastructure, they are usually lower, especially, when additionally taking into account the avoided costs of damages due to flooding. However, the complexity of ecosystems and their functioning makes it difficult to measure the effects of nature-based solutions to prove that implemented measures have been successful.

Performance of Infrastructure-based Solutions

Infrastructure-based solution approaches currently represent the prevailing management strategy to encounter the flooding events in La Picasa basin and as they were designed to drain agricultural land, they allowed an increase in the provisioning ESS of agricultural production in the short-term. Unfortunately, the modifications of the system highly affected its water balance and led to major drawbacks as the regulating ESS 'hydrological regulation' declined drastically. In the medium- and long-term, the benefits for agricultural production derived from the implemented infrastructure-based solution decreased steadily and even turned into more flooded productive area when the principal lagoon increased in its size manifold.

While having an immediate effect, once implemented, engineered infrastructure depreciates over time, and needs high inputs of maintenance and construction works or even a renewal to function properly. Due to the complex social and political framework of La Picasa basin, this maintenance of grey infrastructure has repeatedly failed and led to an increase of problems related to floods. However, the loss of the functioning of artificial infrastructure triggered balancing ecosystem mechanisms and allowed a slight recovery of wildlife in refuges arising in areas affected by floods in the medium- and long-term, thereby positively affecting the regulating and supporting ESS.

Although the applied infrastructure-based measures had a positive effect on the frequency and magnitude of groundwater-related floods, the exposure of agricultural land to floods as well as the overall vulnerability of the upper basin in the short-term, they failed in addressing various disasters simultaneously. On a basin-scale, they even caused the principal lagoon La Picasa to generate floods in the lower basin in the long-term.

The advantage of infrastructure-based solutions in general, is their immediate and easily measurable effectiveness in the short-term. Nevertheless, the costs for infrastructure-based solutions are comparably high when considering the necessary maintenance and renewal costs in the long-term. Taking into account the special case of La Picasa basin, they have not provided an answer for water related problems, but only transformed them and transferred them to elsewhere. When considering that an improved planning could probably improve the effectiveness of infrastructure-based solutions in La Picasa basin, the complexity of occurring social and political conflicts sets serious restrictions for improvements and makes technologically and economically illogical strategies, like the Paraná option, necessary.

Performance of Hybrid Solution Approaches

The idea of hybrid solution approaches is to make use of the advantages of both nature-based and infrastructure-based management approaches, thereby maximizing the benefits for human well-being. In the case of La Picasa, the highly modified system requires some conventional engineered approaches to provide immediate protection against the threat of repeated floods. However, due to

the fact that engineered approaches proved to be invalid in the past, nature-based approaches could be applied to bring the system back to a more ecological state, thereby restoring its natural water cycle.

A combination of both approaches could provide infrastructure-based protection mechanisms for agricultural lands thereby increasing the ESS 'agricultural production' in the short term. The parallel implementation of areas for wetland restoration and conservation would simultaneously allow to improve the ESS 'hydrological regulation' and the supporting function of 'biodiversity and habitat quality'. When the benefits derived from infrastructure-based solutions decrease in the medium- and long-term, they can be compensated by the increasing benefits of nature-based solutions that maximize with ecosystems growing stronger over time.

A combination of both approaches would allow an effective short-term DRR that even increases in the medium- and long-term and becomes more sustainable and cost effective because healthy ecosystems hold the ability to replace grey infrastructure, and in contrary to them, do not need high maintenance input as they are able to maintain their functions autonomously. A wise and basin-wide management plan could allow to lower the frequency and magnitude of floods by making use of ESS, while nature protection areas and buffer zones could decrease the exposure to floods and lower the vulnerability of the SES in general.

The hybrid solution approach would be effective in the short-term due to infrastructure-based strategies, and at the same time benefit from the increasing effectiveness of nature-based strategies in the long-term. Because both, investments for grey infrastructure and the restoration and conservation of wetlands must be done in the beginning, a hybrid approach would be costly in the beginning but would request less maintenance in the long-run. It could be challenging to distinguish between the benefits that both approaches provide and measure how successful each of them contributed to the DRR of floods in La Picasa.

7 Discussion

7.1 Discussing the Historic Development of La Picasa basin

7.1.1 Definition of Time Sequences

The defined time sequences resulted from the input of an extensive literature review as well as data from a ground station in Pergamino. They were used to distinguish between time periods of common characteristics concerning land-use schemes, precipitation rates and prevailing problems related to water resources. Because these time sequences were used as a basis for further analysis steps, it is important that they coincide with time sequences defined in other scientific publications for similar purposes to large parts.

Differences with other authors exist (compare Table 11) but play a minor role in the overall development of the study area and probably arose either because of different foci set with respect to the determining characteristics of the periods or because the research area is defined on a different scale, referring to the whole Pampas or a different part of the Pampas instead of La Picasa basin in specific. Bernardos *et al.* (2001), for example defined sequences with a very similar focus on significant combinations of weather (rainfall and winds), land use (land allocated to crops and pastures), and technology (agronomic practices and farming inputs) conditions for La Pampa province, while Viglizzo *et al.* (2001) set a major emphasis on the development of land-use schemes in the total Argentinean Pampas.

Table 11: Comparison of time sequences
(own elaboration)

Sources	Definition of time sequences									
Wiedemeier (2018)	< 1870	1870-1920	1921-1940	1941-1960	1961-1990	1991-2018				
Bernardos et al. (2001)		1907-1920	1921-1929	1930-1948	1949-1960	1961-1980	1981-1990	1991-2000		
Viglizzo et al. (2001)		1881-1913	1914-1937	1938-1960	1960-1988	1989-2001				

Differences in the definition of time sequences exist, however, when comparing the results of this thesis with defined time periods of the two other publications, it can generally be said that they are to large parts overlapping with the results of the other studies. The defined time sequences in this thesis either coincide with the periods set by Bernardos *et al.* (2001) or, if this is not valid, they do coincide with the time sequences of Viglizzo *et al*. (2001). The results of this thesis can therefore be assumed to deliver the necessary information on the development of the study area and consequently represent a well-founded basis for further analysis steps.

7.1.2 Increase in the Monthly Anomaly of Precipitation Rates from 1931-2015

Diagrams found in current literature (Giordano, Bianchi and Calvi, 2017) indicating the monthly anomaly of precipitation in the study area of La Picasa basin (compare Figure 29), do not show the increasing trend of monthly anomalies starting in the 1990s that were detected in this thesis (compare Figure 30), but rather represent the cyclic variations in dry and wet periods. These results are valid, when considering the shorter time period under investigation, because the calculated values of the "zero" line, refer only to values of the last approximately 30 years. Nevertheless, when considering a longer time period, like in this case dating back to 1931, the monthly anomaly is based on data from several decades and therefore indicates a clearly increasing trend.

Assumptions could be drawn, if this increasing trend is part of a natural climatic variability of the area or also driven by the effects of climate change. Although this thesis is not able to verify one or the other assumption, this discrepancy with currently used climatic data, points out that it could be

important to consider the effects of global climate change and further investigate its role in changes of the system, when developing solution approaches for floods in La Picasa basin.

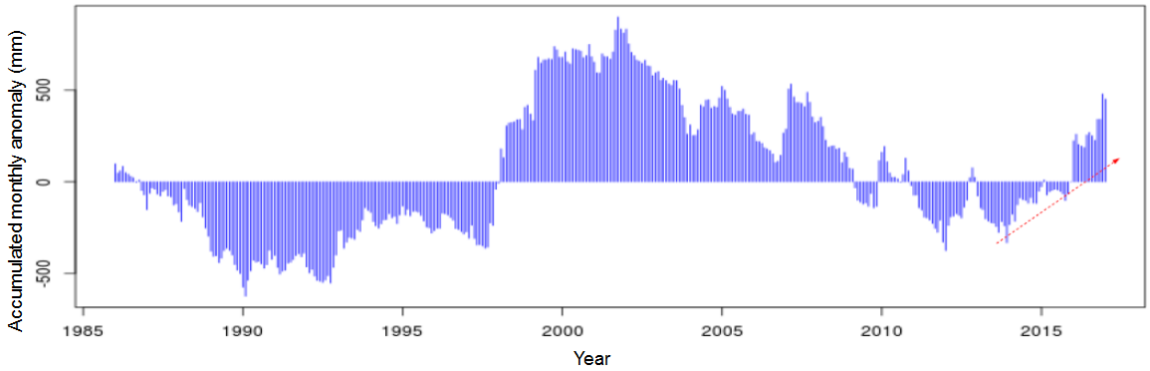


Figure 29: Accumulated monthly anomaly in Laboulaye station (1986-2015)
(Source: adapted from Giordano et al., 2017)

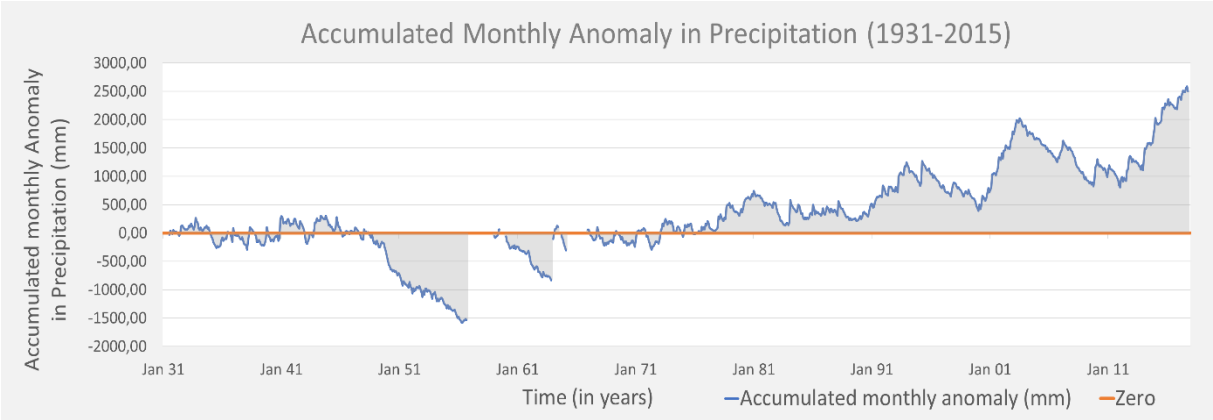


Figure 30: Accumulated monthly anomaly in Pergamino station (1931-2015)
(own elaboration)

7.1.3 Development of Evapotranspiration Rates

Changes in land-use patterns over the defined time sequences suggest that evapotranspiration rates could have played a major role in the development of the SES and problems related to water resources. Unfortunately, the compilation of actual evapotranspiration data that considers the necessary range of factors like wind speed, precipitation rates, solar radiation, air and soil moisture vegetation cover, and temperatures among others (Cesanelli and Guarracino, 2011; Beguería *et al.*, 2014), is very difficult to conduct for the last 150 years due to a lack of data. The general trendline was therefore developed based on qualitative input from local experts (Interview 16-18, Jobbágy (2018), see Annex 5) but is apparently very limited in delivering concrete evidence based on actual evapotranspiration data. Nevertheless, for the period from 1967-2015 with available evapotranspiration data, this general trendline could be supported, since the trend in the calculated potential crop evapotranspiration coincides with the qualitative description.

In general, it can also be said that only considering the land-use schemes for the time sequences by ignoring the climatic variability and other determining factors for evapotranspiration rates, does not allow to take precise statements about the amounts of water that got evapotranspirated over time, but anyhow, it allows assumptions about a general trendline.

7.1.4 The Interplay of Land-use, Evapotranspiration, Precipitation and Channelization of La Picasa basin

Since neither the sole consideration of converting land-use forms, nor variations in climatic data explain the extensive changes that occurred in the study area, it is necessary to set them into a context that embraces the interplay between the social and the natural part of the system. By doing so, this thesis was able to derive assumptions about the determining factors that keep the water balance of the study area in an equilibrium state or cause the system to switch into another state. Those distinct equilibrium states that can either be related to a negative water balance, triggering droughts like experienced during the dust-bowl period or to a positive water balance with water excesses, causing floods as currently happening in the surrounding of La Picasa lagoon, were found to be dependent on major turning points in anthropogenic impacts and on the vertical components of the water balance. Crucial anthropogenic impacts for water related problems were found to be the change in land-use and the channelization of wetlands and agricultural land while the important natural factors were found to be evapotranspiration and precipitation rates.

Applying the SES theory helped combining both perspectives and connecting causes for the current problem of floods with each other. It can be stated at this point that neither the social factors, nor the natural factors do exist independently from each other, but are highly interwoven through complex feedback mechanisms. The attempt of finding a solution for the perceived problems in La Picasa basin that results from these factors, therefore suggests a socio-ecological perspective as a highly relevant approach to grasps this complex interplay.

7.1.5 Ecosystem Services Trade-offs

Derived from this complex interplay of several components, ESS were extracted which are highly related to the causes of identified problems with water resources. The primary trade-off between the ESS 'agricultural production' and 'hydrological regulation' is self-evident because the study area's primary economic income source is the primary sector and floods are obviously a problem that threatens this economic activity on a large scale. Meanwhile, the effects that this primary trade-off holds for the local biodiversity and the ESS 'habitat quality' is from an economic perspective not more than a negative side-effect.

In contrary to this, the previous analysis steps identified the drainage of wetlands and the conversion of natural grasslands into cropland as one of the variables that were playing a vital role in switching the SES from one equilibrium state to another. A closer examination and consideration of the role that the ESS 'habitat quality' could play in future solution paths, holds a high potential for more sustainable and holistic management approaches. By lifting the ESS 'habitat quality' from being solely a side-effect to be a focal point of integrated water management plans, the current paradigm of perceiving disasters would completely be shifted towards a "greener" understanding of the problem situation. In this process, the present perception of disasters, as isolated and fortuitous events and unmanageable products of a capricious and arbitrary nature (Scheijtman, 2006), would no longer be justifiable, and this rethinking could break the limits that currently prevent proper management and design of public policies (Scheijtman, 2006).

7.2 Discussing Stakeholder Dynamics

The identification and the categorization of stakeholder groups is always a complicated process, as it highly relies on objective perceptions of the researcher conducting the stakeholder analysis and the stakeholders interviewed. To avoid personal prejudices as much as possible, the stakeholder analysis applied in this thesis was based on a snowball sampling method that allowed to identify and interview stakeholders that local experts perceive as affecting the system or being affected by the problems occurring in La Picasa basin. Although this method is diminishing the risk that the researcher is

subjectively "choosing" stakeholders, at the same time it is increasing the risk of only including stakeholders in the analysis that are already known components of the system. This could cause a stagnancy of stakeholder dynamics, because already known components are exclusively involved in the process and cause the entire system to fall into a status of inertia. To avoid this, the conducted pre-interviews with experts, not directly involved in the situation of La Picasa basin, were used to develop a basic feeling for stakeholder groups important to be included in a stakeholder analysis.

Rosenstein *et al.* (2009) and Montico *et al.* (2008) identified two major stakeholder groups in La Picasa basin, which are the communities of Rufino, Diego de Alvear and Aarón Castellanos, because they are the ones most affected by the floods of La Picasa lagoon, and the farmers in the basin of La Picasa who were severely affected by the inundations and are still at risk to lose more productive land (Montico, Bonel and Rosenstein, 2008; Rosenstein *et al.*, 2009). Although communities (local stakeholders) and farmers (agricultural stakeholders) were also identified as important stakeholder groups in the process of investigation, this study additionally included various other stakeholder groups, because it assumes that the problems the study area faces are characterized by a high degree of complexity that makes it inaccurate to only include the directly affected local and regional stakeholders. By considering a broader profile of involved stakeholder groups, this analysis aimed to bridge the current gap to a more holistic and diverse context of La Picasa basin's problem situation.

Within the group of agricultural stakeholders, a specific dynamic created through an interesting disparity could be observed. Although the problem situation is affecting all agricultural stakeholders, the least affected by floods are those who affect the system the most. When listing the large influential renters of soy fields on the top, the private farmers of maize fields below, then cattle farmers with mixed systems underneath and in the end the dairy farms, one can assume that the further down, the applied agricultural systems consume more water (Interview 16-18, Jobbágy (2018), see Annex 5). At the same time, those farming systems, suffer more from the occurring floods (see Figure 31). This creates an interesting gap, and, in a way, there is an implicit incentive of flooding the landscape, because it means, opening a niche for tenants even further by beating the renting prices down, when the floods recede. The lack of solidarity with neighboring farmers is also a problem. There is no social concept of a fair use of the basin, neither do the economic market rules allow the farmers to pursue a fair use. This disparity holds a high conflict potential and is of significant importance as it appears between stakeholders that were identified as either "key players" or "context setters" with a high power to influence the future management of La Picasa basin.

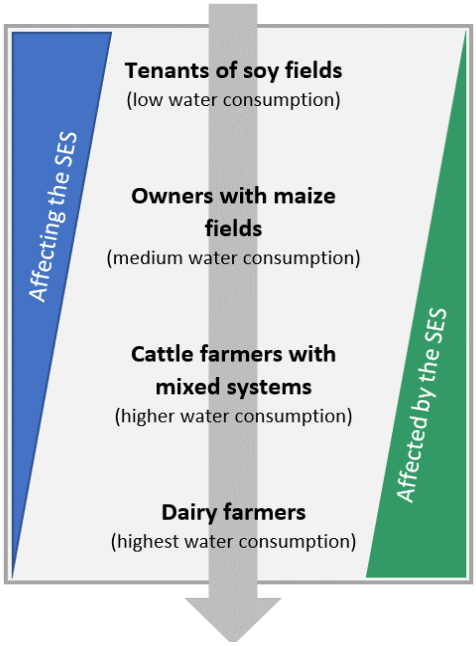


Figure 31: Disparity between affecting and affected agricultural stakeholders (own elaboration)

It was observed that especially farmers are predominantly involved in the basin committees, thereby holding decision-making positions, while other stakeholder groups, such as nature conservation groups, are not represented. While it cannot be denied that most farmers would prefer a sustainable solution for the problems in La Picasa basin, their perspectives on possible solution approaches is apparently highly affected by the need to produce and earn economic returns through agricultural production. Without generalizing the inability of farmers to take integrated decisions, it is debatable if one stakeholder group, with homogenous incentives, can consider and value the versatile interests of

an interdisciplinary stakeholder audience. With respect to other ESS such as 'hydrological regulation' or 'habitat quality' it appears understandable that the voting of farmers would favor 'agricultural production' in a trade-off situation. "It is like giving the wolf the responsibility to care for the chicken." (Interview 19, Bertoni (2018), see Annex 5).

Although a social network between stakeholders exists, several conflicts prevent a proper functioning of this system and a basin-wide integrated management concept based on wetland restoration (Interview 1, Villa Uria (2018); Interview 5-7, Milardovich (2018); Interview 10-15, Maurizi (2018); Interview 19, Bertoni (2018), see Annex 5). The conflict between the three involved provinces, defined as "key players", came to a head in a judicial proceeding in front of the Argentinean Supreme Court of Justice and represents a major limitation for finding a holistic solution in conjunction (Interview 10-15, Duhalde (2018); Interview 19, Bertoni (2018), see Annex 5). The ability to negotiate a compromise between all three provinces seems to be a distant prospect, as the battle lines are drawn. Nevertheless, a quick solution is very much indispensable and could also hold an opportunity as new ways of thinking and acting must be explored of necessity. Applying the concept of ESS trade-offs within the frame of SES theory could fall on fertile grounds in the current impasse and create a basis for a more sustainable future basin management.

Stakeholders that would support a future project which is fostering wetlands and their self-regulatory ESS are currently very sparse among the involved decision-making parties and typical stakeholders that could be in favor of making use of nature-based solutions, such as nature conservation groups or touristic actors, are not well-connected with key players in the study area (Interview 10-15, Furno (2018), see Annex 5). Consequently, it seems more suitable to convince leading stakeholder groups of the benefits that wetlands could hold. Because the region is highly dominated by agricultural actors, a change in land-use management could be more viable when starting out of their inner midst rather than being an artificial outer movement that forces the region's main stakeholder group into a new situation that they do not support. Once current key players are intrinsically convinced of the potential wetlands hold for reducing flood risks, they would automatically look for help and guidance from expert groups and an improved inclusion of further stakeholder groups could become an autonomous process.

7.3 Discussing Identified Problems and Feedback Loops

The problems identified through stakeholder interviews are corresponding to the results of the study conducted by Rosenstein *et al.* in 2009. Corresponding to their findings, problems mentioned by stakeholders were manifold and interwoven in a complex manner, but the three major problems of the study area can still be defined as 1) floods, 2) an inadequate production model, and 3) the loss of critical infrastructure. Although most interviewees state climatic causes as part of the fundamental problem of floods, a general consensus in the belief that the occurring disasters are not exclusively a result of nature but rather are related to anthropogenic mismanagement and impacts, was found.

Going one step further by linking the set of problems with the concept of ESS, a closer evaluation of relevant ESS trade-offs and feedback loops was possible and the potentially important ESS trade-offs identified in the first analysis part of this thesis could further be underpinned by the input from stakeholder interviews. Although several ESS trade-offs were detected as relevant for the study area, due to a lack of data, the results of this thesis were very limited in delivering economically quantifying values for trade-offs between those ESS. Future research projects should further investigate the economic values of ESS to be able to base decision about favoring one over the other in a trade-off situation on concrete facts. Several methods that could be used to quantify the economic performance of ESS exist. They will be described in the chapter 9 Limitations and Research Outlook.

Applying the concept of ESS to the described problems allowed creating a general frame and structure for analyzing important feedback loops between them and the capacity they hold to duplicate or mitigate one another. By doing so, the ESS concept permitted to grasp the functioning of the system of La Picasa basin and proved capable to increase the visualization and resulting understanding of direct or indirect consequences that human actions provoke. The destruction or degradation of functioning ecosystems, such as wetlands and grasslands, in this way could be associated with the described threat for human well-being. This new perspective on problems in La Picasa basin could provoke a change in the mind-set of stakeholders, because in this approach floods do not stand isolated as an uncontrollable "natural hazard", but rather get connected to other components of the system and therefore become "manageable". This concept provides distinct starting points for reasonable management interventions and thereby delivers possible paths to enable an integrated water resources management. A consideration of the basin's natural, ecosystemic and above all, human and social environment, as demanded in a study conducted by Scheijtman (2006), becomes possible with this analysis approach and, besides, it allows embedding concepts and methods for landscape multifunctionality as stipulated by Mastrangelo *et al.* (2014).

The examination of feedback loops between the problems mentioned by stakeholders, allowed challenging the simplification of complex trade-off interactions that are currently limited to a negative correlation between the ability of ecosystems to provide agricultural production and hydrological regulation at the same time. Considering the complex interplay of feedback loops interwoven on multiple levels, clarifies that the conservation of biodiversity is not a contradiction to agricultural production, but could play an integral role in strengthening the entire SES.

7.4 Discussing future Management Needs

Stakeholders made a clear distinction between already existing engineered infrastructure-based solutions for the problem of floods and other nature-based approaches that they expressed to be needed, but that are not applied yet. It seems to be clear to stakeholders that nature-based solutions could represent an opportunity to fully or partially substitute grey infrastructure and, besides, supply various advantages.

Indeed, several scientific publications discussed the potential of nature-based management approaches to provide numerous benefits and their ability to reduce disaster risks. In general, it can be assumed that in the study area nature-based solutions intervening in natural ecosystems could be internally controlled by a basin committee while nature-based solutions focusing on agro-ecosystems are highly affected by external driving forces, which involves a higher risk of inefficiency. Although nature-based solution aiming at making the agricultural production model more sustainable should be highly appreciated as supporting the reduction of environmental problems such as floods, nature-based solutions related to an improvement of natural ecosystems, such as the restoration of wetlands, should represent the focal point of future management strategies because related measures are governable internally.

When nature-based management measures, such as the restoration of wetlands, are used to respond to hazards that occur because of ESS trade-offs, like in the case of La Picasa, they are referred to as Eco-DRR, which are regarded as key management strategies for the protection of ecosystems and associated services that contribute to prevent disasters and reduce risks (Monty, Murti and Furuta, 2016). In the context of an integrated water management, nature-based solution approaches, like Eco-DRR are often also referred to as "green infrastructure" (GI) which describes "natural or semi-natural systems that provide services for water resources management with equivalent or similar benefits to conventional "grey" water infrastructure" (Bertule *et al.*, 2014). These "green" solution approaches

become increasingly recognized as an important opportunity for addressing complex challenges, such as coping with floods (Bertule *et al.*, 2014).

