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Documentary evidence for changing climatic and anthropogenic influences on the Bermejo Wetland in Mendoza, Argentina, during the 16th–20th century

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Abstract. This paper examines the processes underlying changes to the once-extensive Bermejo Wetland, east of the city of Mendoza, Argentina (32°55′ S, 68°51′ W). Historical documents and maps from the 16th to 20th century are used to reconstruct environmental shifts. Historical documents indicate periods of increased snowfall in the adjacent Andes mountains, as well as high flow volumes in the Mendoza River. Data from georeferenced maps, the first from 1802 and the last from 1903, reflect the changes in the surface area of the wetland. The combined data sets show pulses of growth and retraction, in which major expansions coincided with more intense snowstorms and increased flow in the Mendoza River, which in turn influenced socio-economic activities. The wetland became progressively drier during the 19th century, before drying up completely around 1930, due in part to the construction of drainages and channels.

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 shallow pools of water. Historically, wetlands, including swamps, marshes and bogs, have been subject to large-scale drainage. In 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. United States 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 Valk, 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°55′ S/−68°51′ W) based on archival documents from the 16th–20th century (Prieto and Chiavazza, 2006; Prieto et al., 2008), and relate them to the changing streamflow of the Mendoza River (Prieto et al., 1999; Prieto and García Herrera, 2009) and the impact of political and socio-economic activities. To reconstruct the wetland dimensions during the 19th century, unedited archival documents were complemented with historic maps, most of them published. The novelty here is the archival use of documents to reconstruct changes in area and their linkage to historic maps.

The Bermejo Wetland had significant importance with an interesting history that reflects the influence of both climate change and anthropogenic activity. Long-term water-level studies of 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 Valk, 2005).

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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 beginning of the colonial period (1561 to ca. 1760), this sector was one of the most important agricultural and grazing areas in Mendoza. However, high water levels during 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.

In the Province of Mendoza, Argentina, 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 (Fig. 1). The primary source of river flow is meltwater of the winter snowpack in the Andes supplemented by glacier meltwater and regional ground water flow systems. Along its course, the river flows through the three geomorphological units of the Cordillera eastern slope. The first corresponds to the headwaters (32°27′ to 33°20′ S), where the river originates (around 2900 m a.s.l.). Glaciers and the snowmelt accumulated during the winter feed the three main courses forming the river. The second is the sector where the Mendoza River borders the Uspallata valley through the south crossing the precordillera as far as Cacheuta. The third corresponds to the dejection cone, a large alluvial fan deposited by the Andean rivers, where the Mendoza River already entered the sedimentary area and widens its course. Its catchment basin has a surface of 8200 km^2, with a discharge of 53 m^3 per second in Cacheuta, with a maximum mean of 750 m^3 per second and a minimum mean of 9 m^3 per second.

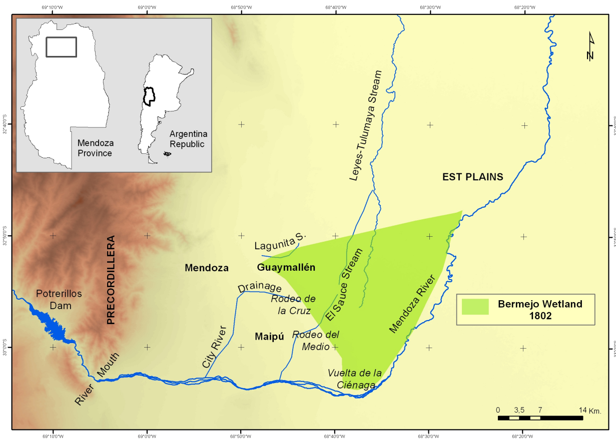

Fig. 1. Study area. The viewer can see the River of the City, the Drainage Channel (Desagüe) and the Lagunita Stream. At the East of the City there was the Great Bermejo Swamp (grey shadow) as it looked in 1802.

This noticeable interannual variation, results mainly from the amount of snow fallen in the high mountains in the winter.

From "Boca del Rio" (River Mouth) the river flows eastwards across the mountains and then turns northwards as it flows out onto the plains.

To the east of the alluvial plain, in 1561 the city of Mendoza was established on the shore of one of the branch of Mendoza river (Río de la Ciudad). This territory was once occupied by prehispanic native groups. During the Hispanic colonial period, this area extended eastwards from the city into the large marsh. The land's main slope points to a southwest-northeast direction and the water streams, drainage and canals converge towards it. The definition given by the Spaniards to that particular ecosystem, "la Dehesa de la ciudad" (City grassland), contributed to specifying its environmental characteristics.

