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Chapter 6

A SEDIMENTARY BASIN AS A CRADLE FOR BIODIVERSITY: THE CASE OF THE SALADO BASIN IN THE BUENOS AIRES PROVINCE, ARGENTINA

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ABSTRACT

The sedimentary Salado basin is located in the Province of Buenos Aires, Argentina, and extends for about 150,000 km^2; of which 50,000 km^2 correspond to the lower estuary (or marine estuary) of the Rio de la Plata and to the adjacent sector of the Atlantic Ocean.

The basin, which takes its name from the homonymous river that crosses it, is composed of blocks that allowed fluvial-lacunar environments with extended flood plains to be developed. The present configuration of the basin comes from recent sedimentary fill, and shows a broad accretion plain with a low topographic slope that extends with similar features toward the continental shelf. With a sedimentary thickness of over 6,000 m, the Salado basin is characterized by a large vertical development of Upper Paleozoic, Mesozoic and Tertiary continental sediments, with no outcrops from before the Quaternary. The origin of the basin can be related to the development of extensional fractures that took place over ancient weakness zones where the starting aperture mechanism of Gondwana began. The geographical location of the basin, together with its large extent, low elevation over sea level, geology, geomorphology and the prevalent humid climate have produced a particular hydrological behavior with strong ecological characteristics. Vertical water movements (evapotranspiration – infiltration) predominate over horizontal ones (runoff), and there is a strong connection between surface water and

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groundwater. Due to the low topographic gradients the regional velocity of runoff and streams are very much reduced, which results in a longer time of contact between water and the soil surface and the ensuing increase in infiltration and evapotranspiration. Local and regional seepage are identified. Local seepage refers to an active subsurface flow that outcrops in creeks or ponds, forming their base flow. Regional seepage is a very slow passive flow connected with the deep sedimentary layers in which it takes place. Because of the frequent presence of a shallow water table, surface water and groundwater are strongly related, thus allowing the existence of numerous water bodies rich in biotic resources. The study area has a high biodiversity with sectors of considerable importance for conservation purposes. It can really be considered as a cradle for biodiversity, even though sensitive to human activities. The study area periodically experiences prolonged floods and strong droughts that have frequently led to great losses in the agricultural production and in the urban and road infrastructures. However, floods prevent soil from being salinized, and control the spreading of some harmful dicotyledons in pastures. A general monitoring proposal that would be very useful for the management of natural resources is also given.

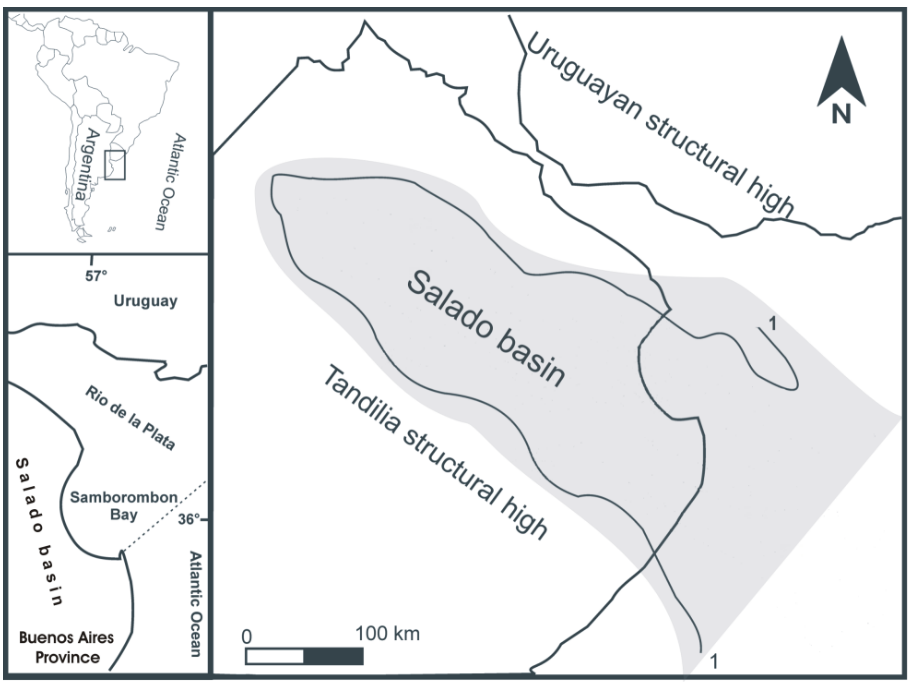

Figure 1. Location map of the Salado Basin. The limit of the basin is shown nearly the 1 km isopach.

