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Changing climatic and anthropogenic influences on the Bermejo wetland, through archival documents – Mendoza, Argentina, 16th–20th centuries

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The wrong management of watering in the highest zones of the Mendoza northern oasis, the topography of the terrain and the deficient drainage, together with neotectonics phenomena, but mostly a dramatic and progressive increase of the Rio Mendoza flow volume originated the expansion of the wetlands area at the NE of the city of Mendoza at the turn of the 18th century, while in previous centuries it had retracted to a minimum. The area grew until reaching the dimension of large wetlands in the lowest oasis zones, resulting from a larger runoff and soil saturation by the rise of the phreatic layers. This situation remained throughout the 19th century, affecting the extension and use of the available land for human activity. The purpose of this study was to research this process that culminated in 1930 with the partial desiccation of the area. We have given particular importance to the influence of the climatic fluctuations in the Cordillera de los Andes and to the consequent variations of the Rio Mendoza flow volume in this process. For the analysis we used snowfall series at the cordillera and flow volume of the Rio Mendoza, built by Prieto (2009) with documental data. We analyzed which were the mediate and immediate consequences of the growth and later desiccation of the wetlands over the environment and its present repercussion on the ecosystem (salinization, poor soil drainage, soil alkalinization, sedimentation). In addition, we have also worked over georeferenced historic charts that partially reflect the behavior of the Cienaga del Bermejo during the 18th, 19th and 20th centuries. This behavior characterized by “growth pulses” and retraction moments is reflected in the analyzed charts, where those moments of major growth coincide with cycles of bigger snowstorms and larger flow volume in the Rio Mendoza.

1 Introduction

Wetlands are areas of land whose soil is either permanently or seasonally saturated with moisture (Miller, 2002). Such areas may also be covered partially or completely by

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shallow pools of water. Wetlands, including swamps, marshes and bogs, have historically been subject to large-scale drainage. In the light of a better understanding of the important environmental role of wetlands, increasing focus has been given to wetland preservation since the 1970s. In many locations, e.g. the US and Canada, wetlands are the subject of conservation projects and Biodiversity Action Plans (Mortsch, 1998; Conly and Van der Kamp, 2001; Carter Johnson et al., 2005).

An important recent trend has been to investigate the fluctuation of wetlands in the context of climatic change and its influence on their volume and extension (Winter, 2000; Van der Kamp, 2005). These investigations seek to establish the original (natural) state of these wetlands, how they have evolved over time and how they might respond to global warming.

This paper will examine changes in the large wetland east of the city of Mendoza, Argentina ($-32^{\circ}55' \text{ S}/-68^{\circ}51' \text{ W}$) based on archival documents from the 16th–20th century (Prieto and Chiavazza, 2006; Prieto et al., 2008) and relate them to changing streamflow of the Mendoza River (Prieto et al., 1999; Prieto and García Herrera, 2009) and the impact of political and socio-economic activities.

This is a wetland of significant importance with an interesting history that reflects the influence of both climate change and anthropogenic activity. The novelty here is the archival use of maps to reconstruct changes in area and their linkage to natural archives of related climate changes and historical documents. Long-term water-level studies in wetlands in North America and proxy data (e.g. tree rings) for water levels in this region indicate that oscillatory water-level fluctuations have occurred for thousands of years (Van der Kamp, 2005).

These studies also encounter problems in differentiating between climatic effects and the influence of human activities on wetlands. Many studies attribute the loss of moisture in these ecosystems to both intensive land use and climate. Dale (1997) states that in the USA "Land-use change is related to climate change as both a causal factor and a major way in which the effects of climate change are expressed. ... Projected climate alterations will produce changes in land-cover patterns at a variety of temporal

and spatial scales, although human uses of the land are expected to override many effects.... Therefore, an understanding of the nonclimatic causes of land-use change (e.g., socioeconomics and politics) is necessary to manage ecological functions effectively on regional and global scales". The "gran Ciénaga del Bermejo" was a wide marshy and lacustrine system that occurred east of Mendoza city until the beginning of the 20th century when it was drained During the first times of colonial period (1561 to ca. 1760) this area was one of the most important agricultural and grazing areas in Mendoza. However, high water levels in the 18th and 19th century ruined the agriculture and the grazing fields. Property damage from this flooding led to examination of the occurrence of past hydrological episodes and their relation to climate and land use.