The Mendoza River for its part continues northwards and feeds another lacustrine complex named Guanacache. These two wetlands were part of a single complex formed by the surface water from the Mendoza River and groundwater flow from the cordillera into the lowland (Fig. 2). 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 the productivity of cultivated

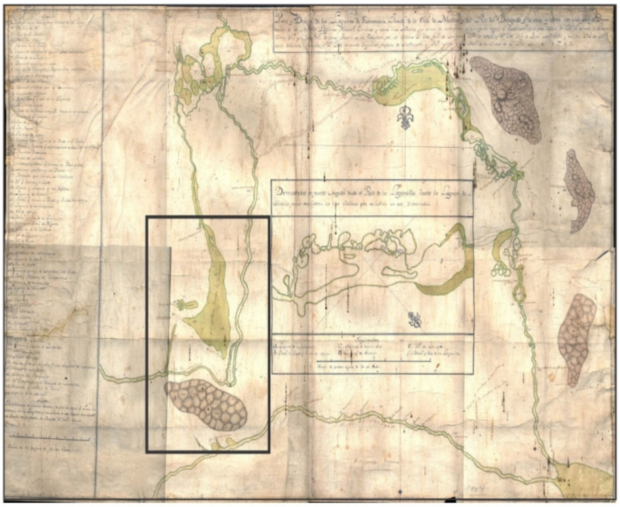

Fig. 2. Map of the Bermejo Swamp and Guanacache Lagoons by Jiménez Inguanzo in 1789. In blackbox is marked the swamp (AGI, Maps and Plans, Buenos Aires, 336, 1789).

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 reeds (*Typha dominguensis*), rushes (*Scirpus californicus*, *Juncus balticus*, *Juncus acutus*), Common reed (*Phragmites australis*) and cortadera (*Cortaderia rudiuscula:* bulrush with sharp leaves South America native) prevailed (Prieto and Chiavazza, 2006).

3 Methodology and sources

A long runoff record for the Mendoza River was obtained using documentary sources from 1601 to 1960. Documents from the Archivo Histórico de Mendoza (AHM) and from Archivo General de la Nación (AGN) and Archivo General de Indias (AGI-Seville) have been used to identify extreme events – floods and droughts – from the 17th century to the first decades of the 20th century and to reconstruct the hydroclimatic variability in the great basin of the Mendoza River during the last centuries (Prieto et al., 1999, 2001a and b). New data was added for the 19th century to form the new data base (Prieto and Garcia Herrera, 2009).

Given that no permanent settlements established along the Mendoza River during colonial times, information on river streamflow variations and floods from the 17th to 19th century was indirectly estimated from the streamflow variations of the Rio de la Ciudad (the City river). In the absence of man-made techniques for water regulation, this branch responded naturally to the increase or decrease of the Mendoza River streamflow. The water extreme abundance or lack of it, caused serious problems for the inhabitants. The date for floods and swellings as destruction of buildings, roads, bridges and public works were systematically recorded in the *Actas Capitulares* from 14 April 1563 when the first act was registered, as far as 1820 (Prieto et al., 1999, 2001a and b). The *Actas Capitulares* were written records of the weekly meetings, held by the local governments in most cities of the former Spanish colonies in the Americas. These records reflect the political, economic, agricultural, social and climatic events that took place during the week, especially those which had adverse economic effects. They constitute a high resolution source of climatic information by his homogeneity and continuity over time.

These important sources were systematically and exhaustively reviewed. Because in the early years some records have been lost, we decided to start the series in 1601. The *Actas* were published to 1675 (Actas Capitulares de Mendoza 1945, 1961, 1974).

This information was complemented with different administrative documents, especially those reports by governors and other government officers sent to the Crown reporting the most relevant regional events, among them those regarding climatic events.

Also we resorted to public and private correspondence, information and descriptions from merchants and travellers crossing the Cordillera in summer. In the course of the 19th century, the written records of the Sala de Representantes de Mendoza meetings from 1820 (Representative House of Mendoza), administrative and governmental documents and military reports were used, as well as scientific observations by early naturalists and old newspapers. In Mendoza, the newspaper activity started in 1823. In the middle of the 19th century they began appearing regularly (*El Constitucional* 1853–1884). *Los Andes* was edited in 1885, being the only newspaper that has been printed without interruptions since the last century to the present days.

Content analysis has been used in different stages: to produce a thematic guide to drive the data extraction, to obtain the corresponding hydrologic categories and to verify the consistency of the collected information. The streamflow increase or decrease in the Mendoza River during summer was taken into account for the searching and gathering of information. Two types of data have been obtained: direct data from explicit references to hydrological events, such as heavy floods or droughts and, indirect data, obtained from reports on the impacts produced by those events, such as collapse or ruin of buildings and routes interrupted because of floods, rivers changed their course, formation of great ravines damages in ditches, channels and dykes, bridges destroyed or covered by water, City river overflows Cordilleran roads harmed. It must be noted that great floods were only recorded when they directly affected the population.