On a global scale, the dominant paradigm of 'building hard structures' for flood protection is increasingly being challenged by approaches that integrate ecosystem dynamics (Janssen *et al.*, 2015). Usually, those Eco-DRR or GI approaches involve a deliberate and conscious effort to utilize the provision of ESS to supply core water management benefits, as well as a wide-ranging secondary co-benefits (Bertule *et al.*, 2014). Applied to La Picasa, natural wetland areas, for example, could reduce the flood risk but simultaneously also could improve water quality, have a balancing effect on groundwater levels, support wildlife and fish, as well as recreational and touristic activities. Nature-based solution approaches in the study area could therefore be employed to support goals in multiple policy areas (Bertule *et al.*, 2014) which could diversify the economic activities and provide a collective future direction for a development project of La Picasa basin.

As functioning ecosystems providing ESS play a significant role in nature-based DRR approaches, the conservation of biodiversity is an inherent concern and vice versa. While the main objective of nature-based DRR to protect societies from disasters is of highest importance in the study area, conservation aims at preserving biological entities such as species, ecosystems and communities and could deliver a range of secondary ecological benefits to La Picasa basin (Monty, Murti and Furuta, 2016). Despite these differences, several commonalities in terms of implemented measures could provide a strong basis for synergies and integration between these two fields and could create a situation that most stakeholder groups could benefit from (Monty, Murti and Furuta, 2016).

The urgent need to reduce disaster risk of floods in La Picasa basin, could therefore indirectly act as an incentive for nature conservation practices, such as the establishment of new management approaches or protected natural areas, without using the conservation value of specific wetlands with their species composition as the primary argument (Monty, Murti and Furuta, 2016). Nevertheless, the provision of key ESS such as risk mitigation can add significance to such conservation decisions and provide non-monetary incentives to manage and protect wetlands for DRR benefits primarily, which ultimately cascade down to conservation of biodiversity (Monty, Murti and Furuta, 2016). Applying Eco-DRR measures in La Picasa basin could represent a holistic solutions for the complex socio-environmental challenges of floods, as an option to serve various ecosystem management approaches simultaneously, rather than a single conservation objective-oriented intervention (Monty, Murti and Furuta, 2016).

Furthermore, the combination of Eco-DRR measures and conventional engineered infrastructure could be vital for hazard management strategies in the study area, because it enables to benefit from complementarities between green and grey infrastructure and ensures an effective functioning of disaster risk reduction (Monty, Murti and Furuta, 2016). While the value and functioning of implemented grey infrastructure can be expected to depreciate over time, nature-based measures can be assumed to grow stronger with the time as vegetation and species communities generate or regenerate (Bertule *et al.*, 2014). Nevertheless, nature-based solution approaches remain a relatively new concept to practitioners and policy makers in La Picasa basin and the lack of knowledge on their effectiveness and implementation process poses a serious barrier to their adoption and scaling up (Monty, Murti and Furuta, 2016).

It can be said that nature-based solution approaches can provide several benefits for DRR when properly applied within the local context of La Picasa basin but can also have disadvantages in comparison to conventional infrastructural approaches and must be carefully chosen fitting to the system's feedback loops and affected ESS. The visualization of feedbacks between components of the problem in La Picasa basin, provides a useful basis, to define suitable nature-based management approaches and identifies grass- and wetlands as central hubs within these interrelations. Putting wetlands in the center of attention of future management strategies could therefore be an effective

nature-based measure to counter the risk of floods and, as a side-effect could boost biodiversity and habitat quality in the region. In addition, a focal point on wetlands does not exclude engineered measures but rather offers an option to diminish their costs and at the same time increase their functioning in conjunction with benefits derived from ESS.

Nature-based solutions should consist of a combination of ecosystem management approaches and engineered infrastructure to ensure effective risk reduction. Unfortunately, the current socio-economic frame in La Picasa basin is clearly favoring infrastructural solutions and due to the high rentability of soybean production, does not allow for more sustainable land-use scenarios (Pre-Interview 3, Bolatti (2018) and Interview 16-18, Jobbágy (2018), see Annex 5). However, the high potential of nature-based mechanisms, when appropriately adapted to the identified ESS trade-offs and their feedback loops, cannot be negated and could take effect, once the socio-economic and management parameters are favorable. Although nature-based solutions are not implemented yet, they are already subject of discussion among local stakeholders and could play a leading role in regional approaches to reduce disaster risk. Consequently, it is important for responsible decision makers, to consider nature-based solutions in the same way they consider infrastructure-based solutions. Nevertheless, their coexistence can only provide beneficial synergies for the region if applied in proper proportions, which leads to the question, which distribution of nature-based and infrastructure-based measures creates an optimum of synergies.

7.4.1 Finding an Optimum between Nature-based DDR Approaches and Engineered Solutions

When natural ecosystems get modified, as it happened in La Picasa basin with the channelization of wetlands, some ESS or 'natural benefits' get lost, but can be replaced by benefits derived from engineered modifications or management of the system (United Nations, 2018). However, there is a 'tipping point', in the process of modification of ecosystems, where benefits from ESS and engineered modifications together reach the maximum and further modifications will only decrease the total flow of benefits (Acreman, 2001).

Modification activities in the study area passed this tipping point and the loss of benefits delivered by the natural system resulted in complex negative consequences for both the social and the natural part of the system. The aim of future management decisions should be to create a situation in which the natural system is still able to provide benefits for human well-being and anthropogenic modifications stay in a range where they add supplementary benefits instead of limiting the natural system to provide ESS. This tipping point is difficult to identify because the optimum of modifications has to be found that allows the ecosystem to continue provide a high amount of benefits, such as hydrological regulation (Acreman, 2001).

Theories exist that deal with the trade-offs managers must consider, when choosing between leaving a system in its natural state or highly modify and manage it. Acreman (2001) developed a schematic figure indicating that as natural systems are degraded and modified more and more, the overall benefits obtained from the natural system decline and ESS, such as hydrological regulation and habitat quality, are lost (compare Figure 32). At the same time, benefits from managed systems increase, as other ESS such as agricultural production rise (Acreman, 2001). It is assumed that benefits derived from highly managed systems reach a maximum and do not further increase, while the benefits of natural systems will decline to zero with ongoing degradation (Acreman, 2001). The total long-term benefits result from adding the benefits of natural and managed systems and consequently reach a maximum before declining (Acreman, 2001). The resulting peak represents the optimum situation which provides the highest amount of benefits for human well-being. The schematic visualization of benefit flows with ecosystem modification could provide a useful and convincing tool to trigger and support a change in mind-sets of responsible decision makers in La Picasa basin.

To achieve an equilibrium between modified and natural ecosystems and their benefits, it is important to consider the value that society places on goods and services because this will shape the exact form of the curves (Acreman, 2001). Besides awareness and education campaigns, it is therefore also essential to quantify the economic value of ESS which could help justifying the allocation of resources to maintain ecosystems as described in chapter 9 Limitations and Research Outlook. Certainly, the perceived benefits will vary between different stakeholder groups, however, similar projects have shown that in the long-term benefits are usually enjoyed by the majority of stakeholders (Bertule *et al.*, 2014).

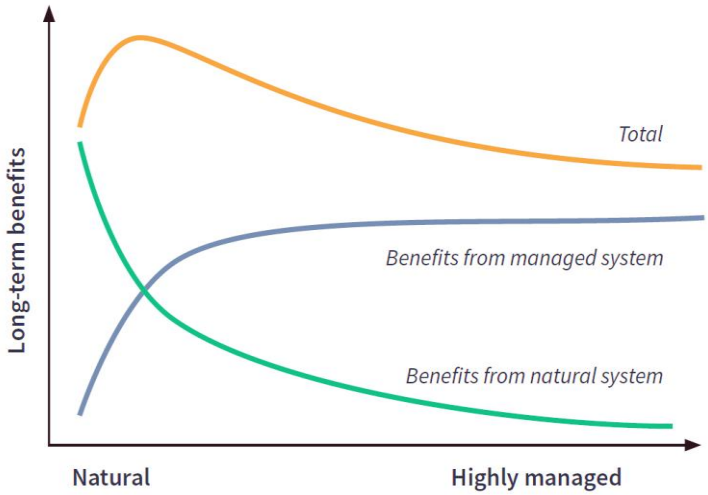


Figure 32: Changes in benefit flows with ecosystem modification (Source: Acreman, 2001 as cited in United Nations, 2018)

Various nature-based solution approaches exist that could be helpful to reach this optimum state of an SES in La Picasa basin that range from conceptual approaches and general guidelines to commonly adopted practices (United Nations, 2018). An example for a holistic framework of nature-based solutions is provided by the World Wildlife Fund (WWF). Suggestions made in the 'Natural and Nature-Based Flood Management: A Green Guide' fit well to the specific case of the study area, because they are based on the concept of integrated flood management and aim to be site-specific, integrated and balanced across all sectors concerned (United Nations, 2018).

The suggested key principles mentioned to achieve a sustainable and holistic nature-based flood management are (World Wildlife Fund, 2016):

- design flood management methods to maximize the net benefits of floodwaters while minimizing flood risk, since flooding can be a natural and beneficial process;
- apply flood risk management with a watershed perspective to understand how a particular community's flood risk relates to the rest of the watershed;
- consider non-structural methods in flood management, and then if needed include structural, natural, nature-based or hard engineering, as part of an integrated approach;
- recognize the multiple social, economic, environmental and political aspects affected by flood management in a watershed;
- integrate flood risk reduction and adaptation to a changing climate into flood recovery and reconstruction, so that flood recovery improves community resilience to future extreme events, avoids introduction of new social or environmental vulnerabilities, and enhances community adaptation capacity to climate uncertainties;
- support social equity and comply with local/national laws and institutions, including informal social norms and customs during decision-making processes; and
- strengthen resilience processes and livelihoods and empower women and/or disadvantaged social groups.

8 Conclusion

The application of an ESS perspective on the current problems of La Picasa basin as well as setting it into the context of SES theory, allowed obtaining an understanding of the role wetlands play in the systemic functioning of La Picasa basin. By reviewing their influence on the historic development of the region it was examined, which part wetlands hold in maintaining the SES in an equilibrium state with respect to the water balance of the study area and which ESS trade-offs are vital to consider when designing solution approaches for the current problem of floods. Connecting historic trends in evapotranspiration with predominant climatic conditions, allowed defining time sequences within the historic development that represent homogenous characteristics in land-use models and water-related problems. Applying the SES theory helped connecting causes for the current problem of floods, with both natural and anthropogenic impacts and enabled an augmented comprehension of the vital role wetlands hold in the complex historic interplay between them.

The examination of important stakeholder dynamics could be achieved through identifying and categorizing important actors according to their expediency to be involved in future solution approaches and permitted drawing conclusions about crucial relationships between stakeholders that create opportunities or restrictions for the conservation of wetlands.

Although a social network between stakeholders exists, several conflicts prevent a proper functioning of this social web and a basin-wide integrated management concept based on wetland restoration. The conflict between the three involved provinces, defined as “key players”, came to a head in a judicial proceeding in front of the Argentinean Supreme Court of Justice and represents a major limitation for finding a holistic solution in conjunction. Nevertheless, a quick solution is very much indispensable and could also hold an opportunity, as new ways of thinking and acting must be explored of necessity.

Applying the concept of ESS trade-offs within the frame of SES theory could fall on fertile grounds in the current impasse and create a basis for a more sustainable future basin management. Because the region is highly dominated by agricultural actors, a change in land-use management should start out of their inner midst rather than being an artificial outer movement that they do not support. Based on stakeholder interviews and expressed requirements for future management strategies, suggestions could be formulated for solution approaches that integrate wetlands into the design of a more sustainable regional development plan.

The analysis of present problems in La Picasa basin and how they interact through feedback loops, allowed deriving management approaches that define the trade-offs between ESS as starting points to inverse negative circuits. Especially nature-based solution approaches, and in specific the restoration of wetlands, were identified to hold a large potential to serve the area with a broad range of benefits. It was found that nature-based solutions hold the potential to perform best in La Picasa basin, when combined with infrastructure-based solutions and that this coexistence provides manifold options to create synergies.

Applying the concept of ESS to the described problems, allowed creating a general frame and structure for analyzing important feedback loops between identified problems and which capacity they hold to duplicate or mitigate one another. By doing so, the ESS concept permitted to grasp the functioning of La Picasa basin’s system and proved capable to increase the visualization and resulting understanding of direct or indirect consequences that human actions provoke. The examination of feedback loops between the problems mentioned by stakeholders, allowed challenging the simplification of complex trade-off interactions that are currently limited to a negative correlation between the ability of ecosystems to provide agricultural production and hydrological regulation services at the same time. Considering the complex interplay of feedback loops, interwoven on multiple levels, clarifies that the conservation of biodiversity is not a contradiction to agricultural production, but could play an integral

role in strengthening the entire SES. This new perspective on problems in La Picasa basin could stimulate a change in the mind-set of stakeholders, because, in this approach, floods do not stand isolated as an uncontrollable “natural hazard”, but rather get connected to other components of the system and therefore become “manageable”.

This thesis provides distinct starting points for reasonable nature-based management interventions and thereby delivers possible paths to enable an integrated water resources management. A consideration of the basin’s natural, ecosystemic and above all human and social environment as demanded in a study conducted by Scheijtman (2006), becomes possible with this analysis approach and, besides, it allows embedding concepts and methods for landscape multifunctionality as stipulated by Mastrangelo *et al.* (2014). It can be concluded that wetlands and related nature-based solution approaches can provide several benefits for DRR when properly applied within the local context of La Picasa basin. However, they can also have disadvantages in comparison to conventional infrastructural approaches and must be carefully chosen fitting to the system’s feedback loops and affected ESS. It was found that a managerial focus on wetlands does not exclude engineered measures, but rather offers an option to diminish their costs and at the same time increase their effectiveness in conjunction with benefits derived from ESS. Nevertheless, the visualization of feedbacks in La Picasa basin, identified grass- and wetlands as central hubs within the interrelations of flood-causing problems and therefore suggests their extensive involvement in future plans. Putting wetlands in the center of attention of future management strategies can therefore be concluded to be an effective nature-based measure to reduce the risk of floods and, as a side-effect boost biodiversity and habitat quality in the region.

The high potential nature-based solution approaches hold, when appropriately adapted to the identified ESS trade-offs and their feedback loops, cannot be negated and could take effect once the socio-economic and management parameters are favorable in La Picasa basin. Consequently, it is important for responsible decision makers to consider nature-based solutions in the same way they currently consider infrastructure-based solutions. Although nature-based solutions are not implemented yet, they are already subject of discussion among local stakeholders and could play a leading role in regional approaches to reduce disaster risk. This thesis could provide useful information for greening the solutions in La Picasa basin and thereby contributes a new perspective to the development of more holistic and sustainable future management strategies.

9 Limitations and Research Outlook

The major limitation this dissertation faced, was the lack of data to calculate exact economic values of ESS that were identified to be crucial for human well-being in La Picasa basin. Working qualitatively on the ESS trade-offs proved capable to solve this problem in the frame of this thesis. Nevertheless, it could be important to back up management actions with concrete numbers that could justify specific foci and could also give guidance in trade-off decisions to find and choose the most cost-effective solution approach. When, for example, choosing the nature-based solution approach of wetland restoration rather than infrastructure-based canals and pumping stations, this decision should be based upon an economic evaluation and comparison of related costs. Future studies should therefore investigate the economic values of ESS in the study area that were identified as significant for human well-being. Several methods exist to evaluate their contribution to cost balances (compare Figure 33).

To measure the economic value of agricultural production, the market-based cost method could be used, but there are also several software tools, like InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) that work with quantitative data sets, or TESSA (Toolkit for Ecosystem Service Site-Based Assessment), which mainly works with qualitative questionnaires (Peh *et al.*, 2013; Sharp *et al.*, 2016). For the ESS hydrological regulation the replacement cost method or avoided cost method could both prove viable to calculate the value that ecosystems provide by stabilizing the water balance. Although InVEST provides several tools to calculate the economic value of water-related ESS, they mainly focus on coastal areas but lack a specific tool for inland wetlands. TESSA could provide a qualitative alternative. By evaluating the economic performance of agricultural production in comparison with hydrological regulation the major ESS trade-off that was defined for the scope of this dissertation, could be further illuminated with concrete numbers. Data inputs required for InVEST tools are predominantly geographical information system (GIS) data and information tables.

Figure 33: Methods for evaluating the economic value of selected ESS (own elaboration)

Besides this major trade-off, future economic calculations of ESS, should also consider the value that nature conservation could indirectly create through making the region attractive for touristic or recreational purposes. Although the assumption that species can be ranked in their importance thereby giving "life" itself an economic value, quickly reaches the boarders of ethical correctness and this study reversely takes up the position that biodiversity holds an intrinsic and therefore incalculable

value, biodiversity parameters and how societies perceive the importance of habitat quality could deliver soft data about the "value" given to it in La Picasa basin. The travel cost method could provide a useful approach to measure touristic ESS values and TESSA also provides a qualitative questionnaire to assess the value of recreation. Future studies working on an economic evaluation of ESS in La Picasa basin, will accordingly require a tremendous data input (compare Table 12).

Table 12: Possible data requirements for future ESS evaluation (own elaboration)

Agricultural Production	Hydrological Regulation	Biodiversity and Habitat Quality	Tourism and Recreation
• Productive areas • Land-use • Revenues/crop • Expected development of crop prices • Cattle prices • Slope • Soil type • Distance to roads • Distance to markets and access	• Water storage capacity (batimetry, topography, satellite images) • Costs for engineered solutions that provide equal service • Costs of flooded Agricultural/ urban areas • Rainfall distribution	• Habitat quality & species composition • Endangered/ endemic species • Academic research/data • Awareness/perception Importance biodiversity • Conservation actions present	• Tourists/ visitors • Economic benefits • Infrastructure available • neighboring cities/villages benefitting • Purpose/ activities • Used travel medium and number of people sharing vehicles • Distance travelled and costs of travelling

Another point that should be taken into consideration in a future project that aims at reducing the flood disaster risk of La Picasa basin, is the potential that a more sustainable and nature-based solution approach could hold for the entire future development of the region. Decisions taken in a short-term to improve disaster risk reduction, could benefit other sectors in the medium- or long term by creating new economic conditions for the study area. When selecting one or another solution approach, responsible stakeholders should keep these opportunities in mind.

Considering the current stakeholder network and power relations between stakeholders it is probable that solution approaches for the rising groundwater tables are primarily designed to serve the needs of the dominant social group, agricultural producers, and to allow similar revenues like produced with the current intensified agricultural system. The INTA (Instituto Nacional de Tecnología Agropecuaria) developed different scenarios that assess the water consumption of distinctive rotation combinations of annual and perennial crops to increase the evapotranspiration over the year to avoid an accumulation of water excesses over the years. Covering the social and economic aspect of a sustainable future development in La Picasa Basin, this approach is not taking the environmental pillar into consideration. Nevertheless, the regions unique flora and fauna and corresponding ecosystems are of high intrinsic value and could support an alternative monetary income through nature-related tourism activities.

For an integrated and sustainable management in La Picasa basin the four selected ESS, 'agricultural production', 'hydrological regulation', 'habitat quality (biodiversity)' as well as 'tourism and recreation' should be taken into consideration. When this is achieved, a future development for the study area could appear promising to create multiscale benefits to most stakeholders. Although the vision of a more sustainable management in La Picasa basin seems to lie ahead the current situation, an ESS approach could transform a vicious cycle into an upward spiral. Nevertheless, it is idealistic to expect this change to happen at a moment's notice and a sustainable development in La Picasa basin will require time, as well as incremental and practicable changes. The following Figure 34 and Figure 35 indicate a positive vision of future management foci in La Picasa basin that favor a gradual transformation of the study area that could boost the region to experience an overall increase in prosperity by avoiding disasters and at the same time restraining the regions dependency on the agricultural sector.

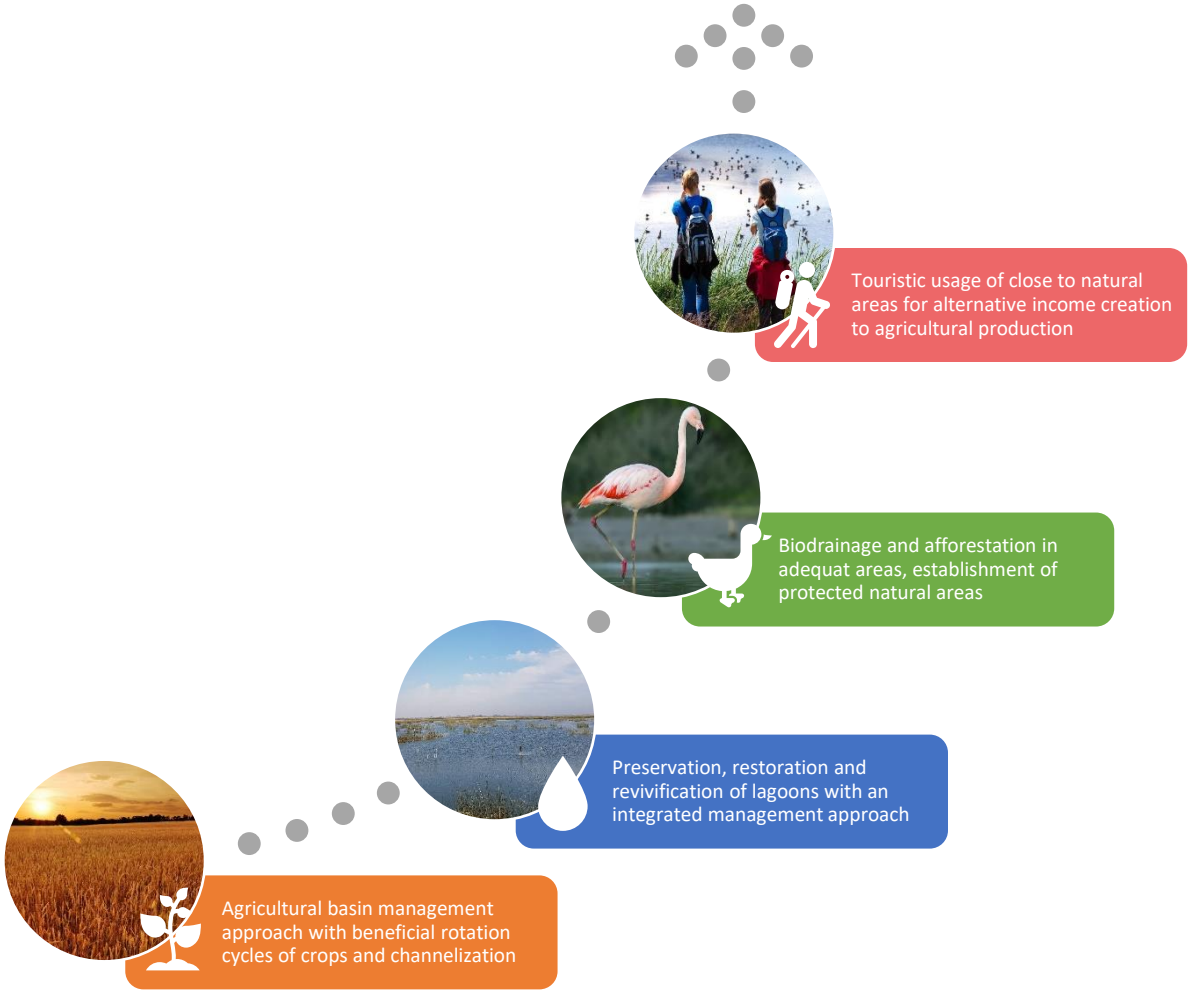


Figure 34: Vision of a sustainable development in La Picasa basin (own elaboration)

