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Chapter - 23

AREAL EXPLOITATION OF GROUNDWATER IN COASTAL DUNES, BUENOS AIRES, ARGENTINA

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ABSTRACT: In the study area, the groundwater of low salinity is restricted to the fringe of coastal dunes. This is the only drinking water source for a permanent population that is greater than 10,000 inhabitants. In summer, the region presents a tourist high which multiplies the population by 5. In this paper the current groundwater exploitation in an area with limited reserves of fresh water, where the demand of water is increasing is described.

The coastal dunes have a morphological expression between 0.5 to 3.5 m.a.s.l. The fresh water lens is limited by sea water and brackish continental water. To avoid the salt water intrusion an areal exploitation is carried out. There is a pumping field located outside the urbanized area, composed of 7 horizontal wells, Ranney type, and of 21 well point systems, each one connected to 10 wells. The extraction depth varies between 4m and 6m.

The system recharge only takes place from the precipitations (1000 mm/y), while the natural discharge is by the evapotranspiration (640 mm/y), with water surplus of 360 mm/y. In the current situation, a direct relationship between the precipitations and the variations of the phreatic level is observed. The extracted flows are in the range of the regulating reserves and therefore there is not a substantial modification of the natural water cycle. It is necessary to increase the drinking water supply to cover the needs of a bigger number of inhabitants. The management pattern should include the selection of new exploitation areas including a detailed water input and output quantification to the hydrological system. An areal exploitation to scarce depth is also recommended, being fundamental that the use areas should be declared reservation areas to conserve the recharge areas and to avoid all possible contamination of the groundwater.

KEYWORDS: Coastal Dunes, Management, Groundwater, Phreatic Aquifer, Pumping Field.

1. INTRODUCTION

The coastal aquifers constitute a system where the interface fresh water – salt water is in a fragile balance. An important quantity of world population is situated in the coasts, and it subsists due to the use of the groundwater.

As the present-day distribution of fresh and saline groundwater in coastal aquifers still reflects former environmental conditions, it is often unclear to what extent the current situation is the result of long-term effects or recent (anthropogenic) changes (Post, 2005).

Sustainable development in the use of renewable groundwater resources requires that the pumping of groundwater does not exceed the recharge. Overpumping of groundwater resources has happened in tracts of China, the Middle East, North Africa, Saudi Arabia and the U.S.A. and the groundwater table has decreased alarmingly in these areas (Backman *et al.,* 2007). Despite the growing need of fresh water in coastal areas, the exploitation of it has to cope with some difficulties. First of all, coastal areas have a natural distribution of fresh, brackish and salt water which is the result of an evolution during recent (Quaternary) geological history. This distribution can be in a dynamical equilibrium. Secondly, high extraction rates lead to lowering of the hydraulic heads influencing general groundwater flow patterns and the water balance of an area (Vandenbohede, 2008). The problem is particularly serious in coastal areas, where rapid population growth and intensive economic activity has increased the need for fresh-water supplies. This need is mainly being satisfied by pumping groundwater from coastal aquifer systems (Trabelsi *et al.,* 2007). This leads to use of the groundwater resources at a time when recharge of the aquifers is lowest, thus causing problems of over-exploitation and subsequently, contamination of groundwater by salt-water intrusion. (Calvache and Pulido-Bosh, 1997). In Argentina, the most studied case is Mar del Plata where overpumping has been manifested with salinized wells since 1971, specially in downtown areas (Ruíz Huidoro and Tofalo, 1975).

In the study area the only drinking water source (groundwater) presents a limited development and it is restricted to the fringe of coastal dunes. The fresh water reserves are directly related to the infiltration processes of precipitation excesses. In this kind of environment, the exploitation of conventional wells is not the most appropriate. Given that the fresh water presents scarce thickness and where it is not advisable to deepen the water table levels below sea level without the risk of suffering saline intrusion, horizontal wells and well point systems have been recommended.