To construct the series, two variables were considered: excess or deficit of water. For those years that, in spite the existence of documents, we have not found reports or claims about the lack or excess of water were considered as normal years.

The content analysis was applied to obtain the equivalence of all indicators into this 5-point scale. This process allowed quantifying the streamflow, assigning a numerical value to each qualitative category: extraordinary streamflow = 2; large streamflow = 1; regular streamflow = 0; low streamflow = −1; extremely low streamflow = −2.

The calendar year was not accounted for, but the summer period from November to March of the following year was considered, so each recorded year includes the two last months of the previous year.

A difficulty in using documentary data for quantitative climate reconstructions is that many series do not have sufficient overlap periods with instrumental data to allow a direct calibration.

According to Pfister et al. (2002) calibration "establishes a transfer function between a series of index values and a corresponding series of instrumental temperature or precipitation measurements".

In the case of the Mendoza River runoff we use reports of the newspaper Los Andes to extend the documentary record and derived indexed time series of Mendoza River runoff from 1885.

We defined the modern period as starting in 1885 when the record of newspaper Los Andes begins. We basically applied the same methodology as the ones used to derive the indices of historical period.

To overlap with periods with instrumental data (52 yr) we used means of the available instrumental runoff data from Station Cacheuta covering 1909–2000 (Neukom et al., 2009).

We applied the Spearman test correlation in the historical and modern periods and Standard deviation:

- Mendoza river runoff: correlations with instrumental measurements, 0.43 (0.02);
- standard deviation: historical (pre-1885) 0.77;
- modern (from 1885) 0.93.

Documentary sources were also used to obtain supplementary data of snowfall in the Argentinean-Chilean Central Andes (1760–1890) (Prieto and García Herrera, 2009).

Otherwise, the archival documents show successive hydrological changes in the wetlands in response to climatic fluctuations in the headwaters. In order to analyze the different changes in the ecosystems of swamp and marshland areas we reviewed documentation in the Historical Archive of Mendoza city, newspaper libraries and regional and national libraries (see the complete list in the Appendix). We applied the methodology used in Environmental History which consists in comparing the ecosystem's current state (through recent studies on climate, geomorphology, vegetation and soil achieved through studies on soil and satellite images analysis) with the baseline (in this case the wetland's condition in the beginning of 19th century) and with the continuing variations that it underwent through our study's time span: 1800–1930). To approach this study, we have turned to historical tracing techniques and carried out a critical analysis of documentary sources such as public documents, government records, public and private correspondence, testamentary and notarial archives.

The following natural indicators were traced in the documentation on this study area: rise and fall of the Mendoza River stream, drought and extraordinary rains, hydrologic hazards, information on floodings and poor soil drainage of the agricultural fields and roads near the swamp, salinization remains, sedimentation, changes in vegetal coverage and of species of local flora and fauna.

The anthropic indicators that stand out are: governmental and private activity in relation to the swamp and its drainage's surface increase; news on new settlements, occupation, sale or abandonment of land that has been taken over by water; use of natural resources related to that environment: bulrush, cane, giant reed, wood, firewood, insertion of new flora and fauna species; construction or abandonment of streets, roads and railway tracks, bridges, canals, irrigation channels and drainage, water usage, specially irrigation channels and its subsequent conflicts.

Once the natural and anthropic information was gathered, it was chronologically organized and interpreted with the help of the annual data belonging to the Río Mendoza stream's, while observing the coincident time frames between the years of abundant water stream and the increase in the swamp's surface.

It was determined that the progress of swamps responded to different cycles or pulses. These pulses, noticeable for pool soil drainage, overflow or increase of surface were generally the creators of complaints and new propositions by the inhabitants of the affected areas in order to start action to dry them. These suggestions were registered profusely in documented sources. On the contrary, the absence of registered information in the documents clearly points to the absence of the phenomena throughout those years. For space reasons, we will only include the obtained information that illustrates our statements. An Appendix with the exhaustive information from the Historical Archive of Mendoza has been added at the end of the paper.

3.1 Overlay and georeference of historic maps

In order to reconstruct the wetland's size during the 19th century we made use of archival documents and complement them with historic maps.

Amongst these maps, we selected the most representative and the ones that gathered the conditions to be georeferenced with precise axis, streets and watering channels that coincide with the actual ones. This would allow them to be localized in a coordinate system that would facilitate the distances and surfaces measurement process. In addition, it was possible to trace and locate the surface that the swamp would have currently occupied and its different phases of progress and decline. This way, even though there are many inaccuracies when comparing maps of different time periods, designed by authors with different criteria and methods, we observed modifications in limits, surface and distribution of the urban infrastructure, such as streets and channels which showed processes of territorial occupation.