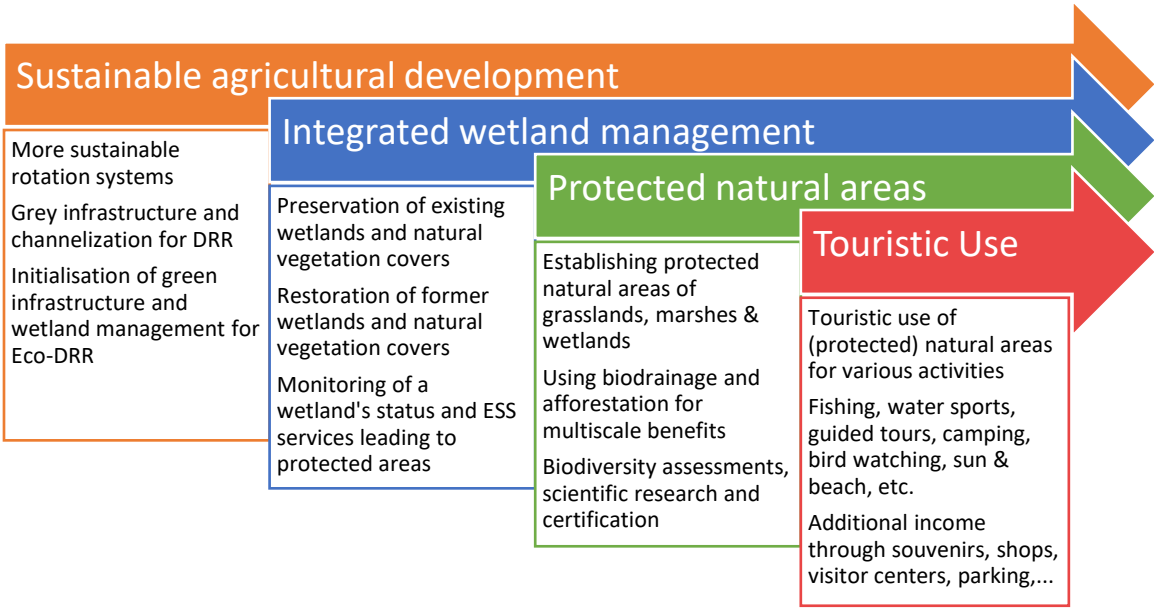


Figure 35: Vision for sustainable management foci for a sustainable development in La Picasa basin (own elaboration)

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Annexes

Annex 1

Pre-Interview Number	Interviewee	Function	Location	Date and Time
1	Andrés Rodriguez	Director LH-CETA; Political and organizational manager of hydrological working group "La Picasa"	Córdoba	12:30-13:30 26.02.2018
2	Juan Carlos Bertoni	Secretary of water resources in the province Santa Fe	Córdoba	10:00-10:30 28.02.2018
3	Pablo Bolatti	Agricultural Engineer for INTA; focusing on applied solutions for agricultural problems related to groundwater table rise, crop rotations and soil classifications	Marcos Juarez	11:00-13:00 15.03.2018
4	Federico Pagnan	Agricultural Engineer and Farmer for INTA	Justiniano Posse	15:00-16:15 15.03.2018
5	Esteban Milicich	Fishermen/Tourism Guide in the lagoon "La Viamonte";	Justiniano Posse	11:00-11:30 16.03.2018
6	Elisabeth Jorro	Responsible for tourism in the Municipality of Melincué and the Ramsar Site Laguna Melincué	Melincué	13:00-14:30 16.03.2018
7	Marcelo Ridolfi	Fisherman and tourist in the lagoon "La Viamonte"	Justiniano Posse	09:30-09:45 16.03.2018
8	Marcelo Diez	local farmer impacted by the increase of size in the lagoon "La Picasa"	Buenos Aires	21:00-22:30 18.03.2018
9	Esteban Jobbágy	Scientific researchers with a focus on eco-hydrological topics	Córdoba	12:00-13:30 21.03.2018
10	Maria Poca	Scientific researcher with a focus on ESS and biologist	Córdoba	12:00-13:30 21.03.2018
11	Natalia Perez Harguindeguy	DiverSus working group, scientific researchers with a focus on sustainable development and biological research questions	Córdoba	14:00-16:00 27.03.2018
12	Esteban Kowaljow	DiverSus working group, scientific researcher with a focus on wetland restoration and carbon sequestration	Córdoba	14:00-16:00 27.03.2018
13	Juan Ignacio Whithworth Hulse	DiverSus working group, scientific researcher with a focus on eco-agriculture and biologist	Córdoba	14:00-16:00 27.03.2018

Annex 2

Main-Interview Number	Interviewee	Function	Location	Date and Time
1	Gustavo Villa Uria	Sub- Secretary of water resources in the province Santa Fe	Aarón Castellanos	18.04.2018 15:00-16:00
2	Alfredo Antonio Raparo	local landowner and expert especially for hydrologic engineering solutions	Aarón Castellanos	18.04.2018 16:00-18:00
3	Walter Ramanzín	president of the Comuna Aarón Castellanos	Aarón Castellanos	18.04.2018 20:00-21:30
4	Alberto Diez	local producer with flooded farmland area	Rufino	19.04.2018 08:30-09:45
5	Diego Milardovich	Coordinator of Region 5 "Nodo Venado Tuerto" in the Ministery "Gobierno y Reforma" from the Province Santa Fe	Venado Tuerto	19.04.2018 11:45-13:00
6	Carlos Castagnani	President of CARSFE (Confederación de Asociaciones Rurales de Santa Fe)	Venado Tuerto	19.04.2018 11:45-13:00
7	Claudio Berrueta	local producer with flooded farmland area	Venado Tuerto	19.04.2018 11:45-13:00
8	Javier Tricarico	Responsable for agriculture of the company Adecoagro	Christophersen	19.04.2018 14:15-16:00
9	Alfredo Raparo	local landowner and expert especially for hydrologic engineering solutions	Christophersen	19.04.2018 14:15-16:00
10	Juan Carlos Duhalde	President of the Interjurisdictional Committee of the La Picasa basin	San Gregorio	19.04.2018 16:30-18:00
11	Omar Maurizi	local producer with flooded farmland area	San Gregorio	19.04.2018 16:30-18:00
12	Federico Furno	local producer with flooded farmland area	San Gregorio	19.04.2018 16:30-18:00
13	Armando Rey	President of the Asociación Productores del Sur de Santa Fe	San Gregorio	19.04.2018 16:30-18:00
14	Mirtha Más	local producer with flooded farmland area	San Gregorio	19.04.2018 16:30-18:00
15	Alfredo Raparo	local landowner and expert especially for hydrologic engineering solutions	San Gregorio	19.04.2018 16:30-18:00
16	Maria Poca	Scientific researcher with a focus on ESS and biologist	San Luis	23.04.2018 10:00-12:30
17	Esteban Jobbágy	Scientific researchers with a focus on eco-hydrological topics	San Luis	23.04.2018 10:00-12:30
18	Juan Ignacio Whithworth Hulse	DiverSus working group, scientific researcher with a focus on eco-agriculture and biologist	San Luis	23.04.2018 10:00-12:30

19	Juan Carlos Bertoni	Secretary of water resources in the province Santa Fe	Córdoba	27.04.2018 17:30-18:00

Annex 3

Interviewee(s)	Location and Date	Summary of the Pre-Interview
Andrés Rodriguez	Córdoba 26.02.2018	The project in La Picasa Basin will mainly be a technical, hydrological study with the three provinces Córdoba, Santa Fe and Buenos Aires involved. Until today the project didn't start and is still under formation. The analysis of ecosystem services is a popular methodology from Europe, but probably is not the solution for the present problems in La Picasa Basin. The project for La Picasa Basin will be structured in two equally valid parts. One focusing on the technological hydrological modelling of the basin, done by the team from LH-CETA and one focusing on the integrated ESS approach done by Jasna Wiedemeier.
Juan Carlos Bertoni	Córdoba 28.02.2018	The potential for a future working group on La Picasa is high due to the importance the whole thematic has for the three involved provinces. The region is one of the most productive areas in Argentina. Even though it suffered from large scale flooding in the last years it achieved an increase in agricultural production numbers, which underlines the extent of intensification the agricultural sector underwent. As the "La Picasa Basin" is divided into three Provinces, the region is not only of economic interest, but also of political, environmental, social and technological importance. Although ESS and their valuation were not in the focus of managers during the last decades, they become more and more important in front of this background and should be included in the mainly technical, analysis of the region. Political and social conflicts are very present and make a close collaboration between stakeholders from all three provinces favorable. This and the long-term scale of the project could be challenging for involved managers. The composition of all ESS the region provides is important for human well-being but of outmost importance during the last years was the water storage capacity (hydrological regulation) in wet periods as flood mitigation measures as well as in dry periods as water reservoirs for the agriculture.
Pablo Bolatti	Marcos Juarez 15.03.2018	There are discussions about, if the Pampas used to be covered by forests or not. In my opinion, the pampas steppe used to be a grassland and there were no forests. There is a study called the "lightening project" which describes that there have been many fires, caused by thunderstorms, which have not allowed the development of forests in this area. The Pampa is characterized by dry and wet periods and the water table varies according to the precipitation events. The variation in the water table depth is mainly explained by vertical processes like precipitation, infiltration, and evapotranspiration. When you check the changes in the sensitivity of the groundwater table in relation to rainfall events, you will see that they correlate. It is discussed if we face a climate variability or a complete climate change in the Pampas steppe. When you check the data of the climate in a time series from 1948 to today, you will see that we are facing a slight increase in precipitation, but that humid and dry periods have always occurred in this area. This is important, because the current agricultural system uses less water, than the precipitation delivers. This is a problem, because the access water adds up on the groundwater level building and we face the problem of water retention in the soils. In addition, there is a lot of run-off occurring due to the excess water which leads to a water erosion process of the soils. There are also some sectors with presence of salts, but the water does not have great electrical conductivity (between 0.2 to 0.7 dS/m). The historical surface of natural wetlands in this area has only been around 2% of the land surface. Currently we face a situation, where approximately 25% of the land are flooded. This phenomenon occurs due to anthropogenic impacts. How to solve the problems of waterlogging? In a first step we need channels to drain these human-made wetlands, then in a second step, we must use crops that have the capacity to drain the soils up to a certain depth to reach the groundwater level. The management of water consumption is a management issue, which requires a basin wide approach. This is important, because there is a correlation between the water balance and the groundwater levels, which are, when too high, affecting the yields of agricultural production. Some possible solutions are related to land use scenarios with changes in the rotation of crops. In the first scenario the rotation is characterized by a first production period of 33% of the surface area with soybeans and 33% of the surface with maize, while in the second production period 33% are made up of wheat and soybeans. In total this scenario would lead to a total water consumption of 850 mm of water / ha. Another scenario with a percentage of soil occupied by perennial crops could achieve a total water consumption of more than 850 mm / ha. In none of all the simulated scenarios, the groundwater level does fall below 5 meters depth. A suggested time horizon for the creation of scenarios is a time span of 5 years, due to the unpredictability of future changes in Argentina. Some of the management problems this region faces are that most owners rent their land to tenants, technological advances and a change in the productive system have caused a lack of labor and cultural changes. Wheat brings a return of 1.77 US $/mm consumed water. Its gross value is approx. 800 US$/ha (with a consumption of 450 mm/ha). This explains, why there is no intention to have natural pastures, because 1 ha used for agricultural production bring an economic return of 480 € while 1 ha used for natural pastures only brings 40 €. <u>Calculation:</u> Wheat: 1ha of wheat consumes 450mm of water per year and generates a value of 800 US$/year ⇒ 800 US$/ha divided by 450 mm water consumed/ha makes 1.77 mm water consumed for each US$ generated, or each mm of water generated wheat with the value of 0.56 US$. Natural grasslands: 1ha of natural grassland consumes 800mm of water per year and generates a value of 46 US$/year ⇒ 46 US$/ha divided by 800mm water consumed/ha makes 17.39 mm water consumed for each US$ generated or each mm of water generates a value of 0.06 US$.
Federico Pagnan	Justiniano Posse 15.03.2018	The current problematic is the result of two factors summing up, the little consumption factor of the agricultural production system and the increase in precipitation. If this increase is a normality or abnormality of the climate, depends on the time scale under investigation. INTA works with data about the humid and dry cycles from before 1970. There is a study of INTA Laboulaye about the precipitation of the region done by the famous researcher Estella Carballo, who is working for INTA Castellar and

		especially interested in the humid and dry cycles of the system. She found out that before the 1920s this region faced a dry cycle that transformed into a wet cycle after the 1970s. Geologists from INA developed a study about the attributes of soil types working with cartography. The village Melincué, for example, would naturally be completely flooded. When the time intervals between very dry and wet cycles are not considered when cities are planned, this is the result. An analysis of the last 30 years is not enough to know where it would be natural to have floods. In addition, the anthropic factor modifies the hydrological cycle with extreme results. It is an agricultural disaster, when 20% of the surface (320,000 ha) are flooded. Justiniano Posse has a precipitation recording system for the last 106 years already. It is difficult to make scenarios, because they depend heavily on incentive policies and change with market prices and taxes. Future changes in the land use composition are unlikely. Around 60% of the land is rented and usually contracts run over one year which results in a lack of planning. The surface area covered with water bodies varies between 20% in humid periods and 2% in dry periods. According to the soil types that INTA developed, the soils of category I-III are very good for agricultural, the soils of category IV-V are used for livestock production and the soils of category VI-VIII are suitable for recreational purposes because they are often flooded areas with rocks. Livestock production is usually done on soils unsuitable for agriculture.
Esteban Milicich	Justiniano Posse 16.03.2018	There are no numbers or data available for the amount of visitors of lagoons and you won't find them anywhere. Anyways, you could go and ask the farmers or private owners of lagoons for visitor numbers and prices they charge. Laguna La Chanchera, Laguna Margarita and Laguna Viamonte are part of the river system Rio Quinto. La Chanchera is completely dried out. La Viamonte is still available for fishing activities. In the different lagoons, prices for taking fisher boats or touristic boats to the water vary between 300 pesos in Villa Canias and 500 pesos in la Magarita. Additionally, in some lagoons there are charges per person (ex. in Villa Cania 50 peros/person). Many lagoons like Laguna Saladillo dried out because of legal and illegal drainage systems. Where were once lagoons today you only find agricultural areas. It's an ecological disaster. There are many dead fishes in lagoons between Ordoniez and Justiniano Posse. There are no governmental regulations for fishing activities in place but fisherman in this region are aware of the importance of respecting the reproduction periods and consequently do not fish between September and February. We are very aware that the conservation of nature is very important for us and required for future fishing activities. Because we see the importance of lagoons, we are collecting lists of signatures to make private landowners aware of the fact that lagoons have to be protected.
Elisabeth Jorro	Melincué 16.03.2018	The lagoon Melincué is managed by the Municipality of Melincué. Visitor numbers of the lagoon are estimated with the help of visitor numbers of the Casino just next to it and range between 140.000-150.000 visits/year. In very dry periods an island in the middle of the lagoon becomes accessible and this special occasion causes visitor numbers to rise from approx. 10.000 visitors/month up to 30.000 visitors/month. The entrance to the lagoon is through the nearby camping club "Fábrica" and free of charge. For the right to fish visitors have to present a fishing license. The prices for fishing are 50$/person plus a fee according to the boat length (>5m = 500$; 3-5m = 400$; <3m 200$). The majority of visitors is externals. Locals do not value the lagoon from a touristic perspective, but the government is working on some changes to foster the touristic use of the lagoon for externals as well as for locals. The lagoon became an official RAMSAR site in 2008 because the local community saw the necessity to protect the habitat for nesting sites of migrating flamingos. Consequently, this conservatory management approach of the lagoon was started with a community internal process which highlights the value the lagoon and related wildlife has for the community. It was declared a RAMSAR site due to a study about the fauna of the lagoon done by Biasatti (Vice Minister for Environmental Affairs) & Luppi (permanent monitoringand data assessment). There are various players involved in studies related to fauna and flora as well as biodiversity. Claudia Rosental from the Ministry of Tourism is responsible for the southern delegation. Eduardo Peralta and Marcelo Romaro from the Universidad Nacional de Rosario are in charge of biodiversity assessments.
Marcelo Ridolfi	Justiniano Posse 16.03.2018	In the three lagoons "Laguna La Chanchera", "Laguna Margarita" and "Laguna Viamonte" there is no touristic infrastructure like offices, shops, bathrooms or other services. Apart from a few fire places there is not even fresh water, energy or cooling possibility. Fishing activities is the only touristic use these private lagoons have and although fishing is so present there are no facilities or services to do the basic processing of freshly caught fish. The only costs that have to be covered are the entrance fees that vary according to the boat size and the lagoons.
Marcelo Diez	Buenos Aires 18.03.2018	As a local farmer the increase in size of the lagoon La Picasa caused the loss of all his land. It is such a pity that so much land got lost because more water than usual is coming downstream from the river "Rio Quarto" Keeping the water on this land is not an option because it is flooded valuable land and losing it means losing everything he owns. Natural ESS of wetlands therefore are not applicable in this case. Someone just has to stop the water from Rio Quarto coming downstream or drain it from where it floods the land he owns. The problem is complex and will be most probably not solved that easily. Due to government changes, corruption and a lack of awareness the complexity of this problem will be very hard to assess and solve.
Esteban Jobbágy and Maria Poca	Córdoba 21.03.2018	Assessing the economic value of the ESS hydrological regulation in the La Picasa Basin is complicated because various systems are connected with each other through the flow of groundwater. An approach could be to simplify the situation and focus mainly on the two predominant factors in the water cycle - precipitation and evapotranspiration. As we do not have the possibility to modify precipitation that easily, it is very interesting to create land use scenarios that modify the regions water consumption (evapotranspiration + consume). The economic valuation could just be related to the amount of water used. A mapping of most beneficial vegetation covers for different areas according to topography, soil types and precipitation combined with some qualitative biodiversity data input could be a useful first stepping stone for a more sustainable future political decision making. The main reason for floods in that area is the "slow motion" part related to humid and dry climatic periods and the accumulation of groundwater over the years. This process is additionally negatively impacted by the real time water consumption of plants which in this case are anthropogenically modified from natural grasslands with a high water consumption during the whole year to crops like soy beans, wheat and corn that consume much less water and often are not planted to cover the whole cycle of a year. To positively influence the problem of the rising ground water table level it is important to consider how deep the roots of plants go and which potential they bare to dry the water table down to deeper depths than surface crops are able to. A qualitative list of options of various vegetation types with their real time water consumption and their roots depths for long-term effects could be another useful

		outcome of the study. Without the flood events in the past years, wildlife in the humid Pampa would not have had any chance to survive. It would be interesting to qualitatively assess which impact flooding events have on the expansion of wildlife. Although floods are therefore a crucial factor for the survival of wildlife in the Pampa, it could be interesting to assess where and with which distance to urban areas these floods would be beneficial for wildlife and the least costly in terms of agricultural and infrastructural loss. There is a similar discussion going on dealing with the peri urban use of agrochemicals. Could that discussion be used for flood events, too? Towns suffer the highest economic costs in case of a flood, while dairy farms are already less impacted economically and the big soy bean farmers are least impacted in economic terms. The next steps for the thesis could be to define input variables for each of the services under investigation to accumulate the necessary data for the data input for an alternative scenario modelling. Hydrological modelling is very often a purely quantitative approach and lacks qualitative input such a biodiversity data.
Natalia Perez Harguindeguy, Esteban Kowaljow and Juan Ignacio Whithworth Hulse	Córdoba 27.03.2018	Clearly define the terms that should be investigated (biodiversity/ land use/ plant ecology/ fishes?). Sometimes the wording makes a difference. Instead of agricultural approach vs. green approach, the wording sustainable vs. unsustainable approach sounds better and keeps ears and doors open. The management approach suggested in the thesis should be realistic enough to convince decision makers. A possible solution development could look like this: planting 20% of the basin with forest would solve the problem of increasing water levels in the lagoon and increase XY biodiversity. Include livestock and dairy production in the agricultural ESS evaluation as well as things beyond the economic evaluation such as benefits on biodiversity to include other stakeholders. There is another German university, the Leuphana, working with very related topics and one of the researchers there already worked with ESS in the Argentinian Pampa (Berta Martin-Lopez). The Leuphana University could be interested in cooperating in a project about the La Picasa Basin. There is another Argentinian University, the UN de Mar del Plata having a working group called GEAP that is working with ESS valuation and this working groups director (Pedro Laterra) could be interested in cooperating. There is another tool besides InVEST called ECO.SER that can be found under www.eco-ser.com.ar. An interest on carbon sequestration and in specific the difference between carbon sequestration in agricultural areas and forests. Potential a wetland has in comparison to forests or agriculture. It is important to have high quality data about: economic values, productivity (livestock/agriculture), new wetlands/lost wetlands, land use history, soil types.

Annex 4

Question Catalogue

1) **How did the Pampas ecosystem develop over time from a natural system to a socio-ecological system?**
    a. How did the Pampa look before the colonization began and what is different today?
    b. What are important turning points for these changes?
    c. What are the major problems this region faces today?
    d. What causes these problems?
2) **Which stakeholders are involved in the socio-ecological system and how do they interact?**
    a. Which stakeholders are key players and what are they responsible for?
    b. Which stakeholders have decision power?
    c. Which stakeholders benefit and which loose from the current situation?
    d. Which stakeholders are highly affected by the socio-ecological system?
    e. Which stakeholders are highly affecting the socio-ecological system?
3) **Which future land use scenarios bare the potential for a more sustainable development of the Pampas, and La Picasa basin in specific?**
    a. What are possible solution approaches for the major problems the region faces today?
    b. How will the land use in the Pampas develop in the future until 2040?
    c. What would be a sustainable worthwhile future development?
    d. Is an ecologically worthwhile future development meaningful?
    e. Which benefits, and which disadvantages would a more ecological land use implicate?

Annex 5

Interview 1: Gustavo Villa Uria, Engineer and Secretario de Planificación de Asuntos Hídricos del Ministerio de Planificación Federal, Inversión Pública y Servicios de la Nación, 15:00-16:00; 18.04.2018, Áaron Castellanos

1) The study area is truly part of the Humid Rolling Pampa, which has certain special characteristics: The region used to be an area for cattle production with natural pastures and historically has been the economic motor of Argentina's welfare. Many landlords from this region were able to build huge palaces in Buenos Aires because the soils were that beneficial that they allowed creating an oligarchy based on livestock farming. Many of the farmers were living in Buenos Aires while the animals were kept on the fields with natural lagoons as water source and natural pastures for feeding. Rufino used to be the national capital of cattle production, which really means something in a livestock intensive country like Argentina. But, as you probably noticed, today we neither have many animals in this region left, nor lagoons with water. So you can see a drastic change in the land use model of this region that actually started taking place in 1985 and the following years. It was caused by changes in the socio-economic conditions and the global market for cereals that fostered the intensive production of crops like soy, maize and wheat with high rentability and consequently minimized cattle production activities. This region is known to hold the most fertile and most productive soils in Argentina. From 1850 to 1860 when the first colonial settlements took place in this area, many of the landowners had family names which still can be found in the big palaces of Buenos Aires. They are evidence of the prosperity this region created by means of livestock farming and the capacities this region still offers today. The principal changes that came along with the transformation of the productive model from livestock farming to crop production, were also deeply socially rooted. The cattle production model was work intensive and the employees had very specific expertise in this field of agriculture. In the 1880s-1890s, with the change in favor of the work extensive crop production model, many of them lost their jobs and migrated to the suburbs of bigger cities like Rosario and Buenos Aires. Some found jobs in the newly appearing industries, but often these jobs were badly paid and whole neighborhoods stayed in poverty. This was the first environmental migration, or a migration caused by the change of the productive system. These changes continued to take place until the 1980ss-1990s. Although this change seems logical, crops like the soybean, do not have a long tradition in Argentina, and soy together with maize are the primary crops that led this change. With the use of glyphosate and other pesticides, the costs of production went down drastically. The soils did not have to be opened repeatedly to guarantee that it is only the crop that grows on the chosen field. In addition, these crops are genetically prepared to be resistant against fungi. All this talks about social changes and changes of the productive system. Especially in the 1980s but also in the 1990s, these changes fell together with an exceptionally humid period, which made infrastructural measures for canals necessary. The agricultural area suffered a hydrological surplus. Natural pastures used to have a water consumption of approximately 1100-1200mm/year while the rainfall reached 800-900mm/year and consequently maintained themselves autonomously. With the land use change and soy as the primary crop, with a smaller water consumption, the water was rising. To avoid the water logging on their agricultural fields, most of the landowners or -tenants constructed canals to drain the water away. Nevertheless, because the basin is an endorheic basin, all the water ends up in the most low-lying location of the basin, which in this case is the agricultural land of Alfredo Raparo. He is the one who receives all the water and there are no environmental services, he just receives all the water, his agricultural land is flooded and cannot produce anything. His family building is completely flooded.