2 Study area: environmental characteristics

The vulnerability of wetlands to changes in climate depends on their position within the hydrological system. Hydrologic systems are defined by the flow characteristics of ground and surface water and by the interaction of atmospheric, surface and ground water in any locality or region. The Ciénaga del Bermejo occupied a large, NE-SW depression that receives surface and sub-surface runoff from the Mendoza River that originates in the high mountains of the eastern slope of the Andes between 32°27' and 33°20' S. The primary source of river flow is melt of the winter snowpack in the Andes supplemented by glacier melt and regional ground water flow systems.

The Mendoza river flows eastwards across the mountains and then turns northwards as it flows out onto the plains. The mountain-front lowland contains large alluvial fans deposited by the Andean rivers. These were once occupied by prehispanic aboriginal groups and the water from this river has been used for agriculture since colonial times in the area presently occupied by the city of Mendoza. Cultivation from this area first extended eastwards into this large marsh during the colonial period. The Mendoza River continues northwards and feeds another lacustrine complex named Guanacache. These two wetlands were part of a single complex formed by the surface water from

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the Mendoza River and groundwater flow from the cordillera into the lowland. High snowfall years in the Cordillera de Los Andes increase both surface and groundwater flow into this large depression. In this area, the water table is very close to the surface and subsurface impermeable strata (*tosca*) facilitate the retention and stagnation of rainwater and groundwater flow from the surrounding area.

Romanella (1957) points out the relatively low slope in the depression (between 1000 and 650 m a.s.l.) which impedes the drainage and facilitates ponding of the converging flows. The highly impermeable layer promotes poor soil drainage in years with high snowmelt flows and a rising water table. These processes still affect productivity of cultivated zones and the urban infrastructure in parts of the departments of Guaymallen, Maipu and Lavalle.

Organic remains from ancient wetland flora are seen in soil profiles indicating that water would have been permanently or sporadically renewed in these wetlands in the past, thus creating the conditions that formed the soil that has supported agriculture and grazing for several centuries (Romanella, 1957). Descriptions of the vegetation of this area during the 18th and 19th century confirm the palustrine environment where *tora* (*Typha dominguensis*), juncos (*Scirpus californicus*, *Juncus balticus*, *Juncus acutus*), carrizo (*Phragmites australis*) and cortadera (*Cortaderia ruidiuscula*) prevailed.

3 Methodology and sources

Archival documents have been used to reconstruct the hydroclimatic variability in the high basin of the Mendoza River during the last centuries (Prieto et al., 1999, 2001). Administrative documents from the Hispanic-American colonial and republican periods as well as old newspapers have provided useful information to reconstruct the climate and the hydrology of the region. Documents from the *Archivo General de Indias* (AGI) in Seville, and *Archivo General de la Nación Argentina* (AGN) and Archivo Histórico de Mendoza (AHM) have been used to identify extreme events from the 17th century to

the first decades of the 20th century. We have also used ancient maps of the region to reconstruct changes in the wetland area.

The archival documents show abrupt hydrological changes in the wetlands in response to climatic fluctuations in the headwaters. The marsh reconstruction were based on archival documents, ancient maps, newspapers and descriptions by travelers, naturalists and scientists. We have also used recent satellite images, archaeological data and interviews to reconstruct the environment in different historical periods.

The wetland dimensions during the 19th century were reconstructed from ancient maps and documents. On four selected maps, we measured the straight-line distance between two reference points – the Pedro del Castillo square, representing the center of the colonial city and the western edge of the wetland. These changing distances reflect the growth and recession of the wetland over time.