The georeferencing of old maps was achieved from the correspondence between the familiar spots on the old map (scanned with 600 dpi precision) and the satellite image previously orthorectified (Landsat 7 ETM+, GeoCover-NSA EarthSat 2000). This way, a resampling of pixels was carried out from an average of 30 control points known in both maps. In this manner, the antique map acquires a coordinate system of the satellite image from the application transformation of cubic convolution (polynomial grade 3). The mean square error (RMSE) reached 15 to 45 m, which is considered a high mistake for studies done with satellite images because it exceeds the base pixel (30 m Landsat 7 ETM+). However, it is considered appropriate for working with historical maps (De Clercq and De Wulf, 2007; James et al., 2012).

Georeference is possible only when there are territorial elements that have remained unmodified (crossings of antique streets, watering channels) both in old maps as well as in modern image. At the same time, the meaningful difference between the Pedro Arata map from 1903 and the old maps from the beginning of the 19th century should be highlighted. The first one is far more precise than the second ones.

The first map of the area where the Bermejo Swamp is clearly imprinted dates back to 1789 (AGI, Maps and Street Plans, Buenos Aires 336, 1789) (Fig. 2). Subsequently, many more were designed. We have only chosen the most representative ones (Espinosa and Bauzá, 1794; Serra Canals, 1800; García, 1802; Hibbert, 1824; Brue, 1826; Álvarez Condarco, 1837; Society UK, 1840; Martin and Tilles, 1951; Arrowsmith et al., 1854; De Moussy, 1858; Wenceslao Díaz, 1861). The main characteristic of these maps is that they were all included in the wetlands of north Mendoza, both the Bermejo Swamp and the Guanacache lagoons, with a regional perspective. The difficulty lies in the fact that they are too broad to overlay them with current maps (see Fig. 5).

Amongst the maps that belong to the first half of the 19th century, the most specific and clear one was designed by Father Domingo García, city parish priest, in 1802 due to the fact the it is specially focused on the city of Mendoza and the Bermejo Swamp. This map was part of a population census organized by this city parish priest. In it, streets, water channels and neighbourhoods are clearly marked and the viewer can identify the same spots in the current configuration (see Fig. 4).

The following map holding these characteristics belongs to another time period of the history of Mendoza (Burmeister, 1861). During the second half of the 19th century, naturalists mainly from Germany and France start to arrive to Mendoza, some of them hired by the national or provincial government and others exclusively for scientific reasons because their objective was to draw maps of the area.

In this paper are analyzed also the maps created by Ballofet (1874), Cipolleti (1896) and Arata et al. (1903).

We measured the straight-line distance on the five selected maps, (1802, 1861, 1864–1870, 1896, 1903) between two reference points – the Pedro del Castillo square, representing the center of the colonial city and the western edge of the wetland. We based on the reference given in the map of 1802 which places the western edge of the wetland in the *Capilla de Nievas* (Chapel of Nievas), which still exists in the same site as *Capilla de Nieve* (Chapel of Snow).

4 Background

The runoff record for the Mendoza River mentioned above was used to relate it with the “growth pulses” and retraction moments of the Bermejo Marsh. The moments of major growth coincide with cycles of bigger snowstorms and larger flow volume in the Rio Mendoza. It is also during these periods when the biggest amounts of complaints are issued by the inhabitants of the marsh’s surroundings regarding its progressive coverage over cultivated areas. The retraction moments was related with low flow period.

Figure 3 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 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

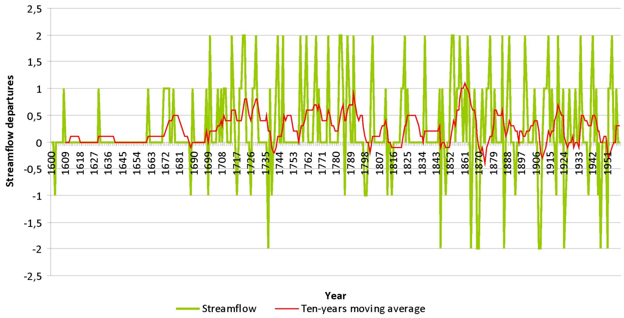

Fig. 3. Mendoza River Streamflow, 16th–20th centuries Categories: extraordinary streamflow = 2; large streamflow = 1; regular streamflow = 0; low streamflow = −1; extremely low streamflow = −2. 10-yr moving average (Prieto et al., 1999; Prieto and García Herrera, 2009; Neukom et al., 2009).