INTRODUCTION

The Salado sedimentary basin is located in the center-east sector of the Province of Buenos Aires, Argentina, between the Precambrian - Paleozoic Uruguayan and Tandilia structural highs, and extends along a northwest-southeast direction towards the Samborombon Bay and the continental shelf (Figure 1). The whole basin is very flat with topographic slopes that decrease from 0.05% in the northwestern sector to 0.02% in the southeastern sector. Slopes in the continental shelf are similar to those of the southeastern sector. The continental region of the Salado basin extends to 100,000 km^2 with a population that is now over one million. Between 25% and 30% of the Argentina's grain and meat production comes from it. Periodically, this region undergoes prolonged floods and strong droughts that bring about great economical losses in agricultural activities, as well as in roads, bridges and urban infrastructure. After a brief description of the physical setting of the Salado basin, this chapter focuses on its significant ecological features, and describes a suitable way of monitoring and transmitting meteorological data in order to mitigate as much as possible the consequences of natural impacts, particularly of flooding due to extreme rainfall.

PHYSICAL SETTING

Geology

The Salado sedimentary basin is one of the many extensional Mesozoic basins along the east coast of South America and the west coast of Africa, produced by the continental rifting that followed the breaking of the Gondwana super continent. The structural tectonic evolution of the Salado sedimentary basin is mainly extensional and began during the upper Jurassic and lower Cretaceous (Ponté et al., 1978; Bracaccini, 1980; Nullo, 1991). Four stages can be identified in the tectonic evolution, namely pre-rift, rift, sag and passive margin (Tavella and Wright, 1996; Yrigoyen, 1999; Tavella, 2005). The northern, southern and eastern boundaries of the Salado sedimentary basin are formed by direct faults that reach several kilometers of throw. This faulting has produced positive areas composed of blocks of igneous metamorphic basement covered by a few tens or hundreds of meters of sediments (Yrigoyen, 1975).

The geological characterization of the study area is based upon drilling profiles from oil exploration wells bored by oil companies between 1948 and 1994 (YPF (Yacimientos Petroliferos Fiscales), Kerr McGee, SIGNAL, UNION, SUN, and Chevron and Amoco). As detected seismically at its deepest part, the Salado sedimentary basin is filled up with over 6,000 m of Mesozoic-Cenozoic consolidated sedimentary rocks. Inside the basin, these sedimentary rocks lie on two basement units. One of these units consists of metamorphic rocks of Precambrian age intruded by granitic rocks of the same age; the other unit is a meta-sedimentary basement of the Proterozoic to Eopaleozoic ages. The basement was always found at the boundaries of the basin or outside it; towards the axis of the basin the geologic profile becomes abruptly deeper (Bracaccini, 1972). A sequence of consolidated sedimentary rocks of decreasing grain size lies over the basement. This sequence is composed of conglomerates, sandstones and reddish-brown mudstones interbedded by effusive and volcanic rocks. It has a maximum thickness of 3500 m (Zambrano and Urien, 1970). Immediately upwards, there is a subsidence stage with consolidated sedimentary rocks of the red beds type and deposited in angular unconformity with maximum thicknesses of 900 m (Zambrano y Urien, 1970). These rocks correspond to facies developed in a proto-oceanic environment.

The stratigraphic sequence continues with the deposition of deltaic and transitional sediments composed of siltstones with small quantities of lime and sandstones. These sediments belong to the upper Cretaceous and have a maximum thickness of 1200 m. They represent the first apparent marine ingression throughout the basin (Zambrano, 1971).