   The parties benefitting from this situation are the landowners in the upper and medium part of the basin, who drain away all the water and do not have to face any consequences for their actions. The ones losing in this scenario are the landowners in the lower-lying part of the basin, owning land close to the La Picasa lagoon and in its expansion zone.

   The region of the La Picasa basin makes up for a large part of Argentina's GDP. Anyways, this zone has never developed an industrial sector for the processing of agricultural goods. Consequently, some of the problems, the region faces today, are related to the fact that the actual agricultural production system only employs parts of the Pampa's population. This production model needs a development towards industrialization because this would incentivize that the part of the population who is working in industries comes back to the rural areas again. In addition, the industrialization of cereal goods could create an important economic benefit for the region.

   And, above all, we need to create awareness and an understanding of the climatic variability and the changes we perceived in the last decades. The farmers in Argentina are not used to understand weather statistics, prognostics or climate variabilities. They hope that every year it rains the same amount and with the same conditions. How do they calculate with that? They prepare their crops to require only the lowest rainfall quantities possible that they calculated from the last year, and every year they produce this way. All the water resources that the crops do not consume due to this calculation, is a hydrological surplus, which, in an endorheic basin like this, end up in the lowest location – the La Picasa lagoon. And this problem of a missing use of water resources could be solved by a better land use with for example a constant land cover and additional winter crops, which would not only consume more water but also add up on the economic output. But most important is understanding the climatic conditions, with rainfall patterns that are relatively new, to be better prepared. If you ask which machinery a farmer owns in this region, they will talk about tractors and seeding machines, but none of them will talk about meteorological stations. And from my point of view this is a very important part of the equipment and the lack of it partly creates our current problems.

   The lack of solidarity with neighboring farmers is also a huge problem. There is no social concept of a fair use of the basin. The economic market rules do not allow the farmers to pursue a fair use of the basin. There are thousands of lagoons in the basin, but when you compare them to older satellite images, you can see that most of them are dried out. This means they do not provide ecosystem services like water provision, environmental quality, or social services to the community.

   Having water in these lagoons also has an effect for the production period, because the lagoons reduce the effects of frosts and there are less losses. This zone held an infinite number of smaller lagoons of which most have disappeared. The water that used to be stored in these lagoons today can be found in the La Picasa lagoon. The surface of all small lagoons of the basin together is ten times bigger than the surface of the La Picasa lagoon. The problem of these lagoons is that their soils do not allow cultivation, therefore they stay uncultivated but are dried out today. Most of the canals build to drain the area are illegal and non-coordinated. But it is very difficult

to get onto private land and check it. The motor which takes out the water from the system is the sun. The bigger the water surface, the more water leaves the system. Having all the water in one spot with less surface, less water is leaving the system.

A plan for the restauration of these lagoons exists, but this plan has to come along with awareness raising campaigns for the farmers, because most of the lagoons are situated on private land. We have to convince the farmers that the lagoons have a value for them. The lagoons in the farmer's property should have a certain level not to flood the whole property but also not to dry out completely. To mitigate the water levels, already existing canals could be used, but have to be adapted to another overflow water level.

Another solution approach is to take out water through the South-Alternative, or if this is not possible to take out water through the North-Alternative that we are already discussing for a long time. The topic has even been discussed in front of the National Supreme Court of Justice. Both alternatives would take out water from the system via the Province of Buenos Aires, because the water naturally flows this way. There is no other possibility at the moment, but we are working on a long-term alternative which could be to take out water via the Paraná river.

2) Which stakeholders are interested in the thematic of the La Picasa basin? There are some stakeholders that are interested in it, but do not know it, for example the Province Mendoza. Every trade-good from Mendoza or San Luis has to go through this region to reach Buenos Aires and the flooding of the Route N°7 through the La Picasa lagoon enlarges the transportation way, which means longer transportation times, longer transportation distances and higher transportation costs. Nevertheless, farmers in Mendoza are not aware that the solving of our problems would be beneficial for them, too.

The intersection of the railway is the same story. Many costs and a lot of time could be saved, but the responsible party is not aware of the fact that solving this problem would create actual money for them. In contrast to the Province of Mendoza, the national Railway company at least is directly affected.

In addition, we also have the directly affected stakeholders, which are the landowners with flooded fields close to La Picasa.

Because there are so many illegals canals build on private land, we are trying to find a control mechanism that is based on remote control and satellite images to control, if former lagoons still exist or are being dried out. If lagoons are not present, we can start an inspection to check its disappearance. The benefits of having lagoons, for example through a higher evaporation and less severe frost periods, are immense. But the problem of lacking awareness and understanding of the system creates some barriers that have to be overcome.

The farmers of this region do not have a long history in doing their business, they are relatively new. They are often renting their land to somebody else, who is managing the land, without a big interest in what they are doing on their land as long as they pay the rent. Even less they are interested in how to conserve their land, its soils and biodiversity. And the managing party is not the owner of the land, so they make the most profit out of the land and leave. And this is the basis of this problem. We have to work a lot on the social side of this problem. We have to create awareness on all levels of the society. For example, who is benefitting from the current situation? I do not know if there are direct beneficiaries of this situation. Maybe when it comes to price speculation or the higher incomes of the transportation sector, but these are only marginal benefits.

The farmers who thought they would benefit from draining the small lagoons on their private land, in the end do not benefit from this scenario, either. And if they still think so they are fundamentally wrong, because, with their behavior, they are harming themselves. Why? Because if we have another dry year, their land will lack the capacity to provide enough water. Due to the lack of humidity, they can also get problems with losses of their soils caused by aeolic erosion.

You could think that the Province of Buenos Aires is benefitting from the situation, because they do not accept water from Santa Fe, but in dry periods like we face now, this can quickly turn around and create a disadvantage, for the farmers with land close to the boarder who are desperate for the water.

It is difficult to identify benefitting parties in this scenario. Yes, there are particular persons that benefit from this situation. Those working with and living from conflicts like lawyers or judges, but in general they are neglectable regarding all the parties with disadvantages.

Which parties are very affected by the situation? All the small villages around the lagoon that are now cut-off from one of the formerly main transportation routes. From the local gas station owners that before had a constant income, to the population of the villages that are cut of from the once neighboring towns, where many have friends and relatives. Technicians who offered their services to 3000-4000 trucks each day, toady do not see one single truck passing the village, while sleepy villages on the other side of the lagoon are suddenly confronted with a vast number of traffic. The whole situation creates complex socio-economic problems. There are children who visited the school in the next village that now cannot visit the secondary school or must live separated from their families. Many farmers lost their land and had to migrate to another city. The roads that must be used now to avoid Route N°7, are not appropriate for this amount of traffic. Consequently, the roads quickly deteriorate, maintenance costs for the Province of Santa Fe are high, while Route N°7 would be financed by the Nation, there are many accidents and many traffic jams. We face a very complex socio-environmental problem, also because the basin is divided into the three Provinces of Córdoba, Santa Fe and Buenos Aires.

Some of the farmers changed their profession into tourism guides, but from my point of view this is not a sustainable adaptation but a survival strategy. Some of these guides are even offering dug hunts to an Italian target group. This is totally against a sustainable understanding and usage of the system of La Picasa. This is to survive. The city should have done something against it, but they let them proceed. The only resources that the farmers who lost their land have left, is their knowledge of the region and the La Picasa lagoon with their flora and fauna. Consequently, they are using it now, to compensate at least partly the losses they had to accept.

Many stakeholders are affecting the unique system of the La Picasa basin. The lack of awareness that the basin is one unit and therefore requires the establishment of a consistent management throughout the whole basin, results in many stakeholders doing their own business. We must organize this basin with all three provinces involved in the process to finally achieve a change.

3) This area is a beautiful place to live and to spend vacations in. It would serve perfectly for touristic activities. But this is not communicated where the majority of the potential customers lives, which is Buenos Aires. That makes it impossible to create touristic infrastructure, like touristic routes, guided tours, information centers and so on. Regional staff could use its knowledge about the system, the flora and fauna, and the conditions but this development requires a better communication, distribution and advertisement in Buenos Aires.

Within the next 10 years, possibly, the current productive system might collapse because the current productive system is based on glyphosate, which is a herbicide that has a life-span of less than 10 years. The laboratories are researching better options to overcome this issue, yet they have not found any. Consequently, we must assume that in ten years, the yields will be smaller than the ones today. Facing this situation, an industrial development of the primary sector in this region is unavoidable. This would create an added value to the products before they are travelling 300-400 km to the next harbor to then be shipped 20.000km more to the final destination. This added value to regional products also includes the possibility to diversify the economic income of this region and at the same time diversify the agricultural production. It opens possibilities to not only rely on the rotation of three major crops (soy, wheat and maize) that are diminishing the soil quality, but also add production cycles of Gramineae or alfalfa, which open the soils and allow that the soil filters. With the current agricultural practices, the soils get compacted and an impermeable crust minimizes the infiltration of water into the soil. We consequently get more runoff that ends up in the La Picasa lagoon, and less evaporation which accelerates this process even further.

A sustainable future development of the Pampa could be achieved with a rotation of crops, with an incorporation of a more intensive milk production, which again needs the production of alfalfa that fosters the creation of a market for alfalfa that is able to compete with goods like soy and maize. The region should head for a more balanced composition of the system, not that extreme like today. The region could change from the current production of vegetarian proteins to animal proteins, which have a higher market value and can be more easily transformed into an added value. Important is also the cooperation with universities, not only for the scientific knowledge they generate but also because we are managers not educators. And a change in the awareness of people starts with education and we must reach many people's minds. Consequently, we must create educators who generate this awareness among their students.

How will the land use change in the future? The land use has to be based on the rotation of various crops instead of the monoculture of soybeans or soybeans and maize in rotation. The system should be more ecological, more environmental, with a variety of products and a variability based on the location and characteristics of the production side. We can not produce the same crop in an area where it rains 1100mm/year or where it rains 700mm/year – there should be differences. And here also the seeding companies play a vital role: The products and elements that they develop should be related to the climate they create them for. Today you can buy any seed for any region with any characteristics and this should be changed.

The usage of pesticides should be a multidisciplinary task and not only an agricultural topic, because they also end up in the drainage canals and finally in the small lagoons and La Picasa, where they could cause damage. Agricultural engineers, farmers, control institutions and biologists should work together, so the usage of pesticides creates benefits to the system and not damages.

One of the most important natural resources that this region holds, is the ground water reserve. Today, with the current agricultural system, we are not tapping into this aquifer and only use rainwater to produce crops. We must come back to a productive system, where deep rooting plants tap this groundwater and every productive unit has at least some percentage with deep rooting plants. This would allow to lower the groundwater level that today are right below the soil surface. Consequently, we should generate an interrelation in the hydrological cycle between the groundwater, sub-surface water and surface water, the storage capacities and the mechanism of evapotranspiration. We must come back to a more natural water cycle. I am not saying we must restore the environment. I am saying that we must restore the hydrological cycle, so we do not have these flooding events anymore and the La Picasa lagoon comes back to its original size. Once the water goes back, we could try to recover the soils that used to be productive, and solve the problems of these families that have their property flooded today. We are also talking about a huge economic value that these families lost, a piece of family history and tradition. Nobody knows for sure, if these soils can totally be recovered, but from experiences, we are hoping it is possible.

I think the benefits of a more ecological land use scenario include global benefits for every party involved, because it restores the hydrological cycle, reducing the problems and conflicts between the involved provinces. The families with flooded land could recover their land, the provinces could earn more taxes because these families are able to produce again, the Route N°7 can come back to carry its normal capacity, the traffic could flow freely again, the conditions in general could improve.

The disadvantages of a more ecological land use scenario are that it takes time until this state of the system will be transformed in a future state. This transformation is dependent on technological changes, is dependent on international markets, and is dependent on influences that are not always clear and visible.

A future sustainable development of the region should be more ecological and more diversified. The general concept should not be a general mask that is used for each and every year, location, situation and climatic condition. This is obviously not in the interest of big seeding companies and would more benefit the smaller seeding companies that could also add to the regional economy. This has also to be seen in the context of the new law about seeds which discusses, who owns the property of seeds. There are many variables that one must have in mind, when talking about the future scenarios of this region. What is important to mention is that we want to enlarge the cake for everyone. We do not want to have part of the cake for us, or give it to someone else, we want it to be better for every party involved. Currently we are working on this development.

Interview 2: Alfredo Raparo, local landowner and expert especially for hydrologic engineering solutions, 16:00-18:00; 18.04.2018, Áaron Castellanos

1) One of the major problems the La Picasa basin faces today is not only the lack of communication between the provinces, but, in addition, the very small amount of water that we can discharge via the South-Alternative. We obliged ourselves not to discharge more water. Buenos Aires is the most powerful province here in Argentina and the most incapable one, from my personal point of view. La Picasa basin is an endorheic basin, which means, it is naturally closed. And the responsible party in Buenos Aires just decided, without any technical foundation that only 5m³ can leave the La Picasa lagoon via the province of Buenos Aires. They have a water exit of 135m³. In this dry period that we face now, on satellite images one can see that many reservoirs in Buenos Aires show such low water levels that the small amount of discharge allowed today, has no logical or technical reason. The province of Buenos Aires could easily accept more m³s without facing any negative consequences, but they insist to do so. Instead they accept a national road (Route N°7) to be flooded that connects Buenos Aires with Mendoza and Chile. I accept that they do not accept more water, when they really cannot handle the water, but in this situation they could. If they would let us discharge 20 m³ nobody would have a problem with that, not Córdoba, not Santa Fe, not Buenos Aires. This decision is pure capriciousness of Buenos Aires. The question is: Why is Buenos Aires only allowing 5 m³ of discharge? There has been an initial study and a master plan created by a consultancy company and they wanted to continue studying this area, but Buenos Aires did not want to pay their part of the costs for that work because they also worked on the territory of Santa Fe. This shows the conflict potential that this basin faces because it embraces three provinces. I have the opinion that the water resources of the basin should be managed by the Nation and not by the Provinces to avoid exactly this kind of discussions. This is showing our inefficiency and the capricious behavior of Buenos Aires. In 2017 there was a meeting between the three secretaries of water resources, Bertoni, Lopez and Bererciartua - all of them educated persons with Dr.-titles, in which they wanted to discuss the situation, but they got exasperated.

   This historic map of the La Picasa lagoon from 1900 shows that although the rainfall was very similar to today, the La Picasa lagoon was comparably small. Some of the former landowners, held extremely large pieces of land. This village, for example, is called Aarón Castellanos after one of the first Spanish colonizers - Aarón Castellanos Velasco. His daughter Mercedes married one of the most influential men of her time, Nicolás Hugo Anchorena Arana and became Mercedes Castellanos de Anchorena. They later constructed the San Martín Palace in Buenos Aires and like many other landowners of this region, had extensive agricultural land. 1924 the La Picasa lagoon faced a flooding event similar to the one we see today.

   There is a flamingo species which is using the La Picasa lagoon for breeding periods. The create small mounds of soil and place their eggs in the middle of this mound. Together with a biologist, we counted 5000 flamingo breeding here. Their breeding ground is a small island with all the necessary conditions to prepare the mounds of soil and to secure the offspring from predators. Now that the water level is so high they have problems to find these islands and so they do not come to breed here anymore. They have always been here but the topic to declare the lagoon a nature reserve, has come up repeatedly, but never was successful.

   My work here is focusing on the technical study of the system, the canal network, the pumping system and which constructions are needed to find a solution. We should propose better solutions and not only claim that a disaster is taking place. What I experienced many times is that farmers believe in several myths that make the parts most effected and dependent on our work, acting and discussing against us. We have a lack of awareness about the system. What we are asking for is to be allowed to discharge water via the South-Alternative, the internal construction works on reservoirs, pumps and canals, and the activation of the North-Alternative. These are the three topics we are currently working on. Many farmers blame us that we are responsible for their ruin. When we are working for the farmers and our measures make them think we ruin them, there is clearly a lack of understanding of what we are doing here. Another myths, who is clearly wrong, is that the high water levels of the La Picasa lagoon have such a high pressure that they cause the groundwater levels to rise, too.

   Many people here have a fundamentally wrong understanding of the systemic interrelationships. When you talk about "the lagoon La Picasa" and you refer to today's water levels, this is wrong. Originally, this area has not been a lagoon. My land has been 11km away from the lagoon. The increase of water levels was unpredictable and, in this form, unexpected because it took place over decades, with repeated increases of water levels, but because there were also small decreases in between, nobody took them as serious as they resulted to be. The foundation of this misinterpretation is the lack of understanding of the system. And this confusion finally resulted in mistakes with grave consequences. If the persons in charge would have taken measures in accordance to the development of the system in time, like for example functioning pumping stations to be able to discharge water in situations when it is necessary, my land would not be flooded today. Many farmers think that soils affected by the flooding event will never have the same productive capacity again. Even the agricultural engineers tell you this and even add that the soils will have problems with salts that will stay in the ground when the water leaves. They say, the soils are inept for at least the next 25 years, so I started researching on this. I checked some reference points over a period of eleven years. In 2002 the reference field was flooded, until 2010 the water levels were decreasing and already 7 years later you see pastures for cattle grazing. In 2013 the field was already back to its old capacities with the production of sorghum. On my land the same process was observable.

2) Another topic is the participation of farmer's in the solution finding process. If you read the signals carefully, the farmers involve themselves - some at least not all – but what happened in this period? Santa Fe shut down a pumping station, because it touched the ground of the lagoon and they did not fix the problem. What we did independently from Santa Fe, is the deepening of the pumping station's bowl so it worked. We did it because we faced a huge pressure of towns to be flooded, not because we wanted to demonstrate that we can do it better. This shows how complicated it is to negotiate everyday challenges in this context.

   La Picasa is the topic which has most press in the country. It is a topic that became increasingly important over the years, especially with the cutting-off of the Route N°7. Seeing the whole dimension of damages, the cutting-off of the road, is just a small part of the story, but the media had found an interesting and representing topic.

3) A number of factors is playing together to create this complex problem. What we are trying to do achieve is that every measure is well-founded on scientific or technical facts. We have to set priorities to achieve this objective and implement the right measures. That's why we are doing the batimetry that's why we are looking for different alternatives and try to convince people to support us. After our negotiations with Buenos Aires, which resulted in a flop, we still have to find a solution and all three Provinces have to work on this. Especially the control of illegal canals should play a central role and requires close collaboration between the provinces. The road – we are always talking about it, because it visualizes so drastically the consequences of this problem – but actually the reparation of the railway is much more cost intensive than the road. In only one year the lagoon increased that dramatically that even many engineers and experts think that it is impossible to solve this issue. Finally, the social part of this systems plays another vital role. In 2012, the farmers, have predicted that all of these problems will occur soon, but their voices remained unheard. It is good have a participation of local stakeholders, but if the decision makers do not listen, this participation is unprofitable.

Interview 3: Walter Ramazín, president of the Comuna Aarón Castellanos, 20:00-21:30; 18.04.2018, Áaron Castellanos

1) I am the fourth generation that was born in this region and I already have children and grand-children, so my family is really connected with this region. From what my grandfather told me, the La Picasa lagoon used to be a normal lagoon, like all the surrounding lagoons in the region. With 300-400 hectares in size, even in wet periods, it was situated 17 km away from Aarón Castellanos in north-east direction. Imagine, it was a small lagoon that sometimes increased in size, but incomparable to its size today. Today, we have 35.000 hectares, ten times more.

The consequences that we face today, are not natural. Although there are slightly changes in the climate, it could have never caused a change in this dimension. The rainfall events are like the ones 100 years ago. We still face years impacted by the El-Niño phenomenon, which are drier, and the La-Niña phenomenon, which are more humid. The climatic variability has always been there. In 1995 approximately, I was already member of the commission of this commune, there was a meeting in which we already informed and warned the former Secretary of water resources about the possibility that the lagoon could increase that much that it could reach up the Route N°33, which is the road that ends in Venado Tuerto, which is also our commune's north-east boarder. The La Picasa lagoon at that time had a size of 20.000 hectares.

The first conflict appeared between the presidents of the two communes Aarón Castellanos and Rufino in the year 1998, because the Route N°33 did not have a drain pipe, so the water could not pass it on its way from Córdoba to Santa Fe. In 1998, when the La-Niña phenomenon caused a wet period, Rufino was threatened, because the road built an obstacle for the water and made it stay in Córdoba. At the same time, the lagoon started increasing in size, although it was still in a 10 km distance from Aarón Castellanos. The president of Rufino gave order to modify the Route N°7 and equip it with the missing pipes. Breaking the water barrier, in one day, the inflow area of the La Picasa lagoon, was multiplied by ten and from that day onwards, it steadily started increasing. A logical development, because suddenly we received water from Córdoba that we have never received before. Already in the year 2000, we had a flooding event very similar to the one we face today and our commune, Aarón Castellanos, started preparing the first protection mechanisms.

From that moment onward, the only possible exit for the additional water was clear. But as you heard before, because of the capricious behavior of one single person, this exit is almost inutile. I am completely against the decisions that my own government is taking. I am aware of the fact that Buenos Aires could easily accept more water and that all the dry lagoons would increase the evaporation manifold, so it would replace ten pumping stations more. We face these problems because of our own capriciousness. Today, the only thing my commune can do, is condemn these decisions, but for the moment we cannot solve these problems. We only know that the next flooding event, will probably set our village under water. All the drainage canals in Córdoba continue draining the water and directing it towards us.

It is an illusion that Buenos Aires will let us take out the water. They are discussing to higher the roads even further than the 1,5 m they already lifted them - and with the railway the same. They are not thinking about the cause of the problem or a solution, they are only treating the symptoms. Why not opening the exit (South-Alternative) and the water flows its natural way? This is the biggest problem of all. And all problems are produced by ourselves, me included.

The Humid Pampa is one of the richest regions in Argentina, but the politicians have an interest in votes and in our village, we are only 600 votes, while just one single building in Buenos Aires already counts 1500 votes. We do not have the strength to cause a difference from that perspective. The water volume that we face that an international road is cut-off or that the railway is lost seems not to interest any politician.

Using the North-Alternative to discharge water, would lower the water levels of the La Picasa lagoon by 60-70 cm. That would spare us another dike. And the necessary construction is not complex. The water would be discharged to the Salado river, but Buenos Aires is blocking everything, so we must think about discharging water to the Paraná river. This solution would mean that we have overcome 40 m of difference in altitude. Imagine the construction that is necessary to build a tunnel to overcome 40 m of difference, while they could easily allow the water to follow its more natural way through Buenos Aires.

The region faces an economic problem today, which is directly related to the road being cut-off, because we do not have a direct connection. In addition, we face too much traffic that causes many accidents in which people die. All the cereals produced in this region are transported by trucks which must use the smaller inappropriate routes now. Today it is even safer to take the unsupported smaller earth-roads, then using Route N°33. In addition, we have many fields under water that are lost for production.

The cause of these problems is the mismanagement of water resources. While the construction of more canals is still going on in the La Picasa basin, at the same time, they do not allow us to discharge water. The hard part is that this problem would be so easy to solve.

That is why I blame Buenos Aires for large parts of the problem. I do not know which reasons they have to decide this way, but there must be a motive that we do not understand so far. Unfortunately, there are always some political strategy-games going on that we fail to fully understand.

As a farmer, I can say that the problems we face now, are the sum of numerous factors which also include the agricultural model of this region. Using soy as the number one aliment, brings the problem of pesticides. You use this Roundup clean with glyphosate and even after harvesting the crop, nothing grows on this piece of land, so consequently, we also do have zero evapotranspiration which again is accelerating our problem. Therefore, we, the farmers, are responsible for large parts of the problem. Also, the deforestation of spots with trees is the result of the soy-boom. We are all part of this ecosystem that we changed with the objective to benefit more from it. We are all responsible for the consequences we face today. Together with all the construction works, an infinite number of canals, and the increase in water led to the principal lagoon, we are responsible. The politicians and farmers of this region are responsible.