4 Background

A long runoff record for the Mendoza River was reconstructed using documentary sources from 1601 to 1960 (Prieto et al., 1999) New data were added for the 19th century to form the new data base (Prieto and Garcia Herrera, 2009). Figure 2 shows the number of high or slow streamflow years in each decade between 1601–1960. Between 1601 and 1670 there were few high streamflow (only three years). This scarcity of high flows may be related to a cold episode of glacier advance during the LIA (Bradley and Jones, 1995) when the Spaniards arrived in America. This period of glacier advance has been described from northern Patagonia (Villalba, 1994) and a long cold interval, (mean temperature 0.26 °C below the previous warm period) has been reconstructed for the 1520–1660 interval. Espizúa (2003) also describes a glacier advance in the high basin of the Rio Grande (S. Mendoza) that would have reached its peak ca. 400 yr BP (around 1660). These lower summer temperatures could have limited snowmelt and diminished runoff of the rivers from the Andes, including the Mendoza river. We suggest that the wetland recession during the 17th to mid-18th centuries

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was probably due to lower river flow as a consequence of this period of glacier advance (Prieto and Chiavazza, 2006).

When they founded Mendoza (1561), the Spaniards did not record a large marshy area east of the city nor did they register a high frequency of floods in the first decades after the conquest. During the 16th–17th centuries the wetland was restricted with water outcropping in some places forming small ponds and marshes. There were some reeds (*Phragmites australis*) and excellent grasses (common grazing land) (Prieto and Chiavazza, 2006). The Spaniards alternated in that time the grazing of animals with cultivation of this fertile soil in small lots where they grew wheat, maize and other cereals, in addition to planting the tree fruits and the first vineyards.

A gradual increase in the frequency of large streamflows occurred from the 1670s to the 1730s and coincides with the beginning of the period of large wetland expansion (Prieto et al., 1999). Several decades in the 1770s to 1840s show an elevated frequency of high streamflow years as a consequence of several years with intense snowstorms in the cordillera after 1760 (Prieto and Garcia Herrera, 2009) , The resulting expansion of the wetland led to the loss of agricultural land and grazing fields. The fertile swamp soil was slowly covered by the advancing water producing the maximum wetland expansion ca. 1800 (Fig. 3)

“...coming the great ruin of the swamp that with big speed is eating the principal fields of the city, ...” (AHM, C17/D13, 22 June 1799)

The growth of the marsh area had both natural and anthropogenic causes: the area has a north east to south west slope that makes drainage (both surface water and groundwater) naturally converge towards the natural depression. The considerable increase of Mendoza River streamflows and higher frequency of great floods after 1670 led to soil saturation and rising water tables in the wetland. In 1789 a diversion channel was built to carry the flow of a branch of the Mendoza River eastwards into the wetland and prevent the floods from reaching the city. The resulting enlargement of the wetland led to proposals from the inhabitants to drain the marsh. The publicity given to this

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issue in contemporaneous documents confirms that the growth of the wetland was a significant issue at the time (Prieto et al., 2009).

“... little by little the river has increased, ... every year there are repeated and excessive damages... because it is almost impossible to stop during the summers a river with so much flow volume ...” (A.H.M., Carp.37/Doc. 20, “Presentación de los vecinos”, 9 September 1805)

The wetland reached its greatest area (58 000 ha) in 1802 when it was 2.82 km. from the city centre. The first project to drain the wetland was in 1803 (AHM, C37/D27, 1803).

In 1815 the wetland was ca. 40 km from east to west (AHM, D73/C236, 20 October 1815) and a few drainage projects were slowly developed. The rudimentary technology of the time consisted simply of opening new channels that would allow drainage of part of the wetland into different areas and was not very successful.

“The captain don Ignacio Escalante and others (were) interested in opening a course through which the marsh waters drain, because they have flooded and lost our haciendas to the east of this city, we say that: six years ago... in this townhall in regards to an interesting work having agreed to it many times” (AHM, C37/D28, 1806).

Finally in 1828, following a year with abundant snowfall in the cordillera and the very wet period of the 1820s, the people affected by the marsh held a meeting “... to try (and plan) about a work... that desiccates it (the wetland) or at least avoids (reduces) its progress” (AHM C100/D55, Mendoza 1828/39). However, this work was not carried out.