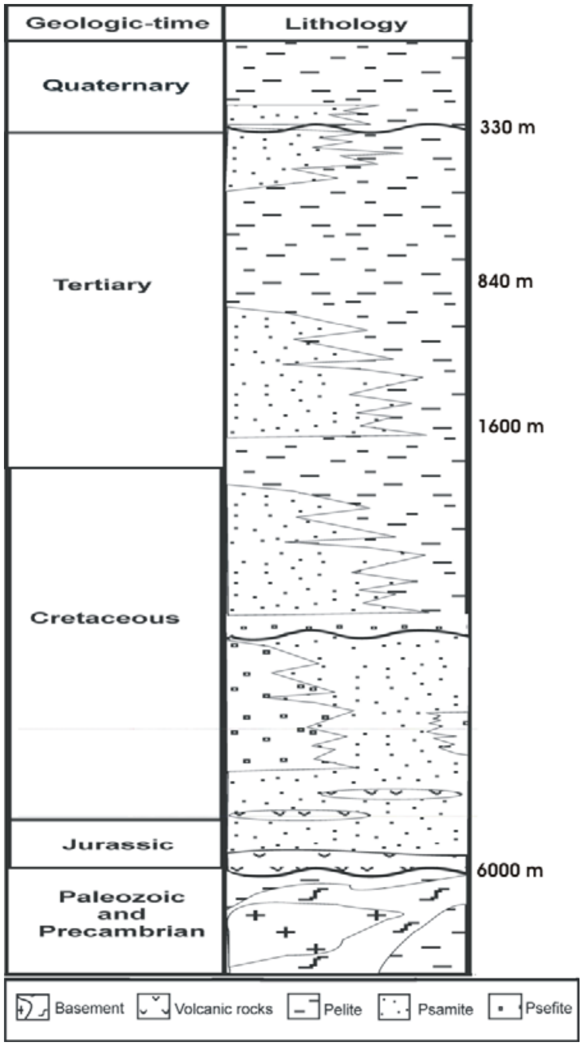

Figure 2. Stratigraphic column of the Salado Basin. Numbers to the right are the corresponding depths in meters. Bottom: Lithological references.

Between the Eocene and lower Miocene, and over the marine units, transitional Tertiary sediments are deposited followed by continental red layers of regressive character. Eastwards, these formations pass into deltaic and marine deposits that become dominant before reaching the continental slope. The whole sequence has a maximum thickness of about 800 m.

Another large sea-level rise took place during the early to middle Miocene. This formation is composed of a series of clay, clayey sands and green sands with calcareous levels and marine fossils. The Cenozoic sedimentary process ends during the Pliocene with continental clastic accumulations of fluvial origin and late Pliocene age.

Finally, Quaternary sediments are deposited in angular unconformity over Pliocene sediments. These sediments are mostly represented throughout the basin by Pampean sediments. The stratigraphic column of Figure 2 summarizes the filling of the basin.

Climate and Hydrology

The climate of the Salado sedimentary basin is humid temperate. The average rainfall for the period 1897-2010 is 870 mm/year, with extreme values of 1500 (in 1973) and 380 mm/year (in 1916). These variations of rainfall determine the existence of dry and humid periods. Figure 3 shows the evolution of annual rainfall together with the curve obtained with a 10-year moving average. Periods with rains above or below the average are thus clearly identified. According to the Thornthwaite and Mather (1955) method, the evapotranspiration is 770 mm/year. Because of the low topographic gradients, vertical water movements (evapotranspiration and infiltration) prevail over horizontal ones, thus making variations in the surface water and groundwater storages a significant term in the hydrological budget. Although the information available to quantify surface runoff is scarce, it has been estimated in about 4% of annual rainfall. This includes the base flow of the streams. The natural morphogenic potential of the plain is thus reduced, and the development of a suitable drainage network is consequently hindered. Because of this and the numerous shallow depressions distributed all over the basin, prolonged large floods often occur.