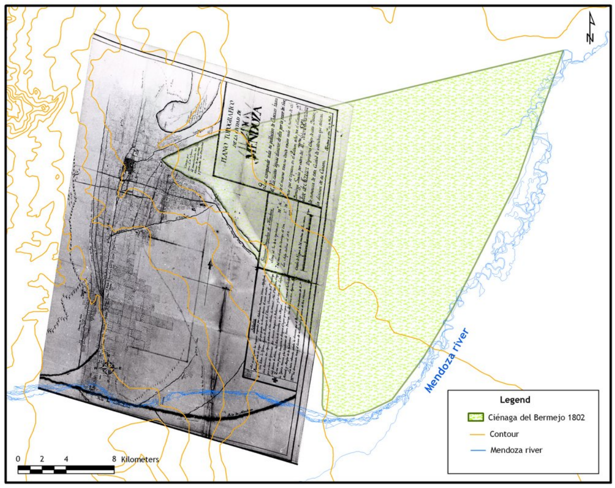

Fig. 4. The Bermejo Wetland. Topographic map of Mendoza in 1802 made by the father García (AGN., IX-45-6-7). In it are marked: the Toma de la Ciudad (city water catchments), the new main stream, the more relevant channels, swamps and crops. Map legend: "swamp that is sterilizing the fields of its banks and losing farms".

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). Some 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.

During the last years of the 18th century, the city inhabitants raised a popular protest and that was reflected on the documents. The swamp had been considerably enlarged and its growth continued. A considerable amount of land located on its shore had been invaded by water and mud, which brought negative consequences to the area's economy. This was reflected on the cultivated parcel's price and the abandonment of the most fertile areas. In regards to that, D. Isidro Sainz de la Maza requested the town council to take measures to control the progress of swamps given that "...with time, the swamp is growing so steadily that many of the estates and lands are lost and abandoned by their owners and others become unfit". (AHM, C17/D13, Capitular Act June 1799). Members of the town council of Mendoza also acknowledged the situation when government employees started to request for help and measures to solve the problem: "coming the great ruin of the swamp that is rapidly consuming the city's main fields" (AHM, C17/D13, 22 June 1799).

The testamentary archives reflect these events accurately. To test the progress of the marshy area over the properties we examined the wills of neighbors that owned land in the ancient meadow (Prieto et al., 2008). Around 1797, the problems caused by the progress of the swamp over the croplands were first acknowledged in the valuation of the land in the Testamentary Archives (AHM, Protocols, Carp. 251/Testamentaries).

The growth of the marsh area had both natural and anthropogenic causes: the area has a south west to north east 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 issue in contemporaneous documents confirms that the growth of the wetland was a significant issue at the time (Prieto et al., 2008).

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

The wetland reached its greatest cover area (58 000 ha) in 1802 when it was 2.82 km from the city centre (Fig. 4). From this year onwards, the area remained stable until 1848 through a long period with lower snowfall and streamflow and little human intervention (see Fig. 3). The marsh's stability during these years can also be confirmed by examining the maps of that long period (1802–1860) since it is represented with the same dimensions in all of them (Fig. 5).

Fig. 5. Maps of the Bermejo Wetland from different years between 1794 and 1861.

The first project to drain the wetland took place in 1803 (AHM, C37/D27, 1803). Between 1806 and 1808 the neighbors of the swamp area continued to demand to the town council the realization of the project.

"The captain don Ignacio Escalante and others (were) interested in opening a course through which the marsh waters could drain, because they have flooded and lost our haciendas (estates) 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).

In 1815, the wetland was ca. 40 km from east to west and a few drainage projects were slowly developing according to Tomás Godoy Cruz, a city official:

"…the swamp is currently covering over eight miles of Mendoza's finest pieces of land, both because of their quality and location. The progresses made daily and visibly over nearby estates clearly forecasts that in few years' time, its limits will reach the gorge's slope" (AHM, D73/C236, October 1815). The precarious technology of the time simply consisted of opening new channels that would allow drainage of part of the wetland into different areas and was not very successful.

After thirteen years without information on the wetland in the documents, finally between 1828 and 1839, following a year with more abundant snowfall in the cordillera and the short wet period of the 1820s, the people affected by the marsh held a meeting "…to try (and plan) a project… that desiccates it (the wetland) or at least avoids (reduces) its progress" (AHM, C100/D55, 1828/1839). However, this project was not carried out.

Fig. 6. The Bermejo Wetland in 1861 according the Herman Burmeister map (Library of the Museum of Mendoza Foundational Area).

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 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.

"The advance the swamp is making from its source is notorious to the extent of having already cut the railway road (to Buenos Aires) and having caused some poor soil drainage in some lands to the southern part of Rodeo de la Cruz. Therefore, there is popular agreement on the fact that the partial drainage systems applied up until now have turned out to be an inefficient solution" (AHM, C101/D35, 3 June 1848).