2) The three involved provinces are major stakeholders. The Nation, as well, should have an interest in this topic, because a national route is cut-off. The Nation should have more decisive power in this problem, to solve the conflict between the three provinces. We do not have the time anymore, to wait for discussions between the three provinces to be solved. We were lucky that the dry period came just in time for our dikes not to break. Last year in March and April, we had 500 mm of rainfall, this year only 100 mm. If it would have rained the same amount, the whole village of Aarón Castellanos would have been flooded. Not human made structure saved us, but nature. We were in such a critical moment that with one rainfall event of 100 mm, we would have been flooded. We were lucky, because many thunderstorms passed us without losing one single drop. We are trying to mitigate the consequences of our actions while nature is way more powerful – and, also changing. Now, nature pays us back, what we produced. Even the climate change is human made. We are paying for the consequences already and we do not know how much longer it will take us to come back to a stable state. I promote to respect nature, because sooner or later, it will defend itself. We are part of the big problem.

   When three provinces cannot find a solution for a complex problem like this, the Nation should intervene. Unfortunately, the province of Buenos Aires is the most powerful of the three involved and highly influences the Nation in political questions. I think even if the Nation would intervene, it would decide in the interest of Buenos Aires. Buenos Aires does not even participate in the meetings about La Picasa.

3) If Buenos Aires does not allow discharging water via the South-Alternative and we do not proceed in the North-Alternative, I do not see a change in the future. The damage this region will face, will be huge and once productive soils, will be lost because of an increase in salinity. At least we want to live, where we want to live. It is a right founded in our constitution and we want to achieve at least this.

   I think it makes sense to reforest the spots that are without trees today, to recover the forests that we had before. In addition, a rotation of crops, like our grandparents used to have, should be fostered, not only soybeans, soybeans and soybeans. The soybean is the primary reason for the problems we face today. If you do a rotation of crops during the whole year, we would also have a year-round evapotranspiration. Wheat in winter, soy in summer or you could also do wheat in winter, soy in summer and another production period of wheat in autumn. But because the rentability of wheat is not comparable with the one of soy, we only see soy fields here. Every year, there are 6 or 7 months, in which the soils are blank and there is no evapotranspiration. And in addition, we continue contaminating our basin more and more with the pesticides that cause these blank fields after the production period ended. The lack of wet lagoons, in addition has the disadvantage that in dry periods, as we face today, many farmers loose high percentages of their crops because of a lack of water that before was stored in the lagoons. It is difficult to balance, because either you have your fields flooded or completely dried out. Argentina has such an enormous size, with accordingly huge natural resources that it is not necessary to take care of each and every single hectare. While in Germany, you would probably take care of this hectare, here we can easily compensate it. That is a problem.

   From my point of view, nature has an enormous capacity to regulate the hydrological cycle, like it did before humans intervened, and we must try to come back to a more ecological thinking. I think many people are aware of the fact that nature has these abilities, but a long history of political incentives, to produce soy, made it impossible to survive with an ecological approach. Eucalyptus consumes approximately 150 l water each day, which it pumps from the groundwater. Thousands of eucalyptuses could help solving our problem. But it is also difficult to replace a eucalyptus that used to be more than 50 years old, pumping and consuming 150 l/day. If today I plant a eucalyptus tree, I will not see it reach 50 years anymore, and it wont pump more than 20 l/day for a long time. What we already lost, the regulation capacity of nature is immense. And we are aware now, but this awareness is very young. We already lost a lot of time. To better include nature in the problem-solving process, we need a strategic management plan for the whole basin. I am not powerful in this respect, not even the three provinces are powerful enough to make decisions.

   We see an international road cut-off and hundreds of families threatened to lose their land and belongings. But we must continue fighting, because if not, nobody cares about us. More ecological solution approaches, like planting eucalyptuses, could also be a more autonomous approach that decreases the dependence of my village to the disagreement of the three provinces. But still, even if we organize ourselves, we are still dependent on the whole basin, because we receive water from the whole basin. Strengthening nature is a very nice approach, really complex and difficult, but it is not impossible.

Interview 4: Alberto Diez, local producer with flooded farmland area, 08:30-10:00; 19.04.2018, Rufino

1) In 1963 when I arrived here, I was 15 years old, the lagoon only had a surface of 5000 hectares. Today it has more than 50.000 hectares - it experienced an 11-fold increase in its size. What the story tells us is that this is a low-lying and closed water basin. Our problem is that the whole basin is sending us water and we do not have a natural exit of the water. Consequently, we need a constructed solution, but the provinces involved, especially Santa Fe and Buenos Aires, are not negotiating successfully.

This whole region used to be a cattle production area. 40 years ago, we still had cattle everywhere. My father had 400 cows and we left them in the Pampa. They had everything they needed there, to grow and give milk. Today we only see crops. There has been a complete change of the productive system 30 years ago. The major trigger for this change were political incentives for producing cereals instead of cattle. This new type of agriculture evapotranspirates less water than the cattle production system. We have a political problem here. The three provinces implemented pumping stations to enable the water discharge via the South- and the North-Alternative, but from all these pumping stations only one is actually functioning.

The reunions of the committee of the basin, are taking place, but if you are there for 15 years, repeating the same things over and over again and nothing changes, the people involved get tired. This is what is happening. They do not find solutions, the next flooding events already happened or are about to happen in the near future. The causes for the increasing size of the lagoon are all the illegal canals constructed in Córdoba, without having in mind that anthropogenic intervention in the system, changes the whole water balance. I think there is more water coming from up-stream. We do not have an integrated management concept that guides through the system. Whoever wants to start construction canals, is able to do so. We have a general problem. The actions are not based on scientific studies, they are not existing here. If a farmer has 1500 hectares water logged and he knows that a drainage system would allow him to produce on these hectares, he builds a canal. Every farmer is only thinking in his own benefits without mentioning the systemic consequences of his actions.

Evapotranspiration and the climate is helping us a lot now. The water level of the lagoon is decreasing a lot with the evaporation and because we had very few rainfall events in the last months. The amount of water that these small canals and the pumping station discharge, is almost unnoticeable. The water level is sinking, but not due to the constructed infrastructure, but due to evaporation.

2) The landowner in the area are especially affected by the flooding of the La Picasa lagoon. I expect the responsible persons in the three provinces to find a solution, but they are not successful so far. This is affecting all of us here in Rufino and also in Aarón Castellanos. There are very little cases, in which former farmers transformed their profession successfully and even benefited from it. I think the best possibilities to do so have the people in Aarón Castellanos because they are close to the water. They are most threatened, of course, but they also have the possibility to use their land for other purposes than farming like for example for touristic purposes.

There are also some activities related to fishing, but the amount of fish harvested is declining, so I guess we already broke the sustainable amount of fish that can be harvested without causing damage to the ecosystem. But people will not stop. Fishing developed into a major activity in Aarón Castellanos. It is even more – it became an economic and beneficial activity. Many fishermen stay overnight, and huts were constructed in the village to provide the necessary infrastructure. These activities are not organized in a group or institution, neither are there entry fees to the lagoon or for fishing. The fish harvested is sold in this region.

Many former farmers had to find an additional income source to survive. For years already, I run a small motorbike shop in Rufino, where I sell motorbikes and everything you need for your bike to secure my income. My land is flooded, and these flooding events have cycles, so I do not know, when my land will be free of water and if the soils will be productive again. I had no other chance than finding another income source than agricultural production.

Many people also left this region and migrated to Buenos Aires or moved back to their hometowns. Many left their land abandoned until they know what to do with it, if the water is sinking. There are single cases, where farmers committed suicide. A neighbor of mine and Alfredo Raparo for example shot himself. It is very hard to looses everything. And especially when you are already more than 70 years old, you grew up on this land, your parents worked hard for this land and you do not see any other possibility. There are people that do not find a solution for their situation and the State is not helping us. Sometimes they ask, “How can we help you”, but in the end, they never act accordingly.

Many people who rented the land have companies that come to work in the fields during the busiest time in the season. But this is getting less and less because the farmers here lost a lot of land to work on. Many times, the farmers live in the villages, not on their land, because the production becomes less and less work intensive. Today we need much less people to work on the farms, than before.

We have the Route N°7 cut-off, which is a national road. People living in Mendoza or Buenos Aires do not pass through here anymore. This implies huge economic losses. We are only 400-450 km from Buenos Aires, but people do not come to spend their vacations here.

I observed changes in the species that can be found here, today. The water brought species that we never had before. I saw many vipers, water hyacinths and river fish species, where nobody knows where they come from. Many species that always used to be here in return disappeared.

Key stakeholders are the landowners and the government of Santa Fe and Buenos Aires. I have been very involved in this thematic. I participated in the meetings of the basin committee, but whenever there was a difficult decision to take, the responsible persons could not find an agreement and went to court. This takes so much time that the basin committee is inefficient. In addition, from my point of view, the provinces also have other priorities. The problem we face is a political one and we also must search for solutions on this level. But the only stakeholders who are really interested in a solution and keep holding this committee alive are farmers and not politicians.

3) We face an inertia and I believe the time will pass, another generation will be responsible for the farms, but still the general behavior will not change. People will continue focusing on their own benefits without thinking about the consequences for the entire system. This is a very limited mindset, but I lost my believe in an improvement of the situation. The management approach of this basin is

completely disorganized. The people must trust in the management decisions, too, to achieve a central management of the basin. This is not that easily achievable, especially when it seems like the politicians follow a hidden agenda.

The land use change will not change significantly, if political incentives do not change extremely. I think to finally achieve a change, the priorities of the responsible parts above must change. There must only be one influential politician, whose land is affected by the flooding of the La Picasa lagoon and the whole situation would change. We are unlucky that in our neighborhood, there is not one single owner with a lot of power and influence, so we are forgotten and the last point on the priority list of politicians.

Walter Ramanzín built 6 vacation apartments in the backyard of his house, which indicates in which direction the situation is developing. He is heavily affected by the increasing water level, the dikes almost broke during the last flood. Many people left Aarón Castellanos to the surrounding villages. The village today has a population of 340 persons and almost 100 persons migrated out of it.

I do not believe in a change because people are so inert. Maybe I am the wrong person to talk to you, because my land is water logged and nothing changes for years. I have seen so many charlatans, not charlatans – people with good intentions, but in the end, they do not have the money or power to cause this change. I am frustrated with this situation. My land is flooded, my house is destroyed, they stole everything out of my house – the kitchen, electronics, my dad's old trophies, everything – I do not believe in a solution. We are already facing this situation for more than 15 years. For me the solutions must be top-down organized. We landowners are in the lowest decision-making level and therefore we cannot find a solution. We can try to create pressure, to make the ones above finally take decisions, but nothing else and that is frustrating.

Maybe this situation is wanted, to prevent floods in other regions. It is obvious that it is wanted that everyone sends its water to this lagoon and not somewhere else. The lagoon increased tremendously in such a short period of time. The negotiation is unbalanced.

The shallow lagoons in this region have always been wet and evaporating a lot of water. I see it important to recover them, but I see it very complicated because of all the illegal canals. In addition, most are on private land and not all farmers do not support this development. Although the lagoons are part of the regulation of the system. I think it is possible to achieve this, but I know how complicated it is to bring all the parts together. This has to be an approach in which the whole basin is cooperating, and I doubt that this will happen here, in the short-term.

Interview 5-7: Diego Milardovich (DM), Coordinator of Region 5 "Nodo Venado Tuerto" in the Ministery "Gobierno y Reforma" from the Province Santa Fe; Carlos Castagnani (CC), President of CARSFE (Confederación de Asociaciones Rurales de Santa Fe), Claudio Berrueta (CB), local farmer impacted by the increase of size in the lagoon La Picasa; 11:45-13:00; 19.04.2018, Venado Tuerto

1) DM: For decades already, a project exists to find innovative solutions for the problem we face with the La Picasa basin. The problem is the execution of this project. The construction of canal was started with detonations that was supposed to create the necessary water exit towards Buenos Aires, but after this, nothing else was done. Then the two alternatives, the South- and the North-Alternative came up, but what happened? At the same time, many canals were constructed in the upper part of the basin. Consequently, all the water was sent towards the La Picasa lagoon before having defined an exit solution. This is a summary of the problems that this project faces. In few years one of many shallow lagoons of the region that nobody knew, transformed into a lagoon with thousand of hectares surface area.

   I think the trigger of this problem, is the mismanagement of this region. One basin should not be managed by distinct provinces, like in this case. Hydrological basins do not respect political boarders. The three provinces are not able to find a solution for how to manage the water resources of this basin. A basin should have an integrated management with only one director taking decisions based on scientific information.

   CC: What we are lacking today, is that we work together. Everyone works on their own and in their own interest, but unfortunately, who must pay for the consequences of this inefficiency, is the farmers of this region. This inefficiency caused huge social damage to the population living here. Many families have flooded land, farms and homes. We need a change in mentality, so that we stop playing political games with the people living here.

   In my opinion, what changed is the climate, because today we have higher precipitation values (DM: 100 and a bit mm/year more), and the technology. The seeding technology went through an impressive change in the last years. The no-tillage approach of the direct seeding technology makes it possible to have agriculture in areas that were not productive before. An additional advantage is the higher profitability of agriculture rather than livestock production.

   DM: There is a rapid advance of the agricultural sector over traditional livestock production areas, mainly due to the direct seeding technologies, the new herbicides, and progresses in genetically modified organisms (GMOs) like soybean. In areas where before you could have four cows in one hectare, now farmers are able to produce cereals more profitable. This area used to be dominated by grasses, especially Gramineae with rhizomes. Only with the appearance of glyphosate a transformation of this landscape for agricultural reasons was possible. Before, it was only possible to do livestock farming because it was very expensive to control the grasses mechanically. The soybean appeared in Argentina in the end of the 1970s, while the process of direct seeding appeared in the end of 1980s to the beginning of the 1990s. All of this is part of the green revolution. As we are contemporaries of this revolution, I think we cannot picture the whole dimension of this change.

   Another important phenomenon in this region is the displacement of the farmers. 75% of the total land in the La Picasa basin, is managed by tenants – persons who are not the landowners. No law exists that protects the land from being unsustainably managed.

Most contracts are contracts over a time period of one year, which results in short-term thinking and profit maximization instead of protecting the soils and a sustainable rotation of crops. While the system of a soy monoculture makes absolutely sense from a profitability perspective, it highly affects the hydrological cycle. Soy in a monoculture consumes approximately 400-600 mm/year, while this region has a medium precipitation value of 900-1200 mm/year. In addition, the rainfalls are more intensive, meaning that the rainfall events, bring more rain in a short period of time. And we have the blank fields – there is not one crop, no grass that would slow down these water masses. The whole basin faces a faster run-off process due to this monoculture. We work with a logic that 70% of the precipitation infiltrates into the soil and 30% are the run-off. With this situation, I think that we face the opposite of this logic.

CB: We realize that in heavy rainfall events we have a lot of run-off and in the softer rains that we are more used to, a much bigger percentage of the precipitation infiltrates into the soil, and we have much less run-off.

CC: It always depends on the point of view, when discussing about what the major problems are: If you ask me, what is the general problem in this region, I have to tell you, there are many topics. From my point of view, the primary problem is a lack of infrastructure. The second problem is that the Nation is not directing the three provinces involved to find a solution. Instead, we are stuck in their disagreement. The third problem is, the political incentives to produce cereals instead of cattle, because they are more profitable.

DM: I am totally convinced that with the second water exit in the North, we would have solved the problem. I heard about the most bizarre theories, like for example a navigable canal – I think, who had this idea, is a case for psychological treatment. The two alternatives together could solve our problem. We will always face humid periods. In the next humid period, the water levels of the La Picasa lagoon will most probably increase even further. But with two alternatives we would not have a problem. Therefore, I agree with Carlos: There is a lack of infrastructure, a lack of attention, a lack of management.

CB: From my point of view, it is mainly the lack of management. The Salado river is completely dry. The possibility exists to regulate the water, so we do not face further floods. This is a negotiation point with Buenos Aires – we must find an agreement with them, so that the water levels will be regulated in the future.

DM: I want to add another point to this discussion. I see there is a lack of a general understanding of the environment and water resources in specific. I saw the same farmers who were asking for the drainage of the shallow lagoons on their land, announcing emergency cases in dry periods, because they had a lack of water. There is a huge lack of awareness and understanding among farmers, which role the water of the lagoons plays in the production cycle. There are areas in this region that are naturally not adequate for agricultural production. Especially in humid periods, it becomes obvious that this natural order sometimes exceeds the human ability to shape its environment. What we observe here, is a complete mismanagement of water resources. Many people believe that a good management of water resources is to only find solutions for the discharge of water. In many cases this is true, but in our case, it is not – or it is even unnatural, because the basin naturally is an endorheic basin. Naturally, there exists an infinite number of shallow lagoons in the basin that appear in humid periods and disappear or shrink in dry periods. They used to be a natural regulator. That is the natural situation of our region – it is not true that we are only flooded, because we receive an additional amount of water, but up to a certain amount, these floods are natural. The floods we face are groundwater flooding events. The problem we face is not the lagoon La Picasa itself, but the rising level of groundwater caused by a mismanagement of water resources and the monocultural approach of this region.

2) From my point of view, a key stakeholder in this problem situation, which was absent for a long time, is the Nation. This basin involves the three provinces of Córdoba, Santa Fe and Buenos Aires, which all have a different legislation. Accordingly, they also have different approaches to manage water resources and are still trying to find a consensus in this. They need a certain kind of organization which could be the role of the state. Then, of course we need better cooperation between the three provinces.
Fundamental is also the role of the basin committee, but the committee that exists today, in which Santa Fe plays a vital role, is an incomplete basin committee. The only stakeholders it represents are farmers, but in reality, the basin is much more divers.

CB: The basin committees do also exist, because there was a deficiency of the Nation, to solve the issue. Framers should not be in charge of solving hydrological management questions, this is the Nations tasks, but the state has other priorities.

DM: Anyways, it is necessary that the farmers are also represented in the committee and are participating in the process of finding a solution instead of just getting order from above what to do.

CB: The most affected party of this problem situation are the inhabitants of this region.

DM: We have whole villages flooded, roads cut-off like the national Route N°7, we face a terrible economic problem, because every economic service that exists around traffic routes, is unnecessary. Approximately more than 70% of the economic volume generated in this region, moves around in the regional communities, and they all depend on the primary sector.

CC: I have a vision. I do not think that anyone is benefitting from this situation, but I think that fishing offers a lot of opportunities. Usually, the ones working in this field have not been fishermen before but are the ones who have their land flooded and try to find a way to survive. I think, if all the sectors would cooperate, all would benefit from it. Here we are in sector N°5 – we have a total amount of 19 sectors in this region. Just imagine, in every sector, 5 fishes are caught each day. This is almost 100 fishes caught per day in all of the sectors together, which means 36.000 fishes per year. If you sell each of the fishes for 10.000$ (ARG), this is a huge economic fortune.

CB: The Nation's and provinces' failure to efficiently manage the water resources of the basin resulted in farmers getting organized in small groups to foster more political pressure and a change in this.

DM: The farmers do not have a common view on the problem. In the south they blame the farmers in the north and in the north, they do not care about the suffering of farmers in the south. But the logic behind this problem is relatively easy: Either we solve the problem of all, working together, or we will not solve the problem of any one. This is also a cultural question and requires a change of mindsets.

CB: Illegal canals in our region cause the area to dry out much faster after precipitation events than they usually would do.

CC: The presence of these illegal canals is due to an absent of control from the Nation or the provinces. I am not justifying their construction, but the canals are a result of an absence of political regulation.

DM: From my point of view, these illegal canals are the result of two things: The lack of control and the impunity of people acting against existing rules. If these two points would work out, the state would not have such an amount of bureaucracy and could solve these issues by activating control mechanisms. There are even cases, where people knowingly accepted the punishments for draining the land, because they knew they would generate more money with the agricultural production enabled by the canal, than he would lose by paying the punishment. He saw it as a cost in his balance sheet.

3) CB: We need an integrated management for this region, we need a committee that represents all stakeholders and the entire basin. The current committee is partial because only Santa Fe acts as an agent for it.

CC: A change in the current land use patterns towards more diversity with grasses and cattle production in between, could be a reasonable scenario.

DM: We need to establish clear rules for farmers, because currently they are only following the political incentives to produce as much soybeans as possible. They do not have any other choice than producing soy, because they would not survive producing livestock. As soon as the state promotes a diversification of the agricultural model in this region, giving more attention to the problems, the monoculture generates today, I think we would quickly see a diversity of products grown here. The state is a fundamental stakeholder and responsible for setting the frame for our acting.

CC: I think a solution for this problem, will take a lot of time. Of course, we are responsible to foster this solution, but we are dependent on many exterior influences, political decisions, market developments and the climate.

DM: From my point of view, ecological solution approaches are important, but it is difficult for us to protect lagoons, because the social pressure is immense. We cannot justify keeping lagoons just for the protection of a dug, when people feel threatened to get flooded.

CB: In addition, many of the lagoons do have ecological problems, too. We see a lot of non-native species, the lagoons have a lack of oxygen or dry out, so the fishes die. What went wrong, is that the canals are constructed in a way that they dry out the lagoons and do not prevent them to flood their surroundings. But these shallow lagoons are an important part of the hydrological cycle and responsible for the regulation of it. They could buffer the effect of rainfall events on the water levels of the La Picasa lagoon and also on the groundwater level.

DM: The state and the farmers should intend to fulfill their roles in this system: The farmers have to know, which kind of land they own or manage, if their land is prone to floods, they have to accept this. The state should assure that in the case of floods, farmers have an alternative income, the access to their land is secured, and that they get compensated for what they lost. They should introduce insurances for the affected farmers. Insurances should be an integrated part in the sustainable management of water resources.

Interview 8-9: Javier Tricarico (JT), Responsable agricultura por la empresa Adecoagro; Alfredo Raparo (AR), local landowner and expert especially for hydrologic engineering solutions, 14:15-15-15; 19.04.2018, Christophersen

1) JT: In this region lagoons are natural and since there are people in this region, also registers exists about these lagoons. They vary naturally with climatic variability of wet and dry periods and appear, disappear or connect with each other depending on the amount of precipitation. The necessity to understand this natural system already exists till the first colonizers settled down in this region. I am an agricultural engineer from Buenos Aires and live here for 12 years. I did not grow up here, so I cannot give you information about how the system changed from my own experience, but I know, there were always fluctuations in the water level of the lagoons, depending on dry and wet periods.

When I arrived in this region, the green revolution already had changed the land use of this area from cattle production with natural pastures or Gramineae towards soy monocultures. When the first colonization started the natural vegetation, which was composed of species that appear after flooding events, only allowed for livestock farming with cows or sheep. With the years, the objectives of agriculture changed and today soy, maize and wheat are the three most produced crops in this region.

AR: There are two perspectives on the change this region faced: From a hydrological point of view, we are talking about a land use change. From an agronomic point of view, we are talking about a transformation from tillage to no-tillage practices. For the hydrological cycle, it is of tremendous importance, when fields stay without a vegetative cover for 6 months a year, because it has immense effects on the evapotranspiration. From an economic perspective this makes absolutely sense, because it is the most cost-effective form to produce.

An intensive agriculture started in the 1970s with the use of machinery. Before, each farmer could seed not more than 30 hectares because the seeding demanded a lot of workforce. When the first tractors appeared in the 1960s, they were used by some farmers

with traditional tillage practices, but they did not yet bring the big revolution. When the no-tillage technology started, the agronomic perspective considered it as a water and soil conservation technique. Nowadays, it is a problem that less water is lost from the soil. A rotation with soybeans and wheat consumes 1100 mm/year which is similar to the amount of water consumed by natural pasture.

JT: What we are trying to do in this company is to use the maximum amount of water available in the soil as part of our production cycle. On average, water is a limiting factor for production in this area. In this context only two crops could be grown each year – one in summer and one in winter. The rain water is normally not sufficient for this rotation cycle. Therefore, we are obliged to leave areas of our farm without crops to be able to retain more water in the soils. Consequently, the common saying that agriculture is the main responsible for floods in this region is not true. Sometimes the water use of crops is higher than the precipitation provides, and sometimes it is less.