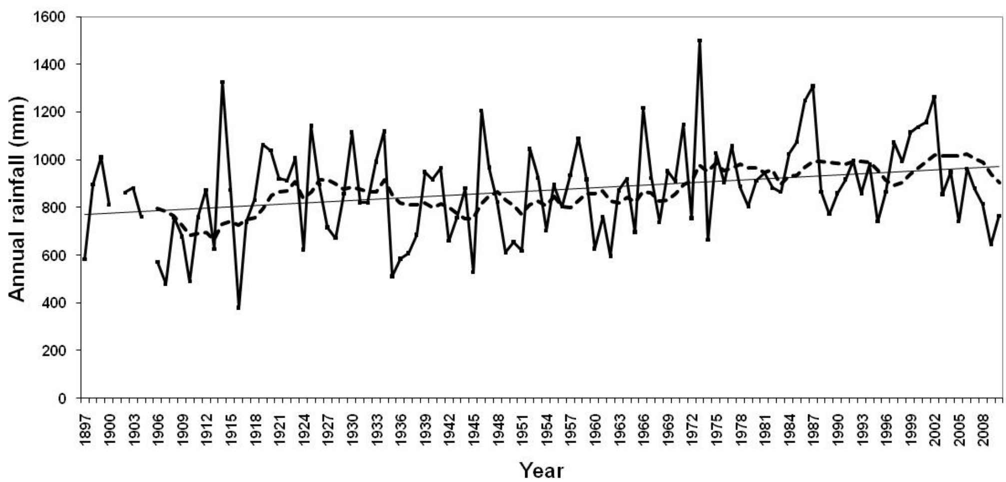

Figure 3. Typical annual precipitation of the Salado Basin (1897 – 2012). The dash line represents the mean rainfall obtained with a 10-year moving average.

Groundwater flux has local and regional characteristics. The local flux appears in the uppermost Quaternary hydrogeologic units and refers to a seepage that is the basic discharge of those ponds and creeks in which it outcrops. The regional flux is a deep and very slow seepage in the Tertiary hydrogeologic units fed by the difference between inflow and outflow of local groundwater in the uppermost layers (Kruse and Laurencena, 2005).

Due to the lithology of its hydrogeological units, the Salado sedimentary basin has a hydrological behavior that can be assumed to be continuous in time and space, even though horizontally and vertically heterogeneous. The uppermost unit is recharged by rain infiltration. Because of the very low topographic gradient of the basin, surface storage occurs over extensive areas, thus increasing the regional infiltration.

Ecological Features

The continental portion of the Salado sedimentary basin, called the Salado Depressed Zone, is a significant productive region. Human activities are mainly devoted to agriculture in the northwest and cattle-raising in the southeast; both are strongly influenced by dry and humid cycles that produce short or long-range changes in water availability. Although wetlands are distributed all along the Argentine coast, the most typical and extensive are those in Samborombon Bay, where muddy, tidal flats extend over 100 km of coastline. These wetlands are of great ecological importance, and can be considered as a cradle for the development of the high biodiversity they shelter. It is worth noting that the coastal fringe of Samborombon Bay was selected as a Ramsar site in 1997. Changes in the hydrological processes are therefore critical in any analysis and prediction of the behavior of this valuable environment.

Under natural conditions, the most characteristic biome of the region is the Pampean pastureland represented by a prairie ecosystem. Today, however, its degradation state is very high because it has been anthropized in a variety of ways. The natural characteristics of the region, its fertile soils, lack of woods, the predominance of plain landscapes and its humid climate, have led to a strong transformation of the ecosystem by agricultural activities.

As mentioned above, the region can undergo either extreme droughts or exceptional rainfall. Heavy rainfall events have allowed a great number of ponds to be formed. These water bodies are very rich in biotic resources, such as fish and coypus, and are used either for commercial or sport activities. Vegetation and cattle-raising studies have shown the significance of flooding as a control of soil salinization, as well as of some species of dicotyledons that could be harmful as pasture.

A remarkable characteristic of the Salado basin is a clear asymmetry with respect to land use. Intensive agriculture can be recognized in the upper basin, while extensive cattle-raising is mainly found towards the lower basin. The coastal fringe of Samborombon Bay is a natural environment with protected zones, usually wild and underused. Human activities are also present through the presence of nutrients, mainly phosphorus and nitrogen compounds, from extensive agricultural areas, as well as from local sources, such as septic systems and industrial waste waters.