Although the period between 1850 and 1880 was characterized by high streamflows (see Fig. 3), since 1865–1870, the series shows a clear, decreasing trend defined by an increase in the frequency of years with very low flow stream that coincides with the first serious attempts to dry the swamp.

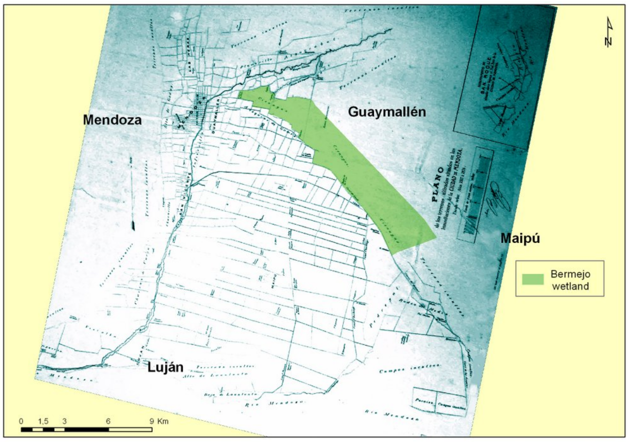

Fig. 7. The Bermejo Wetland in 1874 according the Julio Ballofet map (Mitre Museum, Buenos Aires City).

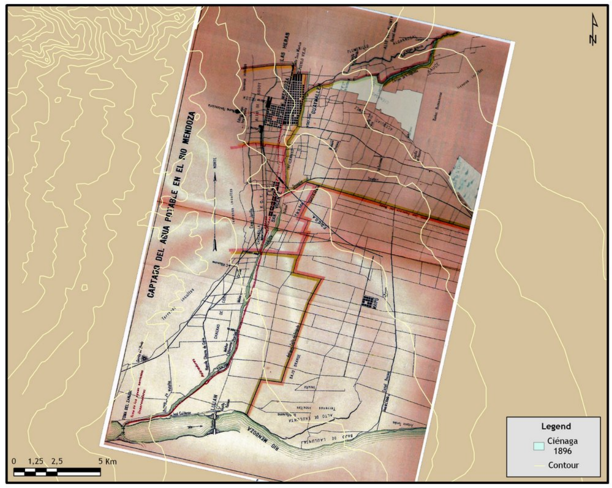

Fig. 8. The Bermejo Wetland in 1896 according César Cipolletti map (Coni, 1897).

The 1864 census (Censo de 1864, AHM, C15/D24: Guaymallén) clearly shows the swamp's magnitude at that time in relation to the cultivated areas in the Guaymallén department. Whilst the extension of the whole Department was 25 785 ha, only 7478 of them were cultivated with alfalfa and 897 hectare with vineyards and fruit trees. The uncultivated lands, most of them swamps, covered 17 500 ha in Guaymallén alone.

By 1868–1869, both *El Constitucional* (4089-09/03/1868, p. 2) and government announcements referred to the state of the road back from the swamp as well as to the poor soil drainage in that area, probably linked to the abundant snowfall during the winter of 1868.

The first effective drainage through ditches begins in 1848 and ends in 1853. From 1860 onwards begins a period in which 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 variables. The Burmeister map from 1861 shows a reduced wetland area of ca. 40 100 ha beginning 5.43 km from the city (Fig. 6).

After a very dry decade with low streamflows of the Mendoza River and the acceleration of drainage works in the 1860s, the Ballofet map (1874) maintains the distance to the Pedro del Castillo Square (2.36 km), but the wetland area decreased to ca. 6800 ha (Fig. 7).

The 1870s and 1880s saw a new period of great climatic variability with intense snowstorms and high summer flows but also high frequency of drought. 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. 1870/1880. The state promoted drainage to develop cultivatable land for the newcomers and immigrants from Mallorca drained the wetland through "sangrías" or drainage ditches. "The invaluable improvements of the swamp's drying process takes place there and is carried out by the hands of land growers" (*El Constitucional*, 4787-03/04/1869, p. 3). Only one big flood occurred during the 1880s 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. 3300 ha and 4.30 km the distance to Pedro del Castillo Square by 1896 (Fig. 8).

The end of the 19th and early 20th centuries saw the renewal of heavy floods and the Cipolletti dam 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, Fig. 3). Two periods in particular show these strong climatic contrasts: the second half of the 18th century and the late 19th and early 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 3100 ha and the distance to the city was 4.43 km (Fig. 9). 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.