5 Drainage of the wetland: the role of climate, state activity and viticulture

Effective drainage works only began in the 1860s with the start of state planning to drain the wetland by the construction of channels and drainage ditches. Mendoza

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Province had experienced chronic economic problems since 1810 that partially explain the delay in carrying out drainage projects prior to the 1840s. After 1850 economic prosperity and stronger state institutions facilitated drainage projects. In addition the political and business actors were mobilized by an urgent need to develop efficient and rapid transport that avoided the wetland areas. The creation of the Topographical Department of the Province of Mendoza in 1853 marked a breakthrough as this organization inspected, opened or improved transportation routes, and specifically the road Vuelta de la Ciénaga in Rodeo del Medio. The aim of the works was mainly to clear the old road to Buenos Aires, covered in long sections of stagnant water that impeded traffic and disrupting trade with that city.

Although the period between 1840 and 1880 was characterized by high streamflows (between two and six per decade, Fig. 2), the new drainage works successfully reduced the flood impacts and there was little change in the wetland area. In fact, the wetland receded slowly with only minor advances and became more independent of changes in climatic (hydrologic?) variables. The Burmeister map from 1861 shows a reduced wetland area of ca. 42 600 ha beginning 5.43 km from the city.

After a dry decade with low streamflows of the Mendoza River in the 1860s, the 1870s and 1880s saw a new period of intense snowstorms and high summer flows. The 1880s also mark the beginning of grape growing and wine making in Mendoza. This economic development, supported by the state, required an increase of manual labor and encouraged the arrival of European immigrants to Mendoza ca. 1885. The state promoted drainage to develop cultivatable land for the newcomers and immigrants from Mallorca drained the wetland through “sangrías” or drainage ditches. The 1880s had only one big flood and the following dry period and low flows from the Cordillera in the 1890s, combined with additional drainage projects, reduced the wetland area to ca. 26 780 hectares by 1896 (Fig. 5).

The end of the 19th and early 20th centuries saw the renewal of major floods and the Cipolletti dike was destroyed by a great flood in January 1900. This period culminated in the 1911/1920 decade with seven high streamflow years. 1912 was one of the

highest snow accumulation years in the cordillera at Las Cuevas with up to 10 m of snow (Prieto et al., 2001a).

The archival hydrological records show periods when low and exceptionally low streamflows tend to alternate with periods of high streamflow (Prieto et al., 1999).

Two periods in particular show these strong climatic contrasts: the second half of the 18th century and first half of the 20th century. Prior to 1790 the records show approximately one dry year per decade but subsequently droughts become more frequent with three in the 1860s and four in the 1910s.

By 1903, despite the wet conditions in the cordillera, the surface occupied by the wetland was further reduced to 4550 ha and the distance to the city was 4.43 km (Fig. 6). More intense drainage activity confined the wetland to an interrupted NW-SW corridor. According to Sabella (1936) there were only a few relict lakes at that time. The 1921–1960 period was also one of strong contrasts with a positive trend and higher peaks between 1950 and 1960 (five events).

6 Conclusions

Between 1561 and ca 1670 the Bermejo wetland was smaller than its 1800 extent as a result of the cool LIA climate and limited human interventions. Between the end of 18th century and 1828 it expanded to its greatest extent due to increased flows of the Mendoza river and diversions of the river directly into the marsh to alleviate flooding in Mendoza City.

The first drainage projects began at the start of the 19th century but were not effective until mid-century. The wetland area remained stable until around 1848 through a period with lower snowfall and streamflow and little human intervention. The great floods of the 1849–1864 period were accompanied by the first successful drainage projects. However, the floods did not cause significant changes in the wetlands despite the increase of the water availability. The 1865–1870 period saw scarce snowfall and low stream flows which, combined with the first active state drainage initiatives, led to a

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considerable reduction in the wetlands. Changes in land use, the opening of drainage ditches, road and railway construction and improving technology developed the agricultural lands east of Mendoza City leading to encroachment onto the marshland during the late 19th and early 20th century. Wetland dimensions became less and less influenced by climatic factors as state and local farming actions led to the progressive diminution of the marsh size and it had almost disappeared by 1930. Thus, the surface fluctuations and the wetland level slowly become independent from climatic variability.

Nevertheless, at the present day the water table in the former wetland remains close to the surface and problems linked to the ancient wetland continue including the high water table, salinization, poor soil drainage, etc. Further study and development of measures to counter these effects are critical to diminishing the present social vulnerability in housing and economic activities in this area. They are also vital to interpreting future scenarios related to the probable decrease of Mendoza river flows as a result of climatic change.