In the Salado basin, the recurrence of historic floods led the Public Works authorities to construct drainage canals towards Samborombon Bay at the beginning of the 20th century. However, results have not been optimal, as floods have occurred ever since. Not only have these drainage canals been almost useless to fulfill the purposes for which they were built, they could likely be the cause of chemical pollution and salinization, among other undesirable effects. This is because water is actually being transferred through the canals from agricultural zones to zones with extensive land use, wetlands, or lotic ecosystems (rivers and creeks), and could therefore produce pollution by fertilizers or some other agrochemicals. In addition, these water transfers could affect the structure and functioning of natural systems by overcoming their limits for the assimilation of nutrients and contaminants, thereby causing eutrophication of the water bodies (a state given by an excessive fertilization of the water bodies with an explosive increase in algae and a remarkable decrease in dissolved oxygen). But this is not the whole story. In areas prone to salinization, the water transfer between drainage canals, together with the drop in the amount of surface water due to hydraulic works, could very likely produce quick processes of secondary salinization, hence perturbing the natural environments of the basin. In this way, the protective effect of flooding against soil salinization could eventually disappear.

It is thus necessary to monitor the hydrological conditions of the Salado basin, as well as the conservation of its natural systems. This leads to the need of performing monitoring programs of surface water, groundwater and aquatic ecosystems, both natural or anthropized. A general monitoring proposal that would be very useful for the management of natural resources is given below.

RISKS AND ENVIRONMENTAL MONITORING

Before any attempt to design a network for collecting and recording environmental data from the Salado sedimentary basin, it is inescapable to define two fundamental aspects of the problem, namely the space and temporal scales of the phenomena to be studied. In this regard, it is necessary to take into account what are the purposes the collection of data aims at. In this case, one of the objectives is the hydrometeorological characterization of the basin and the assessment of its water quality. The other objective is to produce reports that warn of floods and droughts at a regional scale. Since both objectives have a broad spatial scale, the required density of data collection stations is low; probably some 20 stations would be enough to fulfill the goals.

With respect to the temporal scale, the largest data collection frequency is required for flood warning. It is assumed as a working hypothesis that the reports for preventing floods will be evaluated at a computer center that must be communicated with the stations. Therefore, data should be sent from the stations to the computer center with a certain frequency. The critical parameters for flooding that should be sampled and transmitted with a higher frequency to the computer center are: rainfall, water level of streams and reservoirs, and water table. Due to the low topographic gradient of the Salado basin, surface water and groundwater run at low velocities; therefore a warning system for flooding at a regional scale could be satisfied with an hourly transmission of data.

It is necessary to distinguish between regional monitoring systems, such as the one put forward for this basin, and those required by densely populated urban areas for warning of extreme rainfall events. This matter is discussed in Kruse et al., (2014). In this latter case the data collection systems for saving human lives must obey other criteria, because it is clear that the spatial and temporal scales are very different from those at a regional scale. Therefore, information should be sent more frequently, and the density of stations should be greater.

In the case of the Salado basin it is convenient to monitor at least the following hydrometeorological parameters: water table, river level and discharge, precipitation, wind and humidity. What are the water quality data parameters to be monitored in order to fulfill the objectives put forward? In principle, one would like to measure as many parameters as possible, but this is not economically reasonable and it would be hardly possible to complete the project because of the high costs it would involve. That is why, at every station, it becomes unavoidable to select those parameters that are most needed to assess the state and evolution of the basin.

For a continuous water quality assessment the most needed parameters are: electrical conductivity, water temperature, dissolved oxygen, pH, turbidity, nitrates and phosphates. In some cases, mainly relative to local contamination problems, it could be necessary to monitor BOD (biochemical oxygen demand), COD (chemical oxygen demand), total hydrocarbons, phenol compounds, cyanides, chromium, cadmium, copper, mercury, nickel, lead, etc.