AR: The no-tillage technology allows to grow crops in years with less than 600 mm/year precipitation. But in years with 1300 mm/year precipitation you could have floods. The objective of no-tillage technologies is soil and water conservation.

JT: Nowadays, we take a step further in this direct-seeding technology by using cover crops. They have a double function: They keep the soil covered with living crops for a longer period with the services of creating soil structure, providing organic matter and they consume the water excess in humid years. It is not recommendable to use them every year, but in years with water excess they are very senseful.

The main problem in the La Picasa basin that I see, is that the water inflow from the upper part of the basin outweighs the possibility of water discharge in the lower part of the basin. The cause of this problem is the lack of infrastructure to extract water from the basin. You have infrastructure to direct water in the basin, but no infrastructure to discharge it. What I see is that during floods the fields located upstream are dry while the fields located downstream are flooded. The canals drain a considerable amount of water, directing the water to the lagoon and the lagoon was increasing in size. There is ten times less capacity to discharge water out of the lagoon than to bring water into the lagoon. Like this it is impossible to maintain water levels stable. Without this infrastructure part of the water would have been retained in low lands in the upper basin.

AR: In one of the canals bringing water to the lagoon, 70 m^3/s were registered where it should have been 12 m^3/s if all the provinces would have respected the agreements.

JT: Since this basin is an interjurisdictional basin, the three provinces should take prevention measures to avoid these problems.

2) The main decision makers are the provincial governments, since they define the amount of water to be drained from the lagoon. Second is the basin committee with the affected farmers, because they have a strong interest in this topic.

AR: For example, when in 2001 I presented an alternative of discharging water from the lagoon into the Arollo del Medio river, which is dividing Santa Fe and Buenos Aires, Buenos Aires blocked this project immediately.

JT: The most affected stakeholders of this region are the farmers. Adecoagro is also affected by the floods. The ones who benefit from this situation are the farmers in the upper part of the basin.

3) Adecoagro in specific follows an approach to integrate livestock production into the agricultural practices. I think this is a model that will rise in the future and it will be accompanied by a rise of new tools for direct-seeding practices.

AR: The shallow lagoons in the area, La Picasa excluded, usually do have a depth of around 1,00-1,50 m. Evaporation values in this region are 1500 mm/year while, in dry periods, precipitation is only 500-600 mm/year. Consequently, these shallow lagoons evaporate completely and disappear. You cannot save the water in the lagoons for irrigation purposes. Groundwater storages do generally also decrease in dry periods and are also dependent on economic situations, because it is costly to pump the water up. One equipment costs 100.000 US$ on average. This is only an option for companies but not for private landowners.

JT: On the contrary, the lagoons do serve as water storages in humid periods, when water is available in excess. The lagoons fill up and store the water in these wet periods, but also disappear in humid periods. Consequently, in dry periods, when we would need the water storage capacity of the lagoons for irrigation, the lagoons do not serve, and in wet periods, when we have more than enough water they are filled or even flood our land.

AR: Nevertheless, we should not drain all the lagoons, because they do have a function in the hydrological cycle. Many farmers did lower the water levels just to avoid any concern. I know there is the idea to restore some wetlands and foster their evaporation. But this is playing a double game. The technical design of the drainage canals must be adapted to both humid and wet periods at the same time. If you design it for wet periods, in dry periods it leads to completely dried out lagoons. If you design it for dry periods, in wet periods the water is flowing above the drainage canals. Water always finds its way. It is very difficult to find an equilibrium in this question and, from my perspective, also more theoretical than practical. I agree that we should not drain lagoons just to drain them, if they do not threaten anything, but I am not convinced of the storage capacity reasoning behind it. As soon as we have two humid years, there will not be any storage capacity left. This is what we see, when we compare the flooding events of 2001 and now. In 2001 the canals did not exist and still we had floods. Today, with the canals, the floods are only more visible, but it is the same process as in 2001. Yes, the canals do accelerate the velocity of the water flow, but they did not change the process itself.

We face a similar challenge with the reservoirs designed to storage water after heavy rainfall events. Of course, it is true that the water should not be discharged as fast as currently practiced, so the water can evaporate over some months within the reservoirs. At the same time, the reservoirs must be in an equilibrium, so they evaporate but could also store the next precipitation. If we have two heavy rainfall events in a brief period of time, the reservoirs are already flowing over. If this is not working, it makes no sense to have reservoirs. They are temporary storages only to win some time after precipitation events – flood detention reservoirs.

JT: The myth that the land use has so much influence on the hydrological cycle that it causes the current flooding of La Picasa cannot be proofed with past flooding events. Anyways, it is the easiest way to find someone to blame the guilt on.

Interview 10-15: Juan Carlos Duhalde (JCD), Presidente del Comite Interjurisdicional de la Cuenca La Picasa; Armando Rey (ArR), Presidente de la Asociación Productores del Sur de Santa Fe; Federico Furno (FF), local farmer impacted by the increase of size in the lagoon La Picasa; Omar Maurizi (OM), local farmer impacted by the increase of size in the lagoon La Picasa; Mirtha Más (MM), local farmer impacted by the increase of size in the lagoon La Picasa; Alfredo Raparo (AR), local landowner and expert especially for hydrologic engineering solutions; 16:30-18:00; 19.04.2018, San Gregorio

1) JCD: This area originally has been a cattle production region for 100%. With the years, the agriculture developed and today this region is mainly producing cereals. If this question has the intention, to find out about if the changing water levels of the lagoon have a relation to the land use change, in my opinion – and I do not have hydrological expertise, if humans would not have intervened in the system of the La Picasa basin, the lagoon would have never increased that much. Before the canals were constructed, it rained in Laboulaye and until the water reached the La Picasa lagoon, it needed 40-45 days. Today it rains in Laboulaye and until the water arrives here it only takes 4 days. The run-off process was accelerated by the canals and all the lagoons that used to store the water in the upper basin, are now collected in the La Picasa lagoon.

   FF: In my childhood, the lagoon was increasing and decreasing between 0 and 5000 hectares. I remember that in the year 1970 the lagoon was very shallow, so my dad could even cross it on a horse. He had to wear sunglasses against the reflection of the salts on the floor. That used to be normal in dry periods.

   JCD: The canals that were constructed, appeared before we had any exit for these water masses.

   OM: Besides, this basin is endorheic. If we did not create an artificial water exit, no water would have left this basin at all. That is how we end up with a surface of 40.000 hectares surface of the La Picasa lagoon.

   MM: Before the canals were build, nobody ever talked about the “La Picasa basin”. “La Picasa” was only a small lagoon. When the construction works finished, the basin of our lagoon increased in size immediately and with it, the water levels of the lagoon.

   ArR: In addition, another problem we face, is that the villages in the east of the lagoon, especially Diego de Alvear and San Gregorio, which are very close to the lagoon, are prone to floods when the water levels of the lagoon continue rising. And they are not only prone to floods caused by La Picasa, but also caused by groundwater. The groundwater level today is very high, but luckily, we face a dry period and therefore the process works in the opposite direction. Now, both the water level of the lagoon and the groundwater level are sinking, but we are aware of the threat of groundwater flooding.

   MM: The ones who suffer most from this situation are the villages in the east of the lagoon.

   ArR: In the 1970s the precipitation values were around 600-800 mm/year. Nowadays it is between 1200-1300 mm/year. San Luis was a desert and a new river appeared. Now, San Luis is one of the best places for agriculture the only problem is the hail. Same can be observed in the La Pampa province which used to be a desert and today is flooded. Nevertheless, the main cause of floods in this area has an anthropogenic origin.

   JCD: Even with this increase in precipitation, it would be absolutely possible to maintain the lagoon within a stable water level, if both water exits, the South- and North-Alternative would function. In 2007, the year with the highest precipitation measured in this area, 18 m^3/s flew into the lagoon on average. If you add the two water exits with each 10-11 m^3/s and the evaporation, the lagoon should not have increased in size. In fact, what happened is that the past 5 years, nothing was done to test the functioning of these two water exits and when the heavy precipitation occurred, they did not work well.

2) I do not know, if the other provinces have a committee, but we have created a basin committee here in this area that represents the farmers in Santa Fe and covers everything that is related to the La Picasa lagoon and the North-Alternative water exit as well as the canals that are necessary for this exit. I think the other provinces do also have committees, Buenos Aires for example has something like a basin committee. They have a basin committee for the Salado river which also covers parts of the La Picasa problematic. And Córdoba does not have a basin committee in this sense, but consortia for canals and roads. They function much faster than we do, because we always must ask for permission, while Córdoba starts with the constructions right away.

   OM: They even do TV propagandas, showing how fast they are in constructing canals, while, in fact, they are creating problems to Santa Fe. The problem is that they did not plan from downstream to upstream, but the other way around. Córdoba is just solving its own issues without considering the effects their acting implies for other provinces.

   FF: I agree, it would have been fundamental to propose a basin management plan the other way around: From downstream to upstream.

AR: The fact that the planning could have been done from downstream to upstream, does not guarantee that Buenos Aires would have accepted the water from La Picasa.

FF: Yes that is right, but at least we would have the possibility for a higher evaporation in the basin before the water leaves it.

AR: If Buenos Aires accepts a national road to be cut-off, I do not count on their support.

JCD: The basin committee from Santa Fe is composed of the 11 districts that this region is made up from, belonging to the 11 villages of this area. The farmers of each of these districts choose four representatives, and each of the communes choose two public officers, and two surrogates. In total, the committee is made up of 88 members, from which 4 persons are elected to be the executive authorities. These 4 persons cannot be from the communes, because the internal rules of procedure empower the farmers of this region. The Communes are integrated in this committee´s assembly, but not in the executive authorities, which are managing this committee. In addition, we are obliged to have an engineer in the committee, which is designated from the province of Santa Fe, which fulfills the role of the technical secretary. Without this engineer's technical understanding, we could not do anything. We are mainly responsible for the administrative tasks. The one who decides with measures we finally should implement is this technical secretary.

MM: Apart from the commune and the farmers, also the hydrological sector is represented in this basin committee, which is basically the technical secretary. But apart from that, no other stakeholders are represented in this committee.

JCD: Just one week ago, we had a meeting with all the three provincial basin committees about La Picasa. The topic of the new water law came up, and one of the points that are included in this law is a reform of the functioning of the committee that also embraces, which parts should additionally be included in the committee, like stakeholders of the industrial sector, responsible parts for infrastructural planning, which stakeholders are interested. Although we already work on these reforms, until today it is not existing.

FF: The touristic sector could also be an interested stakeholder, but until now, they are not involved in the committee, neither do they show any interest to be included.

AR: To try this touristic development, there was a discussion about to pronounce the lagoon a Ramsar Site. But that would mean that for years, we could not execute any construction works around the lagoon. People are afraid that we lose the option to intervene in critical situations, if the lagoon La Picasa becomes a Ramsar Site. In Melincué they do not have the same problematic with rising water levels as we have here, so it was relatively easy for them. Here it is almost impossible, although we have species like the flamingos that would allow this lagoon to become a Ramsar site technically speaking.

MM: For me it would be fine, if they announce this lagoon a Ramsar site as long as they regulate the water discharge of this lagoon, so we can come back to the lives we had before the increase of the lagoon.

JCD: What should also be considered in this respect is that it is easy for the province, to plan a touristic area in this region, but we, the farmers, are the owners of the land that surrounds La Picasa. What today is part of the lagoon, used to be land when we bought the land. We want to recover the land to produce there again. It has an economic value for us. We are not interested in doing tourism there. Maybe it could be interesting for other people, anyways.

MM: I do not think that it is a viable option to combine agricultural production with tourism. It is either or and I would decide for agriculture on my land. With tourism you do not have the same liquidity as you have with agricultural production.

ArR: It also depends on the economic resources, if you can afford, to transform your land from agriculture into a touristic area. Not everyone here has this option.

I think the only beneficiary of this situation is Buenos Aires, because it refuses to accept the water masses.

JCD: I do not completely agree, because still Buenos Aires is receiving a lot of water from Córdoba and Santa Fe. From my point of view, more benefitting, are the farmers in the upper part of the basin, who constructed the network of illegal canals.

3) If all three provinces would act accordingly to the rules that the interjurisdictional basin committee sets, and if all the work would be done to support the necessary infrastructure, to establish a water exit, the problem we face at the moment would be solved.
MM: Juan Carlos Bertoni mentioned that the infrastructural planning for this hydrological basin, with the change in climate and technology, became inadequate to solve the problem we face.

AR: In my eyes, the biggest mistake of the current planning is, the lack of adequate water exits while more and more illegal canals appear. Anyways, I think, the construction of it will be difficult because Buenos Aires is blocking it.

MM: There has never been an agreement that Buenos Aires would accept more than the 5 m^3/s that it already receives via the South-Alternative. The North-Alternative was done anyways, and Buenos Aires is not accepting the additional water.

AR: We are lacking the alternatives to find a solution. It was this water exit or nothing. And well, they created the North-Alternative in 2000.

MM: In 2000 we had a very similar situation like today. But all these illegal canals were not constructed yet, anyways, we faced floods.

JCD: Just a few days ago the province of Santa Fe has passed the new water law that gives us the capacity to control illegal canals when receiving a complaint from one of the farmers. This process is quite fast once a complaint is done, but the farmers are not very eager to act against other farmers.

ArR: I think this is a process that will need a lot of time, but I think farmers will eventually start complaining, because they are also affected by the illegal canals.

FF: I think we face a diverse problem. Lack of infrastructure, illegal canals, missing water exit, lack of control, called it however you want. We need an improvement in all of it and, what I see necessary to achieve this, is a controlling instance. This function could be fulfilled by the interjurisdictional basin committee.

OM: For a long time already, they are sending us 70 m^3/s while the reservoirs number 3, 4 and 5 were not finished. Now they are, because the province of Santa Fe fixed them. That is the point. The problem is that the infrastructure was not finished when the water was already directed towards La Picasa.

JCD: What is happening, is that the interjurisdictional committee is exclusively composed of technicians and the farmers do not have any power to take decisions. Maybe this is one of the reasons why the infrastructure was not implemented. When I participated in one of the meetings, representing the Basin committee from Santa Fe, I did not understand what they were talking about, because they discussed technical issues. That is a problem. I think it is important that interested parties can participate in the decision-making processes of the interjurisdictional basin committee, too.

ArR: With respect to a more ecological land use, where lagoons or vegetation have a regulatory role in the hydrological cycle, I have to say that I see this scenario very unprobeable. Pastures that consume 1200 mm/year do not exist anymore, we do not have the infrastructure for livestock production anymore. Farmers are not farmers anymore, they are tenants.

FF: I also see a cattle production scenario very unprobeable, because the economy does not allow to work with cattle production. Nowadays, all the cattle farms are shut down.

ArR: It is difficult to establish ecological regulation measures, when the water from upstream continues flowing.

AR: What could be a possible approach to overcome this, is that the farmers receive payments for ecosystem services, for their loss of profit while fostering the functioning of ecosystems.

MM: Which farmer would believe in this? Nobody would believe in this, because nobody would pay us for conserving ecosystems.

JCD: When you talk about the impact of the lagoon, you must consider that in the area occupied by the lagoon, between 25.000 and 30.000 calves where weaned. If you consider that we have this flooding problem for the last 15 years, at 20.000 calves a year, this is 300.000 calves in total. If one accounts 10.000 $ ARG for each of them, this is already a sum that equals the amount of money the government must pay for the water exit via the Paraná river. And this is not an unrealistic number, here we are talking about the worst fields in this region.

When you ask me if it is possible to have a greener scenario in the future, I have to tell you that when someone from Rufino come and tells me I have to grow plants, I would kill this person. Farmers do not like it, when someone tells them what to do.

Integrated water management is part of an integrated water policy. In other countries farmers are oriented towards what they should do but they receive payments for ecosystem services, which is impossible here. Here we harvest, and the government takes fees. That could be a starting point for a consensus building and the economic view should be taken into account. We know that with a better management more water could evaporate.

OM: From my point of view this is the last option for a future scenario.

JCD: Every farmer has its own opinion, and everyone believes to know the truth. All farmers transformed into hydrological experts.

Interview 16-18: Esteban Jobbágy (EJ), Scientific researchers with a focus on eco-hydrological topics; Maria Poca (MP), Scientific researcher with a focus on ESS and biologist; Juan Ignacio Whithworth Hulse (JIWH), Scientific researcher with a focus on eco-agriculture and biologist; 10:00-12:30; 23.04.2018, San Luis

EJ: Some groups of farmers are very aware of their responsibility for the changes in the hydrological cycle. Especially the CREA groups, organized leading farmers in their region with influence on a national level, are conscious about their effects on the ESS of the hydrological regulation. They often perceive ESS as important for a proper functioning of their agricultural production process. At least that is my experience. Most private farmers, in contrary, are usually not aware about how much influence they have on the hydrological regulation.

Apart from this ESS many farmers are not aware of or have no interest for other ESS like habitat quality. I made the experience that people living in an urban environment close to agricultural land, value these other ESS higher than the farmers themselves. The perception of having the possibility for going fishing and having wildlife close, not having agro-chemicals close to your house, those values are usually brought by the settlers in the small villages and towns. Many farmers, or people in charge of the decisions, they do not live on the farms, but in Buenos Aires. Anyways, this is another issue. Rufino is the town who loses the most from the Route N°7 being cut-off. They became a dead end in

the middle of nowhere, while before Rufino was a major economic point along the road with service stations, restaurants, hotels, souvenir shops, and so on.

MP: I think describing all of these problems is very interesting, because they are not written down so far. Everybody is talking about it, but nobody has an overview.

EJ: Even if you cannot frame it in a very specific ESS, you can find words for that. Like this area has a rural area with inhabitants and the only possibility to live there is to have a minimum infrastructure. If they do not have it due to the flooding, they abandon these villages. They are abandoning it anyways, but this speeds up the process.

MP: And discussing about how the different solutions, well "the canals" or something else, are affecting the social structure of these villages, I think that is really interesting. A short analysis about that has never been done.

EJ: There is another thing that is interesting with the water balance. If you put a list of players from the youngest to the older ones, in charge of the land, you can put the larger influential one, the renters of soy fields on the top, the private farmers of maize fields below, then cattle farmers with mixed systems underneath and in the end the dairy farm, assume, the further down, the systems consume more water. But at the same time, the farming systems suffer more with the floods. Consequently, there is an interesting gap. If you are the renter of a field with soy beans, you are the one who suffers the floods the least. In a way, there is an implicit incentive of flooding the landscape, because it means, to open your niche as a renter more. You have it easier to beat the renting price down, when the flood recedes. So, this is an interesting disparity that nobody is discussing. Although this situation is affecting everybody, the least affected are those who affect the most, creating an interesting feedback on the system.

Another big question is, when the flood recedes, what happens with the soils? Actually, I think, this is perhaps the best opportunity to start exploring new land uses. The renter will not appear in the beginning, he will wait until others try and see how productive the land is. This is a niche that will come for alternative land uses.

The recovery of soils that used to be flooded, is also a positive feedback that you can break. If you do not do anything, the salts are accumulating in the surface. If you have some cover, the salts go down. The one who know a lot about that is Nico Berta who works with Pablo Bolatti. He has a lot of field experience in this type of questions.

1) EJ: About 10.000 years ago, first humans appear, and that is a big change. Then, there were changes through a lot of fires and the extinction of a range of herbivores.
During the colonization, the first big change in this landscape was the introduction of cattle about 400 years ago. Cattle behaved like a natural population, expanded all over the place and for a long time the system was under a wildlife management of the cows. Approximately 100 years ago, the first ranchers used the natural grasslands but also the beginning of the system of cultivation that was common in those days started in that period. The rancher rented a piece of land to poor immigrants arriving in that time, to do agriculture. The deal was that the immigrants could use the land for three years and give it back with alfalfa. That is the beginning of a system that became very strong in this region. 100 years ago, I would say, a lot of the landscape was natural grasslands, and there were now hotspots, close to the small towns that were the start of this system of rotational agriculture. Wheat, maize, maybe some flowers for three or four years and then the renter gives the land back to the owner with alfalfa. Now the owners realized that with alfalfa they were getting a lot more productivity than with the natural grasslands. This loop keeps going and by the 50s, this landscape developed into a patchwork of alfalfa and agriculture, rotating all the time. In the 80s and 90s the farmers started realizing that they did not need alfalfa, they could do agriculture every year, the prices of agriculture went up and the system transformed into a new system with continuous agriculture. This change was triggered by the no-tilt technologies. It first started with the idea that you can grow wheat and right after you finish it, you go on top the old crop and plant soybeans, so you do two crops in a year. This system was really successful. This region and mainly Marcos Juarez was the seed of that development. By the year 2000, there is very little patches of alfalfa, or alfalfa is gone. Those are the milestones.

   I believe that this region always used to a grassland. You have to go further west to find natural forests. I would say this was a grassland. So, I agree that using eucalyptus and other trees for bio-drainage would not fit in the frame of coming back to a natural state of the system. They would work, eucalyptus for example has a water consumption of approximately 1500 mm/year. The other one who is working that nobody has to work with but that is happening by itself, is the invasion with Tamarix. We are just seeing the beginning of that. The expansion of this invasive species is a very probable scenario on these salty areas. If Tamarix reaches here, you cannot stop it.

   Regarding the impact of land use changes, there is one point that no one talks about: When I started studying agronomy in the 80s, we had the first class talking about the decay of alfalfa plots. No one knew why alfalfa was yielding less and less in the 60s. My feeling today is that because alfalfa became about 50% or more of the area around the 50s, it probably dried down the system. The opposite happened of what we see today. That is my feeling. So, we went from grasslands with some level of flooding, to a higher evapotranspiration that came with the alfalfa, and now, all the way switching back, and even worse, to less water consumption with crops like soy, wheat and maize. It is not just about the annual evapotranspiration, it is also about how the plants can evapotranspire while the system is flooded. Annual crops stop consuming water when they get water logged, meanwhile the natural grasslands, as they have a lot of players, in the case of flooding some species always remain that still work really well and transpiration keeps going on all the time.

   MP: This is interesting to learn about, because if it worked back then, it may could work now, too.

EJ: On a timeline, I would say, the 20s were the boom of this rotation, a time of immigration. The immigrants arrived before that time, but they become a strong factor in the system then. We see a patchwork of Agriculture, Alfalfa and a lot of natural grasses at that time. In the 50s, the landscape is mainly composed of agriculture and alfalfa, which is still dominating the system. By the 80s/90s already, the system is characterized by a pure agricultural system with no-tillage technologies.
The according evapotranspiration diagram, ignoring the variability of rainfalls, would show an increase in evapotranspiration until the 20s and reaching its peak in the 50s, with the alfalfa depending production system, and starting to fall in the 80s and 90s with the beginning of no-tillage technologies and the cultivation of crops that have a lower water consumption.
The land use change within the La Picasa basin, together with some other factors, has changed the hydrological balance. I think the effect on the water balance has been important. There is very little information and it is very hard to construct the effects on run-off. We are talking all the time about the water balance and we do this simple assumption that whatever is not used, goes to the drainage. There are studies about that when the soils are saturated, the run-off is increased because of the slope of the dunes, which are characteristic in that area. But this only explains the fast response of La Picasa. Additionally, you have the slow response. When it stops raining, all the shallow lagoons start drying out and the La Picasa still keeps growing, with a strong delay. This is related to the groundwater system. The effect of sub-surface waters is huge. The easiest explanation that everybody brings, is that the water comes from somewhere else. But it is not the case in the La Picasa basin.

MP: I think it is not only about the land surface, but also about the lagoons and how they are connected. If one lagoon rises, does the next one rise, too? These questions are interesting to ask to find out where the water comes from.