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Table A1. Abbreviations.

AHM	–	Archivo Histórico de Mendoza
AGN	–	Archivo General de la Nación Argentina
AGI	–	Archivo General de Indias, Sevilla

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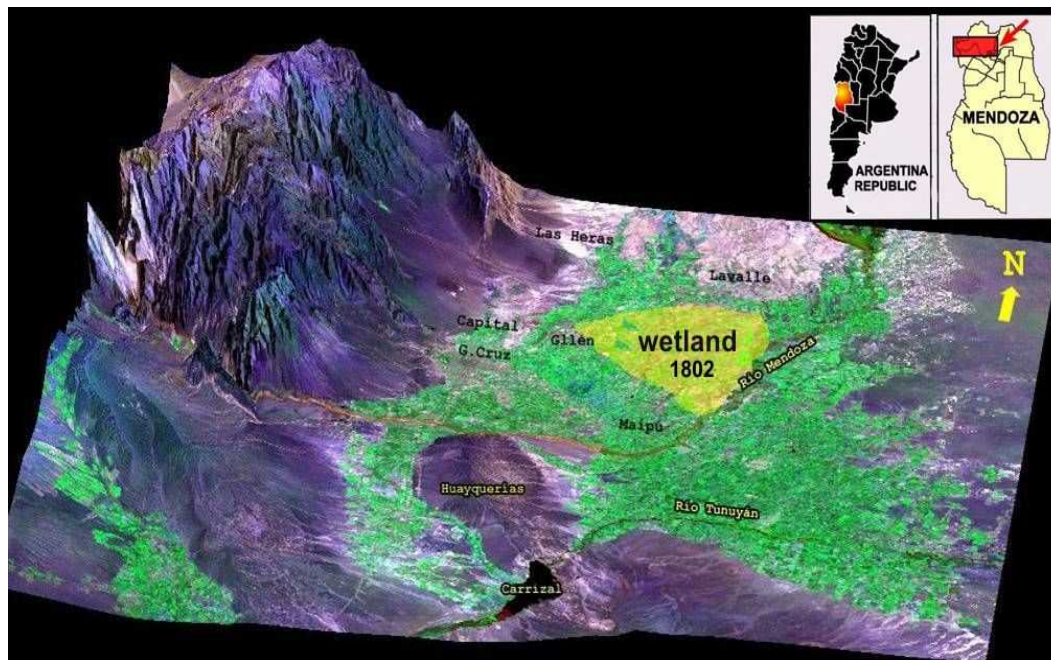


Fig. 1. Location of the Bermejo wetland. The position of the wetland is superimposed on a 1999 Landsat Image.

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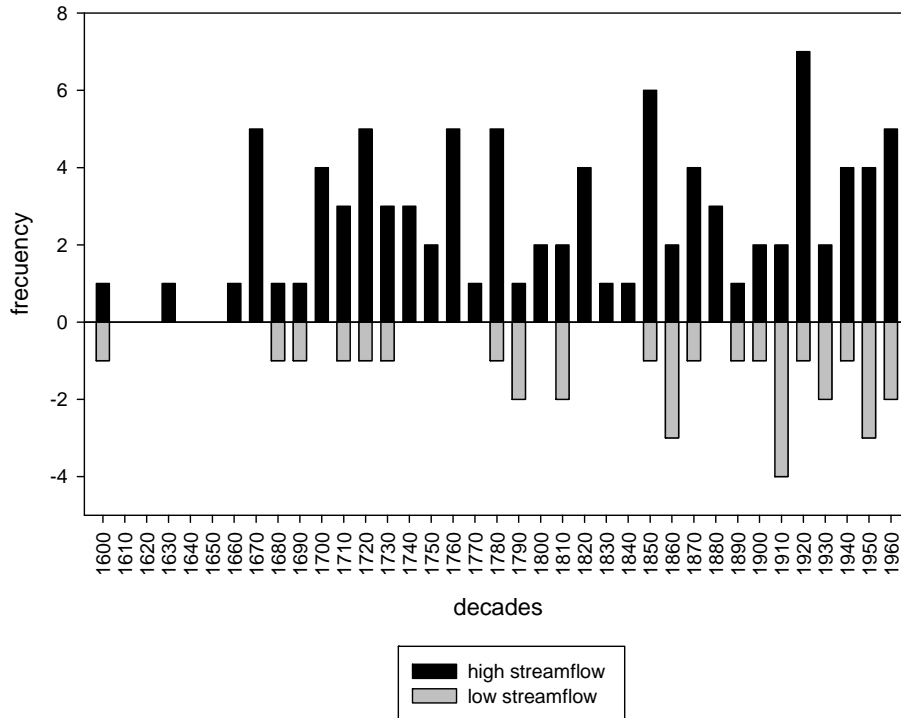