Of course, some stations will be located at the River Salado, or at any one of its tributaries, while others will be at a considerable distance from the river. Similarly, some stations will be near urban zones, whereas others will be in growing regions. Therefore, there is no need to monitor all the above parameters at every station throughout the basin. The stations should thus be designed with a modular concept, that is, every station should be composed of different modules, according to the location of the monitoring site.

As a general rule, every station could be composed of the following modules: (i) an alternative electrical energy module (AEEM), (ii) a communication module (CM), (iii) a monitoring module (MM), and (iv) a data storage module (DSM). As it is well known, digital data transmission and storage are used almost exclusively today (Guaraglia and Pousa, 2014).

In the Salado basin, the AEEM could be a solar panel (SP) or a wind power generator (WPG). If the station were located in a zone with access to a 220 AC source, there would be no need for an AEEM. If there were a temporary fail in the AC power supply, an uninterruptible power supply (UPS) would be enough to let the station keep on working.

If the monitoring station were placed near a town or a road, the CM could be solved by means of cell phone (CP). But if the station were located in an area not covered by cell phone it would have to rely on satellite communication (SC) or radio frequency link (RF). It is worth noting that the communication system to be used will depend on the amount of data to be transferred, because every communication system has a certain transmission capability. Moreover, in the case of satellite communication, the frequency with which data could be transferred will also depend on the possibility of using either geostationary or polar satellites (Guaraglia and Pousa, 2014).

The DSM will consist of some kind of memory that allows digital data from instruments to be stored. This module would be used when the communication system is not safe and data must be preserved under all circumstances. In this way, if the communication system fails, the data are stored and available for in situ collection. The storage capacity of the DSM should be large enough so as to store the maximum amount of data that could be produced during the maximum period between two consecutive visits to the station.

The MM comprises the measuring instruments. This module can be composed of several sub-modules that will combine according to the parameters that are to be monitored at the site where the station will be installed.

There will be places where knowledge of precipitation (P) would be enough; therefore the sub-module P will be the only one needed. In some other places it will be enough to know the water table (WT), so that the WT sub-module will be the only one required. In those places where there is a river, two sub-modules could be required: the river level (RL) and the river discharge (RD) sub-modules. Finally, there could be a water quality sub-module (WQ) where this parameter is of paramount importance.

It is worth noting that the sub-module WQ can, in turn, be thought of as focused onto different objectives according to the types of areas where measurements are to be performed. These areas can be urban, industrial, agricultural, as well as rural non-exploited ones. In any case, the number and types of instruments will once again depend on the site at which water quality is to be determined.

All the sub-modules that the MM is composed of, whatever they are, should have a communication port with the same protocol that allow them to be integrated in a network. Communication protocols define the rules, way, frequency, codes and standards that control the sequence of data exchange during a communication between the sub-modules. It would be convenient that all the instruments could be connected to the same bus (in parallel), so that instruments may be easily added or removed from the MM. In turn, the MM must have a port that allows data to be sent through the CM by using the same or other protocol.

CONCLUSION

The sedimentary Salado basin shows a tectonic evolution of extensional type since the upper Jurassic-lower Cretaceous of the Mesozoic era. The sedimentary thickness is over 6,000 m, including geological units from the Mesozoic and the Tertiary-Quaternary Cenozoic Periods. The present climate is humid temperate with precipitation of about 900 mm, showing an alternation between wet and dry periods, which leads to prolonged flooding and severe droughts. Human activities are mainly devoted to agriculture and cattle-raising; both economical activities being highly affected by the wet and dry cycles. Extended wetlands of great ecological importance display along the coastal fringe. The hydrologic system is high sensitive to changes made by man, so these changes should be included in any prediction of the environmental performance of the region. The monitoring of the climatic, hydrological and water quality parameters is therefore critical for any characterization and modeling of the ecological conditions. The design of a monitoring network should take into account the spatial and temporal scales in which the different phenomena to be analyzed take place. The monitoring operation is the first step for establishing a warning system that allows mitigation of extreme climatic events that are socially and economically harmful for the region.

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