The captation by radial collector wells (Ranney) consists of horizontal wells planned to extract water in aquifers of limited thickness, or in case it is necessary to extract an important flow with little depression. The well point system consists of a series of conventional wells, with little depth, connected to each other by a common conduction that makes the water extraction. It is necessary for the water level to be at shallow depth, since the extraction is not effective if they are more than 5 or 6 m depth. (Custodio and Llamas, 1996)

Figure 1. Location and geomorphologic map.

Since 1980, given the aquifer morphological characteristics and to avoid the salt water intrusion in the study area, an areal exploitation has been carried out by the mentioned methodologies. There is a pumping field located in the south of the urbanized area which supplies the population.

In this work the current management of groundwater exploitation in an area with limited reserves of fresh water, where the demand of water is increasing is described.

2. STUDY AREA AND METEOROLOGICAL CHARACTERISTICS

The study area is located in San Clemente del Tuyú, Buenos Aires province, Argentina (36º22' Lat S, 56º 44' Long W). It is located in the north of San Antonio Cape. It extends to the south through the coastal fringe. The width is 2 km covering an area of about 15 km^2 (Figure 1).

According to Thornthwaite climatic classification, the area is humid, mesothermal, with little or no water deficiency and a summer concentration of thermal efficiency smaller than 48%. The average annual rainfall is 1000 mm of which about the 60% occurs from October to March. The average annual temperature is 14.5ºC and the average relative humidity is 85%. The frequency of winds varies greatly, although the east direction is somewhat more predominant (Consejo Federal de Inversiones, 1990a).

Figure 2. a) coastal dune, b) dune. c) beach, d) continental plain

3. GEOMORPHOLOGY

San Clemente del Tuyú is located in coastal dune and continental plain environments. The coastal dune (Figure 2a) extends uninterruptedly from Punta Rasa to Mar Chiquita lagoon outlet. The width varies between 2 and 4 km. It is divided into beach (Figure 2c) and dune (Figure 2b). The beach area is rectilinear, with a width of between 50 and 150 m and a slope towards the east. The beach is constructional type, without escarpment, with sandy beach. The dunes are located in the west of the beach that has produced them. In the study area they are low and fixed by scarce vegetation. The sand's granulometry is fine grained and the sand presents a general size grain decreasing from south to north.

The continental plain (Figure 2d) is located in the west of the coastal dune. The elevations are less than 5 m.a.s.l. (meter above sea level) in the adjacent area to the Samborombón Bay and it is open to the sea. The natural drainage consists of the Ajó River that drains into the bay and which is fed by streams (e.g. San Clemente Stream) and of artificial channels that facilitate the runoff. This depressed area presents smaller landforms of negative relief that, near the Samborombón Bay and the Ajó River, are true tide channels where salt marshes are formed. (Consejo Federal de Inversiones, 1989)