EJ: All these canals what they do is accelerating the discharge. Illegal canals are everywhere in the region. There is also a lot of agro-chemical evidence that the groundwater supply is very important. The bottoms of these lagoons have a lot of gypsum. The saltiness of them cannot be explained with pure surface-flow. For many paths of evidence, I believe that he groundwater contribution becomes very clear. And that is important for the analysis of ESS. The ESS of preventing deep drainage from the plots in the water shed, is really significant. You can do the assumption that all this water that is left out of the root-zone and infiltrates in the groundwater, has the potential to prevent flooding here or somewhere else. It has a value, a negative value, which is the opposite to most ecosystem services that have a positive value. Here it is about having less. Every morning the world is talking about the global footprint of agricultural products – water is always missing. Here we face the opposite. We do not want so much water, but we want to come back to a system, where grasslands balanced the water cycle. Wetlands have the double functioning of evaporating water and at the same time infiltrating surface water into the groundwater. But people are not aware of this opportunity.

It would be interesting for a new batimetry study to check, whether the sedimentation process in the lagoon was important. With the two batimetries you can compare and see if closer to the canals you are getting sediments or not. I would open the assumption that groundwater can feed the lagoon La Picasa and can be substantial for the water supply.

2) Besides the farmers, which are the most obvious ones, all the people who are working with the logistics of the grains, transporters, stores, those are the first one to suffer excess water. More than the farmers. Than the population of the towns. They get flooded and they suffer more than most farmers. People with the logistics for milk production are also very affected of the flood. Another stakeholder, which is not local but has a huge power of influence, without knowing it sometimes, is the national government with its policies for agricultural products. For example, you close the exports of meat or you change the market of wheat and you immediately have an effect on evapotranspiration of the watershed. National governments are not direct stakeholders, but they have a strong influence on the system as indirect stakeholders. Farmer associations, like CREA, are stakeholders that have often have the necessary resources to be well-informed and technically well-equipped. Very important are also the small farmers, because they are some of the last people leaving their farm. In terms of the area they are not important, but in terms of the perception of environmental change, they are critical. Often these farmers are suffering that their children and grand-children are moving to the bigger cities.

If you are talking about the positive ecosystem services of the water, I am sure that in Rufino people value fishing and recreation close to the water. The water is very important to them. Especially in the context of this transition, where agriculture has eliminated every piece of wild land. Since the 80s to 90s, this was agriculture from fence to fence. There was no piece of wildlife left. And the water, in a way, is claiming it back.

I have the feeling that there are these positive feedbacks. This type of vegetation, so artificial, so managed, you cannot keep track of decreasing the water store. In the past, with grasslands, if you only have 50% of the area with a water table of 30 cm, in the grasslands you have a lot of components that are very happy with that and evaporate a lot of water – with agriculture it stops. The next stop of the water would be a lagoon, the direct incorporation to the lake.

MP: The question is, is there a turning back point?

EJ: Within the farming sight, the stakeholders, I would say, there is renters and owners that do not longer mange the farm but play an important role. Those are together. Then there are the owners that farms which in most cases are very big farms, companies like Adecoagro. Then there are the small farmers and finally, some players that do ranching and dairy farms. Mostly in ranching some are specialized in calving. They nurse the calves and sell them to someone else. The reason they do that is that they can use the worst grass for their business. They are usually located in the salty areas. They can be very important players, going back to these areas that are being left by the water and very salty. This is also related to the soil types and quality.

When you think about, who is winning and who is losing in this scenario, you can do a symmetry comparing, how much farmers enhance the flooding and how much they are affected. Usually they are negatively co-related. The renters just go for one year of soy beans and they suffer the least but create the biggest water excess. On the other end you have the dairy farmers.

People are usually not aware of that and it requires some workshops with exercises about the causes and effects of water consumption and the networks of stakeholders, to make them realize the level of connection within the system. In the end we are a connected world.

I think it is very interesting, when a watershed is shared by three provinces. You experience these political systems and related conflicts about who is in charge, who controls, who is responsible, and so on. You can compare the provinces with each other, in Córdoba for example, there was an incentive of winter crops so in terms of evapotranspiration, they are doing better than Santa Fe, where there was no incentive. This brings a possibility. I would say it is a problem for a more integrated management, but it is an opportunity for some experimentation involving the locals. It can be an interesting situation.

It is a typical scenario with floods: There is a provincial government, they ask, "What can we do?" – "Canals!", then there are some defined budgets for companies to do the analysis and that is it. Nobody else comes to the discussion. And we are not solving the problem with that. We spend a lot of money, but we are not solving it.

3) For the scenarios, I think first of all we have to see the context changes that happened all over the Pampa. I would put one first there and it is large scale automatic agriculture. It is an unstoppable trend. So, whatever we think, needs to consider that. That is the natural trend of the system. When you think about smaller organic farms, this will not happen soon.

Under this general trend, a possible scenario is a more flooded landscape which would favor a more volatile ways of doing agriculture. Renting land when it is possible and leaving it when it is not. That is a very likely scenario. Helped by this context issue.

Another scenario is more cattle production which can happen in many ways. The most likely one that I see, is confining fattening fodder stables. Where what you are going to do is sending forage to the animals that are confined. The question with confined systems is: They can take two paths. You just feed the cows with grains, in that sense the system will stay the same, or you feed them with grain and grass that you cut. That certainly may happen, players that get in on a very massive forage producing scale that cut the forage and sell it.

Much less likely is a scenario with grazing. Grazing will only happen in these salty post-flooded areas but not as a main land use. It is very interesting and has a high potential in the context of water balance regulation, but the players who do that, are usually small and poor farmers that do not have the capital and power to push it forward.

Even less likely than that is a scenario where wildlife is valued. I hope it happens, but I think it will happen soon. At least the valuing of the ecosystems in Argentina – the grasslands – perhaps the most problematic ones, is still very little.

JIWH: Maybe the milk market is increasing, and it will incentivize a mix of alfalfa, grains and grasses.

EJ: Yes, but that is the question, I do not know, if a higher price for milk, as a political incentive for cattle production, would foster the production of alfalfa and grasses or if dairy cows would be fed by grains and low-quality grass that you get from the low-quality soils, only. It depends on many very volatile context issues, like the price of wheat, the price of grains, the price of many things.

Another possibility is that a milk powder plant would be established here in this region. Dairy farms have a big incentive to increase in this region. Usually those approaches start from incentives like that. Otherwise there is no business involved in these scenarios.

JIWH: INTA sees an agricultural solution for the problem. They want to foster a higher water consumption through the rotation of crops during the year.

Another scenario, which will be a more Soviet scenario, but I do not think this will happen, is having tree plantations. If you have a very strong policy of getting into intermediate soil quality areas and have some subsidies for planting trees, it can happen. Subsidies in Uruguay changed the country. If you have 15% of the watershed planted with trees, particularly in areas that generate a high inflow, then that will change the water balance.

MP: Then you will also have changing scenario for other ecosystem services because you are changing the type of land use.

EJ: So far, I do not see tourism stopping in this region. It may change, we were talking a lot about this, while travelling in New Zealand. There are a lot of small destinations all over the country with sights to visit everywhere. But here in this region, we lack the infrastructure. Additionally, most tourist take a sleeping pill in Buenos Aires and wake up in Mendoza. For them there is nothing else to see – just the Pampa.

MP: If you have a huge new wildlife created over there, you can make something like a lodge and create a tourist attraction over there. I am sure it could work because all the people, all the gringos (US-Americans), they love the Pampa. They want to see cows and they would love to see the landscape. I think this is an opportunity for international tourism, but I do not think it would work for national tourists.

EJ: The birds you see here are amazing. You see flamingos, spoonbills, and a broad variety of other bird species. Probably these last two examples, planting trees and fostering tourism, are examples for scenarios that require a top-down approach. Tourism does not need an approach from super top, but from the provinces or federal countries.

One more thing that is important when taking about scenarios is that Argentina could perfectly send its grains to the ports by water using mega-channels. Considering the hydrology of the plains, it makes perfect sense to move grain by water. It can have a lot of negative side-effects, if it is not done right, but I can see a scenario of a super soybean economy or other grains in which someone builds a huge channel or a network for transportation purposes. I would not take it out of the scenarios. It has been discussed for some time.

MP: It could be an opportunity using that extra water for the channels.

EJ: It can be an opportunity, to integrate a navigable canal into the system, and use it as a mean to move the boat, or it can be a problem, because the canal can speed up the transport of water from other places. But I would have this scenario in mind, a lot of people are discussing it and from a perspective of transport it makes perfect sense. And even in the dry periods, with this land use and the land use that will probably come now, it could be feasible. The factors I already mentioned, like the evapotranspiration of plants and their capacity to keep working when it is flooded, plus the capacity to dry the water tables below a certain depth, are very important for the water balance of the region. Alfalfa can do it up to a very deep depth, while agriculture can only do it up to 2 m deep. Consequently, I would say that even in a very dry period, the water table would never go deeper than 3 m. and for the canal that is totally fine. A problem would be if everybody puts alfalfa. Canals are a possibility for the future.

This is also important for ESS-tradeoffs. Alfalfa and wetlands for example, probably if we have a lot of alfalfa we are sacrifying the wetlands.

MP: You can also put these scenarios in conditional terms. You probably do not have a lot of background information for really determining the trade-offs. But you can describe different scenarios and say we need more information on this or this point and that again can set, a scenario for a next study of which of those trade-offs you have to compare. Putting a value, even if it is qualitative like plusses or minuses, to those trade-offs is easier to say which you would rate over the other.

JIWH: Another thing you should keep in mind, is an agricultural scenario with the rotation of the main crops, soy, wheat and maize. It probably is not the main solution but is has an effect on the water balance.

EJ: It makes some difference in the water balance, but the rotation of land cover is only affecting one of the three parts you could use. It is only affecting the transpiration part, but you do not solve the feedback with the flooding that you could solve when instead of having a rotation of soybean and wheat, a rotation with periods of grasses or alfalfa.

MP: Something that might also be interesting to consider, is, how solving this problem with water is affecting other ESS. For example, soil nutrients, nutrient cycling, soil salinity that might change. How does the system look after the dry out? You should mention that the solution for the flood problem, has a lot of collateral effects. It does not only effect just one ESS.

EJ: A huge topic, which is related to the greenhouse gas balance and a huge mystery for me, is the methane. They are still not in the discussions of governments.

MP: That is true, but maybe, this could change in relation with other things. If you start talking about something like Climate Change, it might be interesting for big international solutions and then you might change something local by doing something that is interesting from a global perspective.

EJ: What is interesting for the farmers, is that when there are big floods, there is a change in the frost regime. It is like having an ocean in the inland. Few farmers know this, but some smart farmers realized that when there is a flood, the growing season is longer.
Another thing to mention, is that to foster any kind of change towards one of the scenarios we mentioned, it is necessary, to find big companies that are interested in the topic or finding a solution and to cooperate with them. There is no other way.

Interview 19: Juan Carlos Bertoni, Secretario de recursos hídricos de Santa Fe, 17:30-18:00, 27.04.2018, Córdoba

We have a saying that if you put a frog in a pot with boiling water, it jumps right out again. However, if you put a frog in a pot with cold water and heat it up slowly, the frog gets used to the changing temperature until it reaches 100 degree and the frog is dead. The La Picasa thematic is the first case. The region faced several changes that were slowly taking place and the people got used to it and gave little importance to these changes. Now that it is too late, and many landowners lost land and whole cities are under the threat of being flooded, we see that we have a complex problem.

1) The region faced a number of changes specifically in the agricultural system. The study region used to be a typical livestock production region. Rufino used to be the national capital of cattle production. Today you must search with a magnifier to find a cow. From 1990 onwards, there was a big political change maximizing the benefits of crop production while creating disadvantages for cattle production.

This change in the productive model of the region also had hydrological effects and impacts on the landscape. Roads and railways had to be reorganized. Fundamental changes came with the construction of the net of canals that dried out a large number of lagoons. Historically, an infinity of lagoons existed in the La Picasa basin.

With these changes, they became connected and their water was led to the most low-lying location - the La Picasa lagoon. Before, thousands of shallow lagoons were evaporating water. Now that all the water masses are united in one single location with a higher depth and less surface, the evaporation is not the same. The agricultural model and the network of canals represent two substantial changes, but who is responsible for these changes? The network of canals was organized by the three involved provinces, Córdoba, Santa Fe and Buenos Aires. They have implemented or have allowed implementing a set of canals without mitigating their impact. Everybody was draining away their water without thinking about where it would end up. It is obvious that the farmers of the region are clearly affected by political decisions, technical decisions and from the agricultural system they are working with.

All of this becomes even more evident in extremely humid periods like in 2015/16 and 17. These humid periods are not new, they are occurring for decades already, but they clearly show, how problems are related when it rains a lot. So, we have an anthropogenic change of the system, but we also have a climatic change. If you check the precipitation data of the last humid periods, you will find out that we never faced superior rainfalls. Nevertheless, from my point of view, the changes caused by anthropogenic impact are more important than the changes caused by natural phenomena. The design of the canal-network was incorrectly implemented. When designed, they were thought to be a network of canals and reservoirs for the regulation of water levels. The canals were implemented first and then some reservoirs, although it should have been done in the opposite order. First, the reservoirs should have been completed and then the canals should have been promoted. So, they first build the canals and then they added smaller reservoirs than initially planned, including one reservoir in Córdoba that is not even constructed, causing the water to flow down to the La Picasa lagoon.

2) There is a lack of authority in the La Picasa basin. The state doesn't have the capacity to control the execution of illegal canals. Today, in Santa Fe we are starting with the first activities in this direction. Nevertheless, there is a certain kind of organization because a basin committee exists, but this committee has always had the characteristic that is blamed all the responsibility to the Nation - Responsible and guilty is the state of Argentina. In reality, the "guilt" is shared: There is a Nation that was absent when it came to accept the particular problem under formation in the La Picasa basin and that failed in controlling the execution of canals or even promoted it. But the farmers, who are affected today, were part of this development as well and never complained before the problem became uncontrollable. What should be done now, is finding a consensus in the management of the La Picasa lagoon, when it will be pumped, how much will be pumped and at what water level. This is also what we are researching about now, because we have a more advanced vision.

Nobody is benefitting from this situation, in the contrary, it is a pity. The basin committee is not functioning well. Actually, it is neither a committee, nor it is from the basin. To be a basin committee, it should represent all parts of the hydrological basin and the actual committee is failing in this. In addition, a basin committee should represent all involved stakeholders and this committee is only composed of farmers. It is like giving the wolf the responsibility to care for the chicken. You put farmers in the position to manage water resources, while they are not always the best indicators for how to use the water.

The province of Santa Fe has issued a water law the first of March 2018. The three provincial committees appeared in it like "user associations" while only one basin committee will be integrated in this law. It is my personal challenge to be able to establish the interjurisdictional basin committee with this vision in mind. In the basin committee that exists today there is no way to work efficiently. I am a person that usually promotes cooperation, but Buenos Aires is blocking any consensus. For this reason, the topic of La Picasa has even been discussed in front of the Supreme Court of Justice.

3) I have a positive vision for the La Picasa basin. I know that Santa Fe is already putting a lot of effort to find a solution approach. Between the three involved provinces, Santa Fe is the most affected, because 80% of the La Picasa basin are on its land. Córdoba is not that affected and therefore does not put that much effort in the topic. I am from Córdoba, but sometimes it is difficult to work on topics like this because of the different priorities. Between the canals, the construction works and all these approaches there is no good management in place. We, from Santa Fe and Córdoba, together, we should demonstrate how it should be done right. I have a positive view on this because Santa Fe is dedicating major efforts in the solution of this topic. On first sight, the solution that Santa Fe is working on has something irrational and illogical. But when you find yourself blocked from a wall that does not let you take away water on one side, you do not have any other option than thinking out of the box. The option to take out water to the Paraná river, from a technical point of view is totally irrational. But today, with the actual scenario in mind, I am happy that Santa Fe is promoting the scientific studies for this alternative. Obviously, the dialogue with Córdoba and Buenos Aires should further be improved, but until now, we are lacking concrete actions. If we do not find an alternative soon, this region will suffer the consequences of unilateral decisions that Buenos Aires is taking until today. I think this topic will be solved progressively but this will take way more time than one or two months. It will take a lot of time.

The farmers of the region only see one solution: Canals! They only think in construction works although today's circumstances show them that construction works cannot solve every problem. We need agreements how we want to manage the lagoons, and all of this will take a long time.

There are scenarios with a focus on infrastructure that Santa Fe will implement if there is no way to negotiate a solution with Buenos Aires. But apart from this, there is another scenario without construction works that seems much more interesting to me. The first step that has to be achieved, is that the interjurisdictional basin committee is recognized from the National Congress,

which again needs a law that makes this committee legally valid. This process has already started, and I am positive that in 2018 this law will be passed. Once a legal committee is created our proposal that is also supported by Córdoba, is to create an operative organism. This organism should be composed out of two or three persons that check constantly if what is done in the La Picasa basin is happening according to the rules that the committee sets.

A scenario without construction works and a more ecological focus is only possible if it comes along with a strong planification among the players. We would like to see it in place as soon as possible and if we achieve this objective fast enough, we would like to see an ecological approach.

But reality shows that we will first need a scenario implementing new infrastructure and then a scenario with an ecological focus. The change of the agricultural system for example will take a lot of time. In the short run, the advantages of constructed solutions are that, in contrast to ecological solutions, they create immediate effects. The ecological solution approaches are of highest importance and probably even more important than the infrastructure approach in the long run, but they take time and Santa Fe cannot wait for 50 more years. Therefore, Santa Fe will first go for more canals.

Annex 6

Potential Project Stakeholders				
Nr.	Stakeholder Institution	Representative	Contact Data	Description
Basin Committees				
1	Comité Interjurisdiccional de Cuenca de la Laguna La Picasa	Juan Carlos Duhalde	Tel.: +549 346 215 578 501 E-Mail: duhaldejc@hotmail.com	Presidente/ Management plans of the basin, projects, programs, infrastructural costs, data of the whole basin, structural composition
2	Comité Provincial de Córdoba Cuenca de la Laguna La Picasa	Horacio Herrero	Tel.: +549 351 628 0417 E-Mail: hsherrero@yahoo.com.ar	Internal data, numbers and facts about La Picasa Basin of Córdoba Province
3	Comité Provincial de Santa Fe Cuenca de la Laguna La Picasa	Juan Carlos Duhalde	Tel.: +549 346 215 578 501 E-Mail: duhaldejc@hotmail.com	Internal data, numbers and facts about La Picasa Basin of Santa Fe Province
4	Comité Provincial de Buenos Aires Cuenca de la Laguna La Picasa	Edgar Castello		Secretary/ Internal data, numbers and facts about La Picasa Basin of Buenos Aires Province
Governmental Stakeholder				
5	Secretaría de Recursos Hídricos de Córdoba	Horacio Herrero	Tel.: +549 351 628 0417 E-Mail: hsherrero@yahoo.com.ar	representante de la Secretaría de Recursos Hídricos de Córdoba/ Internal data, numbers and facts about La Picasa Basin of Buenos Aires Province
6	Secretaría de Recursos Hídricos de Santa Fe	Juan Carlos Bertoni Gustavo Villa Uria	Tel.: +549 342 610 9325	Secretario de recursos hídricos/ Internal data, numbers and facts about La Picasa Basin of Santa Fe Province, helpful contacts Engineer, Secretario de Planificación de Asuntos Hídricos del Ministerio de Planificación Federal, Inversión Pública y Servicios de la Nación
7	Subsecretaría de Recursos Hídricos de la Nación	Pablo Bereciartua Alfredo Antonio Raparo	Tel. Offic.: +5411 4349 8559 7400 E-Mail.: aqua@mininterior.gob.ar Tel.: +549 338 241 6917 E-Mail: Alfredo.raparo@hotmail.com	responsable for national political regulations related to the resource water, the National Water Plan, assess national water resources, represent Argentina in international environment; integrated data from whole ARG Consultant and local expert/ Local expertise about the functioning and development of "La Picasa", previous information material, hydrologic data, contacts
8	Ministerio de Gobierno y Reforma de Estado Santa Fe	Diego Milardovich	Tel.: +549 3462 673 614 E-Mail: milardovich@hotmail.com	Coordinador Región 5 Nodo Venado Tuerto en el Ministerio de Gobierno y Reforma de Estado Santa Fe
9	Ministerio de Ambiente y Desarrollo Sustentable		Dirección: San Martín 451 - Ciudad Autónoma de Buenos Aires Código postal: C1004AAI Teléfono: (54-11) 4348-8200	Potential institutional stakeholder for a multidisciplinary "La Picasa" Basin Management Committee; Sustainable regional management approaches for scenario development
10	Ministerio de Medio Ambiente Santa Fe	Santo Biasatti Manuela Luppi		Vice Minister/ Responsible for studies done about flora and fauna in Melincué leading to the RAMSAR titulation in 2008 Researcher/ Responsible for long-term monitoring of the biodiversity of the lagoon Melincué
11	Comuna Melincué Guardafauna Laguna Melincué	Elizabeth Jorro Mario Sachetto	E-Mail: jorroelizabeth@gmail.com	Responsible for tourism in the Municipality of Melincué/ numbers about visitors/year, where they come from, how much tourism benefits from the RAMSAR title

12	Comuna Aarón Castellanos	Walter Ramanzín	Tel.: 549 3382 457 353 E-Mail: w.s.ramanzin@hotmail.com	Presidente Comunal/ Local knowledge, information and experience
13	Secretario de Protección Civil Santa Fe	Marcos Escajadillo (Director)		Data about risk potential in La Picasa Basin, Infrastructure endangered, costs of mitigation measures, people at risk, etc.
14	Ministerio de Producción de Santa Fe	Alicia Ciciliani (Minister)		data and information related to floods, la pampa region, etc.
15	Ministerio de Turismo (Delegación Zona Sur) de Santa Fe	Claudia Rosenthal	Tel.: +549 342 155997878	Data about tourism numbers in "La Picasa", national parcs, travel medium, motifs for travel, etc.
16	Administración de Infraestructuras Ferroviarias Sociedad del Estado (ADIF)	Luis Figliosi		Data about infrastructure in the region "La Picasa" for both tourism potential and critical infrastructure endangered by floods
		Research Institutes		
17	Instituto Nacional de Técnologia Agropecuaria (INTA) Working group CREA	Alejandro Saavedra Pablo Bollati Federico Pagnan Juan Cruz Molina Enrique J. Miles	Tel.: +549 3537 68 2240 bolatti.pablo.@inta.gob.ar Tel.: +549 3537556172 pagnan.luis@inta.gob.ar E-Mail: jcmolina@crea.org.ar E-Mail: emiles1969@gamil.com info@crea.org.ar	data and information related to floods, la pampa region, etc. agricultural problems related to groundwater table rise Agricultural Engineer and Farmer/ cooperation with farmers: consultancy, evaluation of methods, etc Ex-Secretario de agricultura, head of INTA Córdoba, Member CREA Agricultural producer and CREA member productores agropecuarios que se reúnen en grupos para compartir experiencias y conocimientos
18	Instituto Nacional del Agua (INA) Centro Regional Litoral Centro de Investigaciones de la Región Semiarida (CIRSA)	Carlos Paoli Ricardo Giacosa Maria Inés Rodrigues Ana Laura Ruibal	Tel.: +549 351 156 54 2009 E-Mail: minesrodrg@gmail.com Tel.: +549 3543 517060 E-Mail: alrc71@gmail.com	Research Institute focussing on water resources in Argentina data and information related to floods, la pampa region, etc. Batimetry study Water quality, eutriphication, agriculture and water bodies, etc. chemical analysis, water quality
19	Centro Nacional Patagónico del CONICET Research Team GEA, CONICET-UNSL Instituto Multidisciplinario de Biología Vegetal	Esteban Jobbágy Maria Poca	Tel.: E-Mail: jobbagy@gmail.com Tel.: +54 0351 5353800; int. 30049 E-Mail: pocamaria@gmail.com	research data for wetlands in Patagonia, Argentina Eco-hidrology expert in Argentina/ potential academic stakeholder for a multidisciplinary "La Picasa" Basin Management Committee Researcher and Biologist/ Expertise about ESS, La Picasa, Ess-Trade-Offs, ESS valuation and methodology, potential academic stakeholder for a multidisciplinary "La Picasa" Basin Management Committee
		Universities		
20	Universidad Nacional de Litoral – Facultad de Ingeniería y Ciencias Hídricas (FICH)	Raúl Pedraza		Researcher/ Previous hydrological studies (existing hydrological model from 2000) on La Picasa Basin
21	Instituto Nacional de Limnología CONICET-UNL			Research Institute focussing on water resources (especially lakes and lagoons)
22	Universidad Tecnológica Nacional – Facultad Regional Venado Tuerto	Jorge Fernando Amigo		Potential institutional stakeholder for a multidisciplinary "La Picasa" Basin Management Committee; specialised on GIS & Satellite Data
23	Universidad Nacional de Rosario	Eduardo Peralta Marcelo Romaro	Tel.: +549 0341 155149759	Researcher/ Responsible for biodiversity data in Melincué and Santa Fe Responsible for biodiversity data in Melincué and Santa Fe
24	Universidad Nacional de Mar del Plata (Grupo de Estudio de Agroecosistemas y Paisajes Rurales (GEAP))	Pedro Laterra	pedro.laterra@conicet.gov.ar pedrolaterra@fundacionbariloche.org.ar	previous working groups on related topics (agroecosystems, rural development, etc.) in that area
25	Universidad Nacional de Buenos Aires			Potential institutional stakeholder for a multidisciplinary "La Picasa" Basin Management Committee