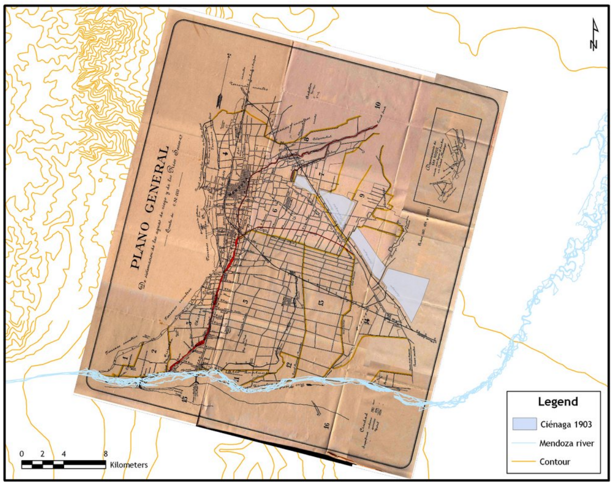

Fig. 9. The Bermejo Wetland in 1903 according Pedro Arata Map (Arata et al., 1903).

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 early in the 19th century but were not effective until the mid-century. The wetland area remained stable until around 1848 through a period with lower snowfall and streamflow and little human intervention. The great flood of the 1849–1864 periods 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 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. The area of the wetland 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, the modern 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.

Appendix A

Maps

1789: Plano y descripción de las Lagunas de Guanacache, jurisdicción de la ciudad de Mendoza según el reconocimiento ejecutado por los Sres José Fco. De Amigorena y Antonio de Palacio. Levantado por D. José Jiménez Inguanzo. Con expediente y autos de D. Francisco Serra Canals AGI, Mapas y Planos, Buenos Aires file, 1789.

1794: José de Espinosa y Felipe Bauzá. Carta esférica de la parte interior de la América Meridional. Biblioteca Nacional de Brasil.

Ca. 1800: Francisco Serra Canals: Plano topográfico de los caminos entre Mendoza y San Luis, por litigio entre el gremio de carreteros y Francisco Serra Canals AGI, Mapas y Planos, Buenos Aires file, 210.

1802: Padre Domingo García "Plano Topográfico del Curato de Mendoza realizado por don Domingo García", 1802, AGN, Sala IX-45-6-7.

1824: Map with the route from Buenos Aires to Santiago de Chile, in: Hibbert Edward "Narrative Journey from Santiago de Chile to Buenos Aires", London.

1826: Brue, Adrien Hubert, Perou, Haut-Perou, Chili, La Plata, 1786–1832, Publisher: A. Brue, Paris.

1837: José Antonio Alvarez Condarco. Mapa de la provincia de Mendoza: levantado por el coronel... Colección Pedro De Angelis, Cartografia ARC.009,14,002, Biblioteca Nacional de Brasil.

1840: Society for the Diffusion of Useful Knowledge (Great Britain), La Plata, Chile, CLL Publisher, Chapman and Hal, London, David Rumsey Coll.

1851: Martin, R. M., Tallis, J., and Date, F.: Chili And La Plata, Publisher: J. & F. Tallis, New York, David Rumsey Coll.

1854: Arrowsmith, John, Marzolla, Benedetto, Parish, Woodbine Date: 1850, Provincie Unite del Rio de la Plata, Argentina, Chili, Uruguay, e Paraguay. Publisher: B. Marzolla, Naples David Rumsey Coll.

1858: De Moussy, Martin. Carte de la Province de Mendoza, de l'Araucanie et de la plus grande partie du Chili. Par le Dr. V. Martin de Moussy 1869 publicado en Atlas de la Confederation Argentina (1869) Argentina y 1973 en París (Paris Librairie de Firmin Didot Freres, Fils et Cie., 1873).

1861: Wenceslao Díaz. Croquis del terremoto que destruyó Mendoza el 20 de marzo de 1861, in: Verdaguer, Vol. II, p. 113, 1932.

1861: Hermann Burmeister (1807–1892). German naturalist. He made most of his work in Argentina. He founded the Academy of Natural Sciences of Cordoba. The original map of 1861 is preserved in the Library of the Museum of Mendoza Foundational Area.

1874: Julio Ballofet (1831–1897) French Surveyor established in Mendoza. He prepared the draft of the new city of Mendoza, after the 1861 earthquake. He was director of Topographical Department of Mendoza. The map presented was commissioned in 1867 by the Government of Mendoza and was completed in 1874. It is located at the Mitre Museum, in the City of Buenos Aires.

1896: César Cipoletti (1843–1908). Italian hydraulic Engineer. He arrived to Mendoza in the late 1880s. He was a dam builder in Mendoza river in 1890. It was the first Superintendent of the General Direction of Irrigation Mendoza. The map analyzed is published in Coni (1897).

1903: Pedro Arata (1849–1922) Chemical and medical Argentine, he was professor at the University of Buenos Aires. In 1903 he was appointed Director General of Agriculture. He was President of the National Council of Education and Honorary professor of the Faculty of Medical Sciences. Two years chaired the National Academy of Medicine. The map is published in Arata et al. (1903).