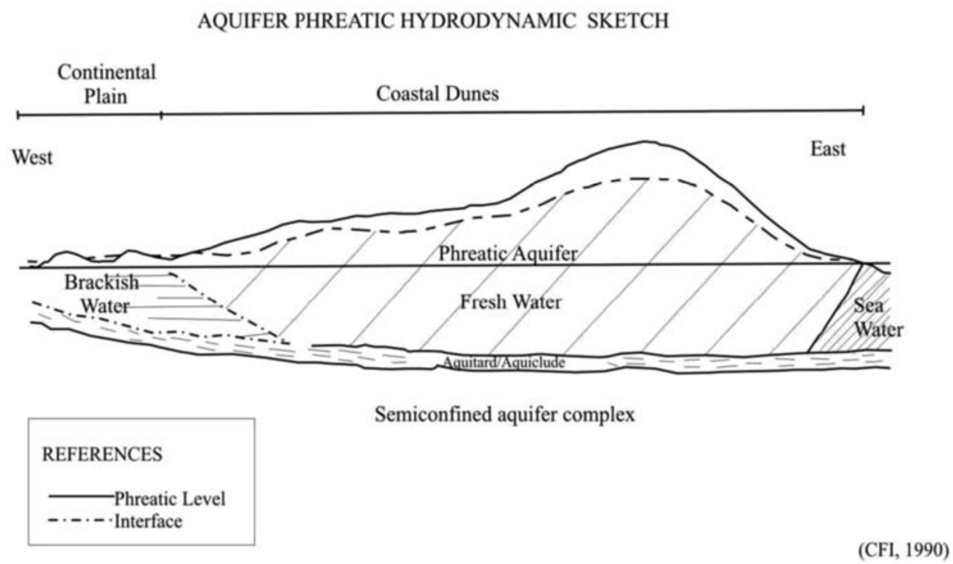

Figure 3. Hydrodynamic sketch

4. HYDROGEOLOGICAL CONDITIONS

From a hydrologic point of view, the area belongs to the Costera Region (González, 2005), where the hydrodynamic behavior is controlled by the geomorphology. The coastal dune is the main area of groundwater recharge. The conduction is made in a short section, and the discharge takes place in two opposing directions, to the east towards the sea and to the west towards the continental plain. The general sketch is limited by two interfaces: brackish water-fresh water to the continent and fresh water- salt water to the sea. (Figure 3) (Kruse et al, 2005).

The main fresh water aquifer is formed by a sand layer (Holocene age) whose thickness varies between 5 and 15 m, overlying barrier sands of 5-15 m thickness depending on the dune altitude. It was created by overlapping of coastal spit facies. In general these sands lie partly on lagoons' clays. The sequence is capped by the modern soils of the region, they are incipient and little evolved. In the coastal dune in particular, they do not show development, they are sandy, excessively drained and unstable. (Consejo Federal de Inversiones, 1990b).

The hydraulic conductivity is about $2.31 \cdot 10^{-4}$ m/s and the effective porosity 10%. The hydraulic gradient for the dune western flank is 0.001 and 0.004 for the eastern flank. It is smaller than 0.001 for the rest of the dune. Consequently, the western flank effective velocity is $2.31 \cdot 10^{-6}$ m/s and in the eastern flank, which discharges to the sea, is $9.26 \cdot 10^{-6}$ m/s. For the rest of the aquifer it is $2.31 \cdot 10^{-6}$ m/s. The average effective velocity is smaller than $1.15 \cdot 10^{-6}$ m/s. (Sala *et al.,* 1976).

5. GROUNDWATER EXPLOITATION

5.1 Exploitation Systems

In the study area, to avoid the salt water and brackish continental water intrusion that limit the lens of fresh water whose morphological expression is between 0.5 to 3.5 m.a.s.l., an areal exploitation is carried out (Ranney and well point system).

There is a pumping field (Figure 4) located outside the urbanized area, composed of 7 horizontal Ranney type wells (flow $1.94 \cdot 10^{-3}$ m^3/s) (Figure 4a). The structure is comprised of a central concrete caisson, 4 m in diameter, excavated to an 8 m depth at which a series of four gravel-packed horizontal laterals extends from within the caisson in a radial pattern located at 4 m depth. The laterals are 4 and 6 m length, both about 0.05 m in diameter. The 4-m length laterals are oriented E-W and the 6-m length are N-S. The gravel screen is 0.75 mm grain size and 0.05 m thickness. Even though the distance between the wells are 25 m, interference phenomena have not been detected, because the alternation of the wells operation is used and it is not common to have the 7 Ranney wells working at the same time.

There are also 21 well point systems, each one connected to 10 wells (flow $3.6 \cdot 10^{-3}$ m^3/s) (Figure 4b).The extraction depth varies between 4 m and 6 m**.** These types of conventional water wells are small in diameter, with little depth. They are a battery of boreholes connected to each other, by a common conduction that performs the water pumping.