26	Universidad Nacional de Córdoba (UNC) Laboratorio de Hidraulica Centro de Estudios y Tecnología del Agua (LH-CETA) DiverSus	Andrés Rodriguez Ricardo Ingaramo Paolo Gyssels Leticia Tarrab Working group Natalia Perez Esteban Kowaljow Juan Ignacio Whitworth Hulse	Tel.: +549 11 5989 4114 androdminplan@gmail.com Ricardo.ingaramo@gmail.com pgyssels@gmail.com Tel.: +549 351 620 9889 ltarrab@gmail.com perez.h.natalia@gmail.com Tel.: 549 3572 401 155 E-Mail: jiwhulse@gmail.com	Potential institutional stakeholder for a multidisciplinary "La Picasa" Basin Management Committee Civil engineer and Director LH-CETA/ Political and organizational management of hidrological working group "La Picasa" Civil engineer/ Technical and academic coordinator of working group "La Picasa" Civil engineer/ Knowledge about environmental engineering (hydrological focus) for working group "La Picasa" Civil engineer/ Knowledge about civil engineering (hydrological focus) for working group "La Picasa" Potential institutional stakeholder for a multidisciplinary "La Picasa" Basin Management Committee; Sustainable regional management approaches for scenario development Researcher and biologist/ Regional knowledge about wetlands and related soils of La Picasa (Trade-Offs?) Fitogeografía, Ecología funcional (ESS) y reciclado de C/N Researcher and biologist/ Restoration of wetlands, dinamíca de nutrientes en el suelo (N/C) Researcher/ Ecohidrología (balance hídrico a escala de parcelas - woodlands nativ/exotic)
27	Leuphana University	Prof. Dr. Berta Martín-López	Universitätsallee 1, C11.210e 21335 Lüneburg E-Mail: berta.martin-lopez@leuphana.de	Researcher/ ESS Wetlands, Existing data and results from previous studies of the region
Nature Conservancy Stakeholders				
28	Ramsar Convention (Program: "Wetlands for the Future")*	Secretaría de Estado de Medio Ambiente y Desarrollo Sustentable	Email: smades@santafe.gov.ar	Information about close by Ramsar sites (Humedal Laguna Melincué); Information about various ESS; Potential Consultancy position; data about wetlands & ESS; important contacts (+ evt. questionnaire for tourists)
29	IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services)	IPBES Sekretariat UN-Campus Bonn	Email: secretariat@ipbes.net	intergovernmental body which assesses the state of biodiversity and of the ecosystem services it provides to society, in response to requests from decision makers
30	Fundación Humedales/Wetlands International	Maria Eugenia Stolk	Email: maria.stolk@wetlands.org	work to preserve and restore wetlands, their resources and biodiversity; Potential NGO stakeholder for a multidisciplinary "La Picasa" Basin Management Committee; Sustainable regional management approaches for scenario development
31	Administración de Parques Nacionales			knowledge & data about ESS "tourism and recreation"
32	Network of bird watching	Prof. Dr. Maria Elena Zaccagnini		Researcher/ Conservation and research related to bird species; Estado de la Biodiversidad para la alimentación y la agricultura, a solicitud del Ministerio de AgroIndustria de Argentina
33	The Nature Conservancy	Gustavo Iglesias	E-Mail: giglesias@tnc.org	mission is to spread effective conservation at a scale that matters, integrating the value of nature into economic decision-making; working in la Pampa region; Potential NGO stakeholder for a multidisciplinary "La Picasa" Basin Management Committee; Sustainable regional management approaches for scenario development
34	Consorcio de Conservación de Agua			consults the implementation of public or private actions with a focus on soil conservation and the promotion of the efficient use of irrigation water
Agricultural Stakeholders				
35	CARSFE (Confederación de Associaciones Rurales de Santa Fe)	Carlos Castagnani	Tel.: +549 3462 509 241 E-Mail: carlos.h.castagnani@gmail.com	Presidente de CARSFE (Confederación de Asociaciones Rurales de Santa Fe)
36	Associación Productores del Sur de Santa Fe	Armando Rey	Tel.: +549 3382 154 605 54 E-Mail: establecimientolateresa@hotmail.com	Presidente de la Asociación Productores del Sur de Santa Fe

37	Adecoagro	Javier Tricarico	Tel.: +549 3462 480 229 E-Mail: jtricarico@adecoagro.com	Agricultural engineer/ Responsable agricultura por la empresa Adecoagro
Local Stakeholders				
38	Private Tour Guide for Fishing Activities	Esteban Milicich	Tel.: + 549 3537 443 899	Fishermen/Tourism Guide in the lagoons "La Viamonte"/ knowledge & data about ESS "tourism and recreation"; qualitative interview (+ evt. questionnaire for tourists)
39	Private Local Fisherman	Marcelo Ridolfi		Fisherman and tourist in the lagoon "La Viamonte"
40	Private Local Landowner Cuenca La Picasa	Marcelo Diez	Tel.: +549 1154 150 185	local producer with flooded farmland area
41	Private Local Landowner Cuenca La Picasa	Alberto Diez	Tel.: +549 3382 413 135	local producer with flooded farmland area
42	Private Local Landowner Cuenca La Picasa	Claudio Berrueta	E-Mail: claudioberrueta@gmail.com	local producer with flooded farmland area
43	Private Local Landowner Cuenca La Picasa	Federico Furno	Tel.: +549 3382 1544 7289 E-Mail: fgf.63@outlook.com	local producer with flooded farmland area
44	Private Local Landowner Cuenca La Picasa	Omar Maurizi	Tel.: +549 3382 1567 2293 E-Mail: maumag56@hotmail.com	local producer with flooded farmland area
45	Private Local Landowner Cuenca La Picasa	Mirtha Más	Tel.: +549 3382 1557 8501 E-Mail: mirthasmas@hotmail.com	local producer with flooded farmland area

Annex 7

Rainbow Diagram Categorization					
		On a scale from 1 (least) 2 (Moderate) to 3 (Most)			(based on Stakeholder Interviews)
Stakeholder Groups	Stakeholder Sub-Groups	Affecting	Affected	Affecting and Affected	Justification
A: Basin Committees	1 Interjurisdictional Basin Committee			3	**A 1:** Plays a significant role in defining which measures are taken in the La Picasa basin, most members are farmers that are affected by the identified ESS trade-offs
	2 Provincial Basin Committee			2	**A 2:** Play a role in defining which measures are taken in the La Picasa basin but meet unfrequently and are affected by the identified ESS trade-offs
B: Governmental Stakeholder	3 National Government			1	**B 3:** Is indirectly affecting the situation through laws and is indirectly affected through the cut-uff national Route N°7
	4 Provincial Governments			2	**B 4:** Are affecting the situation through implementing measures and negotiating among them as well as affected by the identified ESS trade-offs
	5 Regional Governments			3	involvement and interest, are representing the regional population that is highly affected by the identified ESS trade-offs
C: Research Institutes	6 Agricultural Research Institutes	3			**C 6:** Are affecting the situation in the study area through the results of research focusing on agriculture which is the major economic activity in the region
	7 Water Resources Research Institutes	3			**C 7:** Are affecting the situation in the study area through the results of research focusing on water ressources research which is of highest importance in the region
	8 Environmental Research Institutes	1			**C 8:** Are affecting the situation in the study area through the results of research focusing on environmental research which is of low importance in the region
D: Universities	9 Directly Involved Universities	2			**D 9:** Are affecting the situation in the study area through the results of scientific work related to the identified ESS trade-offs
	10 Potentially Involved Universities	1			**D 10:** Are indirectly affecting the situation in the study area through the results of scientific work related to the identified ESS trade-offs
E: Nature Conservation Stakeholders	11 International Nature Conservation Groups	1			**E 11:** Are indirectly affecting the situation in the study area through environmental commitment
	12 National Nature Conservation Groups	1			**E 12:** Are indirectly affecting the situation in the study area through environmental commitment
F: Agricultural Stakeholders	13 Farmer Associations			3	**F 13:** Are affecting the situation through high involvement and interest, are representing the regional farmers that are highly affected by the identified ESS
	14 Tenants	3			**F 14:** Are highly affecting the situation through their agricultural management practices but are not affected by the consequences of the identified ESS trade-offs because they leave as soon as they face some
	15 Landlords	2			**F 15:** Are indirectly affecting the situation through renting their land but are not affected by the consequences of the identified ESS trade-offs because they often live in far-away cities
	16 Owners that farm			3	**F 16:** Are highly affecting the situation through their agricultural management practices and are highly affected by the consequences of the identified ESS trade-offs
	17 Agricultural Companies			2	**F 17:** Are highly affecting the situation through their agricultural management practices and are highly affected by the consequences of the identified ESS trade-offs but are able to mitigate the effects better than
	18 Dairy farmers/Ranchers		3		**F 18:** Are not affecting the current situation through inappropriate management practices but suffer the consequences of the identified ESS trade-offs the most
G: Local Stakeholders	19 Fishermen		2		**G 19:** Are affected by the current situation because shallow lagoons are dry and they have to drive far to be able to fish
	20 Tourism Related Stakeholders		1		**G 20:** Are slightly affected by the current situation because shallow lagoons are dry and fishermen come to to the La Picasa lagoon and demand some services
	21 Service Providers		3		**G 21:** Are highly affected by the situation because the cut-off Route N° 7 causes all traffic to stop
	22 Urban Population		3		**G 22:** Highly affected by the situation becaus is threating their property and lives and causes complex socio-economic problems

Annex 8

Stakeholder Mapping Categorization				
		Low or High		(based on Stakeholder Interviews)
Stakeholder Groups	Stakeholder Sub-Groups	Power	Interest	Justification
A: Basin Committees	1 Interjurisdictional Basin Committee	low	high	**A 1:** Low power because functioning control mechanisms are lacking, high interest to find a solution
	2 Provincial Basin Committee	low	high	**A 2:** Low power because functioning control mechanisms are lacking and because of conflicts between the three provinces, high interest to find a solution
B: Governmental Stakeholder	3 National Government	high	low	**B 3:** High power to intervene through national legislation but low interest in the study area
	4 Provincial Governments	high	high	**B 4:** High power to intervene through the implementation of measures and high interest to find a solution
	5 Regional Governments	low	high	**B 5:** Low power to intervene in the situation because they are dependent on provincial and national governments but high interest to
C: Research Institutes	6 Agricultural Research Institutes	low	high	**C 6:** Low power to directly intervene in the situation because they are dependent on provincial and national governments but have a high interest in the specific situation of the study area
	7 Water Resources Research Institutes	low	high	**C 7:** Low power to directly intervene in the situation because they are dependent on provincial and national governments but have a high interest in the specific situation of the study area
	8 Environmental Research Institutes	low	low	**C 8:** Low power to intervene in the situation because they are dependent on provincial and national governments and are not integrated into the situation so far
D: Universities	9 Directly Involved Universities	low	high	**D 9:** Low power to directly intervene in the situation because they are dependent on provincial and national governments but have a high interest in the specific situation of the study area
	10 Potentially Involved Universities	low	low	**D 10:** Low power to intervene in the situation because they are dependent on provincial and national governments and are not integrated into the situation so far
E: Nature Conservation Stakeholders	11 International Nature Conservation Groups	low	low	**E 11:** Low power the intervene in the situation because they are dependent on provincial and national governments and are not interested in being integrated in projects in the study area so far
	12 National Nature Conservation Groups	low	low	**E 12:** Low power the intervene in the situation because they are dependent on provincial and national governments and are not interested in being integrated in projects in the study area so far
F: Agricultural Stakeholders	13 Farmer Associations	high	high	**F 13:** Have a high power to influence the management practices of farmers in the region and have a high interest in finding a solution for the situation
	14 Tenants	high	low	**F 14:** Have a high influence on the management practices of large agricultural areas in the region but have a low interest in finding a solutio because they are not bound to the land.
	15 Landlords	high	low	**F 15:** Could have a high influence on the management practices that take place on their land, but often have a lack of interest
	16 Owners that farm	high	high	**F 16:** Have a high influence on agricultural management practices on their land and also have a high interest in finding a solution for the problems in the study area
	17 Agricultural Companies	high	high	**F 17:** Have a high influence on agricultural management practices on their land and also have a high interest in finding a solution for the problems in the study area
	18 Dairy farmers/Ranchers	low	high	**F 18:** Have little influence of the problem situation but have a high interest to find a solution for the problems in the region
G: Local Stakeholders	19 Fishermen	low	low	**G 19:** Have little influence on the situation and are only slightly interested in finding a solution for the problems the region faces
	20 Tourism Related Stakeholders	low	low	**G: 20** Have little influence on the situation and are only slightly interested in finding a solution for the problems the region faces
	21 Service Providers	low	high	**G 21:** Have no influence on the situation but are highly intrested in finding a solution for the problems the region faces
	22 Urban Population	low	high	**G 22:** Have no influence on the situation but are highly intrested in finding a solution for the problems the region faces

Annex 9

Stakeholder perception of problems, related ESS trade-offs and management needs									
Interview Number & Interviewees	Problem Identification				Related ESS Trade-Offs	Identified Management Needs			
Interview 1	drainage water ends up in the principal lagoon	no industrial sector for processing of agricultural goods	unemployment because jobs only exist in the agricultural sector	lack of awareness and lack of alternatives	agricultural production vs cattle production	wetland restoration plan	ESS valuation	launch of Paraná water exit	regional income diversification
Gustavo Villa Uria	urban migration	hydrological surplus	lack of social concept for a fair use of the basin	illegal drainage canals	agricultural production vs hydrological regulation	awareness raising campaigns	implementation of the South and North alternative	implementation of control mechanisms (remote sensing)	strengthening of the dairy production sector
	lack of understanding climatic data (farmers)	lack of meteorological stations	lagoons do not provide ESS (dried out)	lagoons and canals are on private land (lack of control)	agricultural production vs habitat quality (biodiversity)	creation of a market for alfalfa	education campaigns	introduction of deep routing plants	make use of the groundwater aquifer
	lack of understanding of the system	high percentage of tenants	soil erosion and threat of droughts	economic losses		diversification of the production model			
	national road cut-off	surrounding roads deteriorate fast	accidents/traffic jams	unsustainable rotation of crops					
	decreasing soil fertility	compaction of soil and higher run-off	less evaporation	floods					
Interview 2	lack of communication between the 3 provinces	capriciousness of Buenos Aires	conflict potential between the 3 provinces	inefficiency of of basin committees	agricultural production vs hydrological regulation	declare La Picasa lagoon as nature protection area	grey infrastructure	functioning pumping stations	basin internal construction works
Alfredo Raparo	small amount of of water that can be discharged (via South alternative)	national road cut-off	initial master plan inadequately implemented	the Nation should be in charge	agricultural production vs habitat quality (biodiversity)	technical studies	more canals	Activation of the South and North alternatives	participation of farmers in the solution finding process
	unlogical amount of water discharge allowed (5m³/s)	common believe in untrue myths	lack of awareness and understanding	unfunctioning pumping stations		scientific and technical research	control mechanisms to avoid illegal canals		
	nobody is in charge of maintaining grey infrastructure	voices of local stakeholder (farmers) remain un-heard	agreements between the 3 provinces get ignored	Buenos Aires province blocks new alternatives					
Interview 3	natural water basin got modified (broken barriers Route N°33)	evaporation from lagoons that are dry could replace pumps	unsustainable agricultural model	inner conflicts	agricultural production vs cattle production	implementation of the South and North alternative	launch of Paraná water exit	reforestation of former forest areas	adapted rotation of crops
Walter Ramanzín	drainage canals direct water towards La Picasa lagoons	next flood will set Aarón Castellanos under water	use of pestizides in soybean production causes blank fields with los evapotranspiration	nobody thinks about the cause of the problems	agricultural production vs hydrological regulation	nature-based solutions	basin-wide strategic management plan	formation and organization of local stakeholders	
	lack of responsibility from the Nation	biggest problem is that the South alternative is not working	the votes of the local population are politically unimportant because they are small in number	economic problems because Route N°7 is cut-off	agricultural production vs habitat quality (biodiversity)				
	Inappropriate and unsafe transportation of goods and persons	productive area is water-logged	mismanagement of water resources	wheat and soy do not have the same rentability					
	contamination with pesticides	threat of droughts	lack of power of communes and the 3 provinces						

Interview 4	the basin is naturally endorrheic	political incentives fr producing crops like soybeans	current agriculture has a lower evapotranspiration	failing negotiations between the 3 provinces	agricultural production vs cattle production	constructed solutions are necessary	foster higher evapotranspiration rates	involvement of more stakeholders (not just farmers)	trust building in management approaches
Alberto Diez	lack of functioning grey infrastructure	illegal canals	modification of the hydrological cycle	lack of integrative management concept	agricultural production vs hydrological regulation	basin-wide organization and management	requires a top-down organization (from the Nation)		
	lack of scientific understanding of the system	migration out of the region	loss of local species	lack of interest and prority of the region in policy	agricultural production vs habitat quality (biodiversity)				
	egoistic behaviour of farmers	agricultural system has a low work intensity and leads to unemployment	introduction of new species	farmers have a lack of influence					
	transformation of the profession is difficult (from farmer to tourist guide)	Route N°7 is cut-off and causes economic losses	inefficiency of the basin committees	lagoons are on private land					
Interview 5-7	execution of projects was wrongly done	mismanagement of the region	lack of planning	lack of grey infrastructure	agricultural production vs cattle production	innovative solutions	project works	integrated basin management scheme	centralized decision making
Diego Milardovich, Carlos Castagnani, Claudio Berrueta	the Nation is not involved	lack of acceptance of natural limits (drainage)	farmers should not be in charge of managing hydrological resources	wrong political incentives (to produce crops instead of cattle)	agricultural production vs hydrological regulation	Involvement of the Nation	solutions beased on scientific information	political incentives for cattle production	grey infrastructure
	egoistic behaviour of farmers	economic losses	flooded productive land	flooded property	agricultural production vs habitat quality (biodiversity)	Nort and South alternatives	Stakeholder participation	representation of all stakeholders in the basin committees	change of current land use pattern
	higher precipitation values	groundwater flooding	high dependency on 1° sector	change in technology (no-tillage)		diversification of the production model (with cattle and grasslands)	Creation of alternative income options	insurances or support mechanisms for affected farmers	
	rentability of crops in comparison with cattle much higher	introduction of glyphosate and related introduction of soybean	lack of attention and management	lack of cooperation between the 3 provinces					
	displacement of farmers by tenants	lack of laws to protect land from being unsustainably managed	short-term contracts (between land-owners and tenants)	lack of understanding of the system					
	lack of awareness	lack of control mechanisms	soybean monocultures affect the hydrological cycle	mismanagement of water resources					
	teh only stakeholders represented in the basin committee are farmers	profit maximization more important than protection of soils	blank fields foster a faster run-off effect and low infiltration	incomplete basin committees					
Interview 8-9	lack of an interjurisdictional basin committee	main problem is the lack of infrastructure to take water out of the basin	canals directing water to La Picasa lagoon but no water exit	ten-times higher inflow capacity of canals than outflow possibilities	agricultural production vs cattle production	soil covers with living crops	integrate livestock production into agricultural practices	create water storages	
Javier Tricarico, Alfredo Raparo	it is a myth that land-use has such a big influence on the hydrological cycle (cannot be proofed)	limiting factor for production (of crops like soybeans) is the availability of water (from precipitation)	lagoons are not appropriate for water storage (needed ESS)		agricultural production vs hydrological regulation				
					agricultural production vs habitat quality (biodiversity)				

Interview 10-15	land-use and other anthropogenic impacts have caused a modification of the hydrological cycle	run-off is much faster than before	canals were constructed before a water exit was implemented	the basin is naturally endorrheic	agricultural production vs cattle production	make the South and North alternatives work	Stakeholder participation in basin committees	control mechanisms to avoid illegal canals	creation of controlling instance
Juan Carlos Duhalde, Armando Rey, Alfredo Raparo, Federico Furno, Omar Maurizi, Mirtha Más	no stakeholders are represented apart from farmers	natural pastures do not exist anymore	rising lagoon levels and rising groundwater levels cause floods	increase in precipitation	agricultural production vs hydrological regulation	involvement of interested parties	information activities	payments for ESS	integrated water policies
	floods are man-made	reaction to floods instead of prevention	the touristic sector is not present	farmers are not farmers anymore - most are tenants	agricultural production vs habitat quality (biodiversity)				
	Córdoba province is fast in constructing canals without being aware of possible consequences	lack of planning from down-stream to up-stream (infrastructure was implemented the other way around)	low evaporation because water leaves to the principal lagoon so fast	no infrastructure left for cattle production					
	lack of water exit (South and North alternatives)	illegal canals	control of illegal canals is limited because farmers do no complain about each other	unfunctioning grey infrastructure					
	lack of understanding of technical data and information								
Interview 16-18	lack of awareness on how much land-use practices influence the hydrological cycle	farmers do not value ESS different from agricultural production	negative effect of land-use on the water balance	crops do not evapotranspire when flooded while natural grasses do	agricultural production vs cattle production	bio-drainage options	exploit grasslands double function to continue evapotranspiration while water-logged and increased infiltration to groundwater	incentivizing dairy farmers or ranchers on recovered land after floods	involvement of stakeholders
Esteban Jobbágy, Maria Poca, Juan Ignacio Whithworth Hulse	no wildlife left in a purely agricultural landscape	lagoons caused by floods oten only refuge for wildlife	lack of awareness and understanding	lack of a fair use of the basin	agricultural production vs hydrological regulation	consideration "green" solution approaches	touristic offers for international birdwatchers	foster the industrial sector (ex. With a milk powder plant in the region)	cooperation between the 3 provinces
	discrepancy between farmers and urban population in ESS perception	Route N°7 is cut-off and causes economic losses	gap between causing and suffering parties	lack of kowledge about the system and consequences of the current situation	agricultural production vs habitat quality (biodiversity)				
	low water consumption and evapotranspiration of crops	little knowledge about run-of effects	the connection of surface waters and the groundwater system not understod	fast and slow response of the system to rainfall events					
	conflicts between the 3 provinces	accelerated discharge towards the principal lagoon	migration to urban environments						
Interview 19	modification of the hydrological cycle	less evaporation caused by less lagoons	floods caused by the change of the agricultural model	network of canals (mainly illegal ones)	agricultural production vs cattle production	generate capacity to control illegal canals	create a committee that is representing important stakeholders	Launch of the Paraná solution	integrated management plan for the use of lagoons
Juan Carlos Bertoni	lack of mitigation of negative anthropogenic impacts	climate change and higher precipitation values	incorrect implementation of grey infrastructure (canals and reservoirs)	lack of a powerful authority	agricultural production vs hydrological regulation	recognition of the interjurisdictional basin committee through the national congress	create an operative organism in charge of controlling parctices in the basin (work group)		
	lack of capacity to control illegal canals	committees blame the Nation and refuse taking responsibility	committees are not representing all stakeholder groups	lack of integrated and basin-wide management	agricultural production vs habitat quality (biodiversity)				

Declaration in lieu of oath

by

Jasna Wiedemeier

This is to confirm my Master's Thesis was independently composed/authored by myself, using solely the referred sources and support.

I additionally assert that this Thesis has not been part of another examination process.

Place and Date *Signature*