Fig. 2. Mendoza River Streamflow, 16th–20th centuries (Prieto et al., 1999). Bars show the number of years in each decade with extreme high or low streamflows (for details see Prieto et al., 1999).

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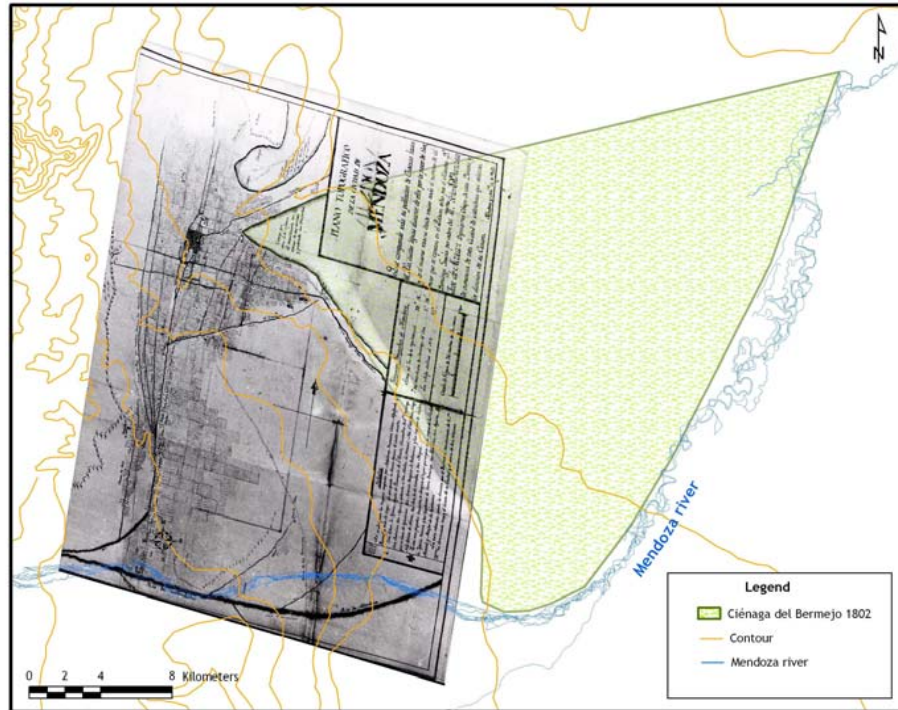


Fig. 3. The Bermejo wetland. Topographic map of Mendoza in 1802 (AGN, IX-45-6-7). In it are marked: the Toma de la Ciudad (city water catchments), the new main stream, the more relevant channels, swamps and crops.

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Fig. 4. The Bermejo wetland in 1861 according the Herman Burmeister map (Museo Area Fundacional).