Appendix B

Sources from Archivo Histórico de Mendoza

References to manuscript sources in the Archivo Histórico de Mendoza are denoted by the initial AHM, followed by the name of the section of the Archive where the documents located and a number identified the files, to which the documents belong, and then the number of each document.

Appendix C

Colonial Period

C1 Actas Capitulares de Mendoza

18th century until 1820: Files 12: 1700–1720; 13: 1721–1745; 14: 1746–1760; 15: 1761–1774; 16: 1775–1785; 17: 1786–1799; 18: 1800–1810. Agreement Books of the Cabildo, from 1790 to 1806.

C2 Government Section

Cabildo: files 21, 22, 23 24, 25 26.

Cabildo: Public Works and Irrigation: files 33, 34, 35, 36, 37.

Judiciary Section: file 192.

Execution of the will: inventaries: from 1774 to 1796. Landowners invaded by swamp. Files 240, 247, 250, 251, 254, 257, 258.

Appendix D

Independent Period

Sala de Representantes Acts (continuation of the Cabildo) from 1820 to 1830.

Execution of the will: inventaries from 1811 to 1900: Landowners invaded by swamp (non exhaustive-list). MOYANO, María Alejandra.27/11/1811. C 32, INDEPENDIENTE, judicial, testamentaria, "M", 1811–1823 "Valor de un terreno: por la proximidad a la ciénaga y escasez de agua se tasa en $30 la cuadra = $60.1 1/2."; BARRAQUERO DE ORTEGA, Clara, 26/01/1835 C 6, INDEP, Judicial. Testamentaria. "B"Años: 1811–1836 Un casco de estancia que se halla tres leguas de la ciudad, situada en el centro de la ciénaga, bastante lagunoso y salitroso; ANZORENA JOSEFA, 3/6/1846, C2, Independiente,Testamentería " quatrocientos quarenta y dos sepas moscatel en buen estado y si de peligro por la sercania de la sienaga pr. lo qe consideré cada una á rial y medio é importan ochenta y dos p. siete r."; MAZA, Juan Isidro y su esposa Mercedes Anzorena. 29/07/1854, C 36, INDEPENDIENTE, Judicial. "M"Años: 1854–1859 "Valor: por estar sin cercos ni tapias, por estar cenagoso y cubierto de pájaro bobo pero susceptible de disecarse se tasa a $8 la cuadra = $114.4 5/8"; FRET, Jacoba 06/02/1856, C20, INDEPENDIENTE, judicial, Testamentaria, "F", 1845–1856 "sigue un campo cenagoso… pero productible en paja y totora con superficie de 4 cuadras 12084 v."; GUARDIA, Santiago y su esposa María del Carmen Alvarez, 06/05/1856, C26, INDEPENDIENTE, judicial, Testamentaria, "G" "Valor: $30 la cuadra por su mala condición a causa de su inmediación a la ciénaga = $38.75 1/2"; GUTIERREZ, José Fructuoso. 26/08/1859, C26, INDEPENDIENTE, judicial, Testamentaria "como 5 cuadras en el E muy arruinadas, todo se esta perdiendo por falta de desague".

Letter Books of Government and Treasury Protocols, (1850–1900) Notary Protocols of Guaymallén: buy and sale of properties. It were revised the Notary protocols corresponding to Francisco Álvarez, Pascual Jellemur, Pompeyo Lemos, Ángel Navarro, Salvador Reta and Ramón Videla , Notaries. Protocols No. 535, 536, 537, 539, 542, 543, 544, 546, 548, 550, 551, 554, 555, 556, 558, 560, 565, 566, 569, 571, 573, 574, 581, 582, 583, 586, 585, 586, 588, 589.

Topographic Department: corresponding Memories.

Messages of Governors of the Province of Mendoza from 1860 to 1900.

Files of Countryside Departments of Mendoza: No. 133 Capital and Guaymallén (1857–1872).

No. 582 La Paz (1814–1872).

Letter books Files No. 27 (1848–1854) and No. 28 (1855–1876).

Irrigation files: 100 (1810–1837), 101 (1839–1851), 102 (1852–1854) 103 (1854–1856), 104 (1856–1858) 106 (1862–1864) 107 (1865–1867) and 108 (1867–1869).

Government Memories: file No. 130 (1847–1893).

Province of Mendoza Census 1864, Las Heras, file15/D23 Guaymallén file 15/D24.

General Census of the Mendoza Province , produce in 18-8-1909 by Francisco Latzina and A. Martínez, Bs. As., Cñía. Sudamericana de Billetes de Banco, 1910.

Appendix E

Newspaper libraries

Newspapers from 19th and 20th centuries: El Constitucional from 1853 and Los Andes from 1885.

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