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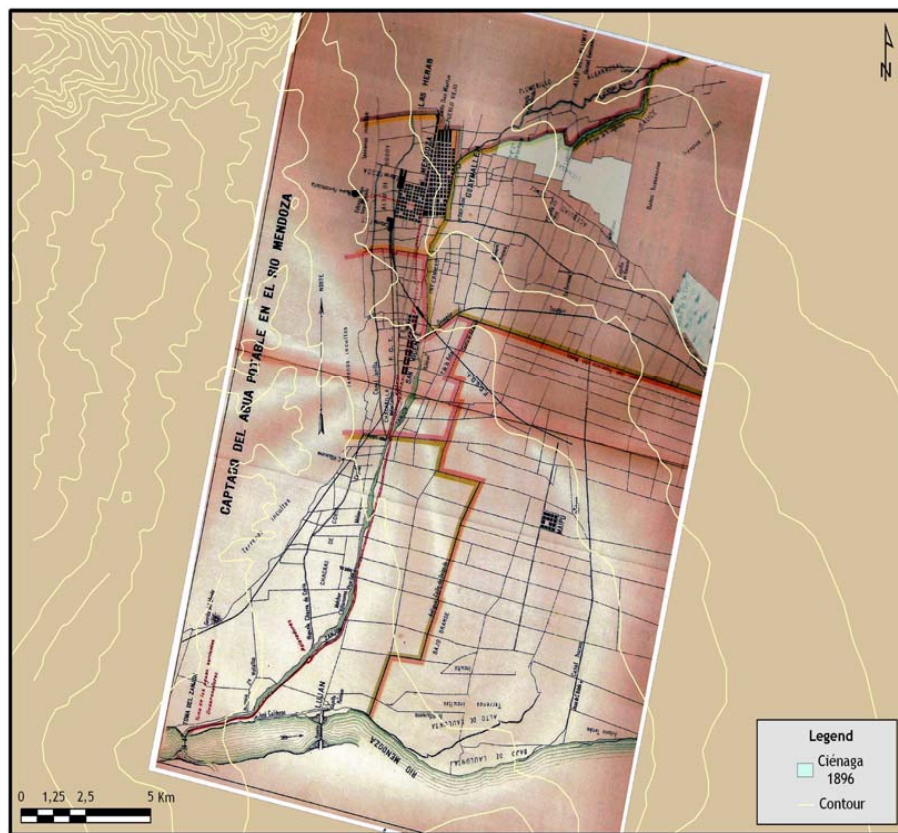


Fig. 5. The Bermejo wetland in 1896 according César Cipolletti map (Coni, 1896).

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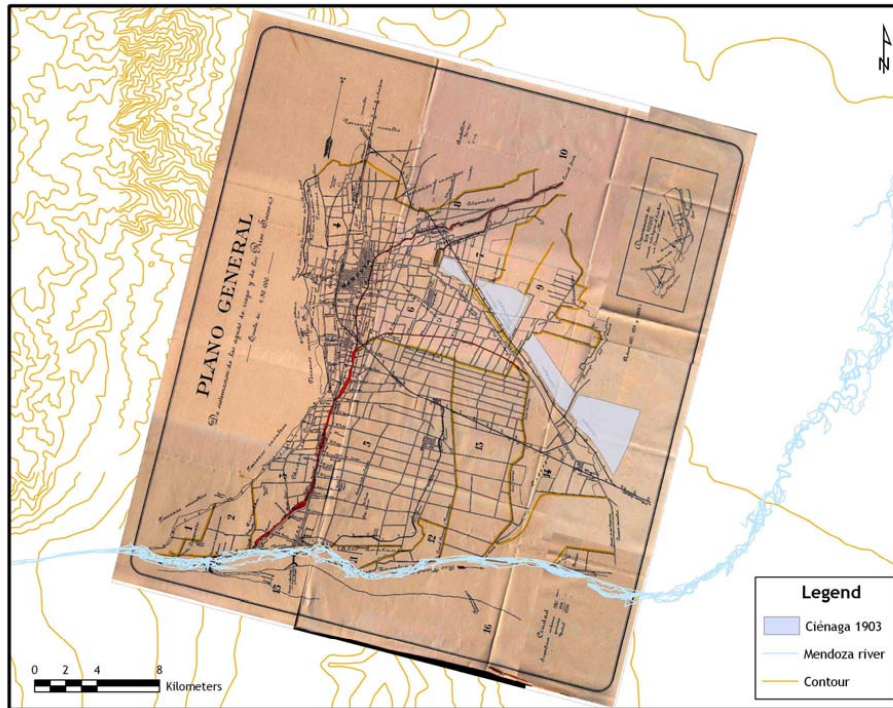


Fig. 6. The Bermejo wetland in 1903 according Pedro Arata Map (Arata et al., 1903).