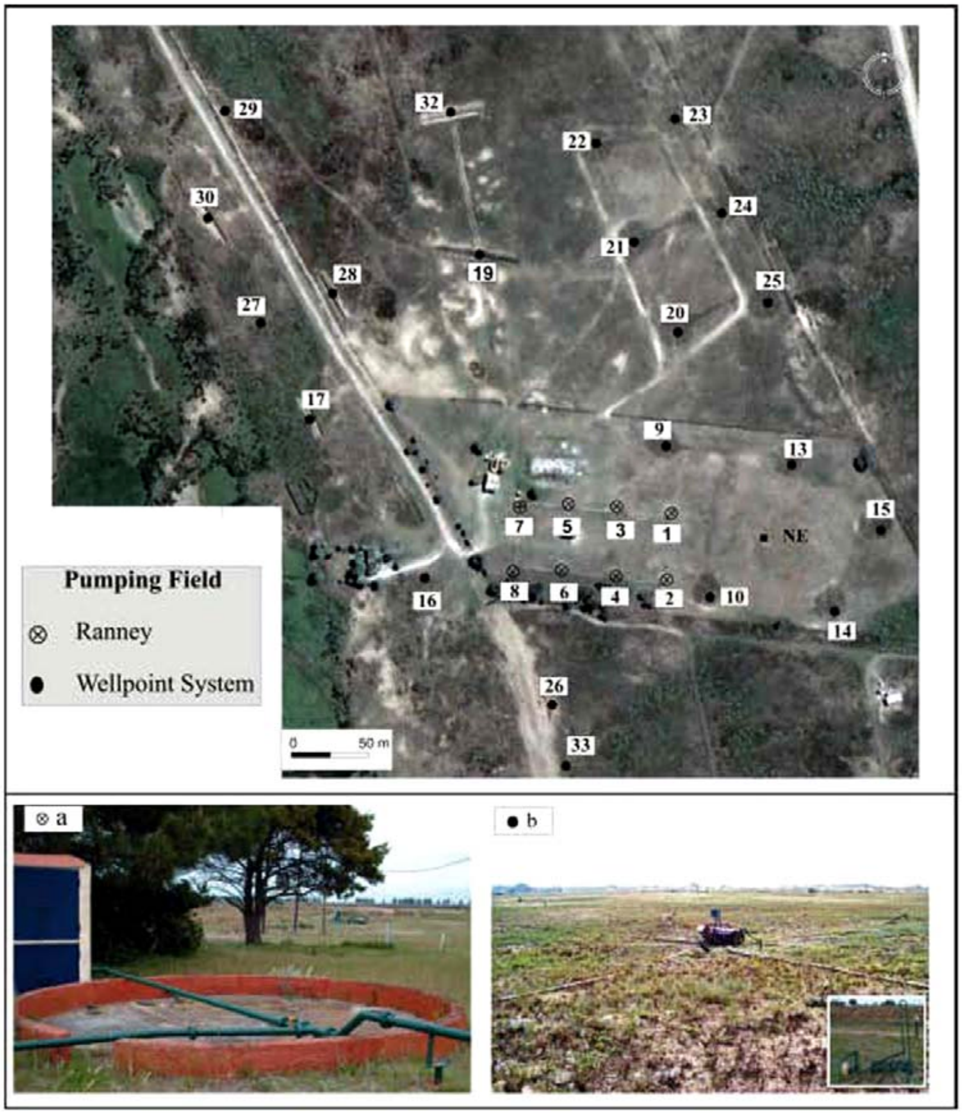

Figure 4. Distribution of the wells in the pumping field a) Ranney, b) Well point system

5.2 Extraction Characteristics

The diary production data of the water treatment plant were analyzed, they were given by the water and sewer services company of the town. The extracted flow variations and the evolution of the phreatic levels measured in the site were evaluated.

The annual extraction flow is about 200000 m^3 with a progressive increase tendency. It is in summer time when the maximum extracted flow values are observed. The extraction flows have a maximum value in January and February (1200 m^3/d) which coincides with the greatest tourist influx.

The minimum flow is shown between May and June with values between 250 and 300 m^3/d. The medium value of extraction in the remaining months it is in the range from 400 to 500 m^3/d.

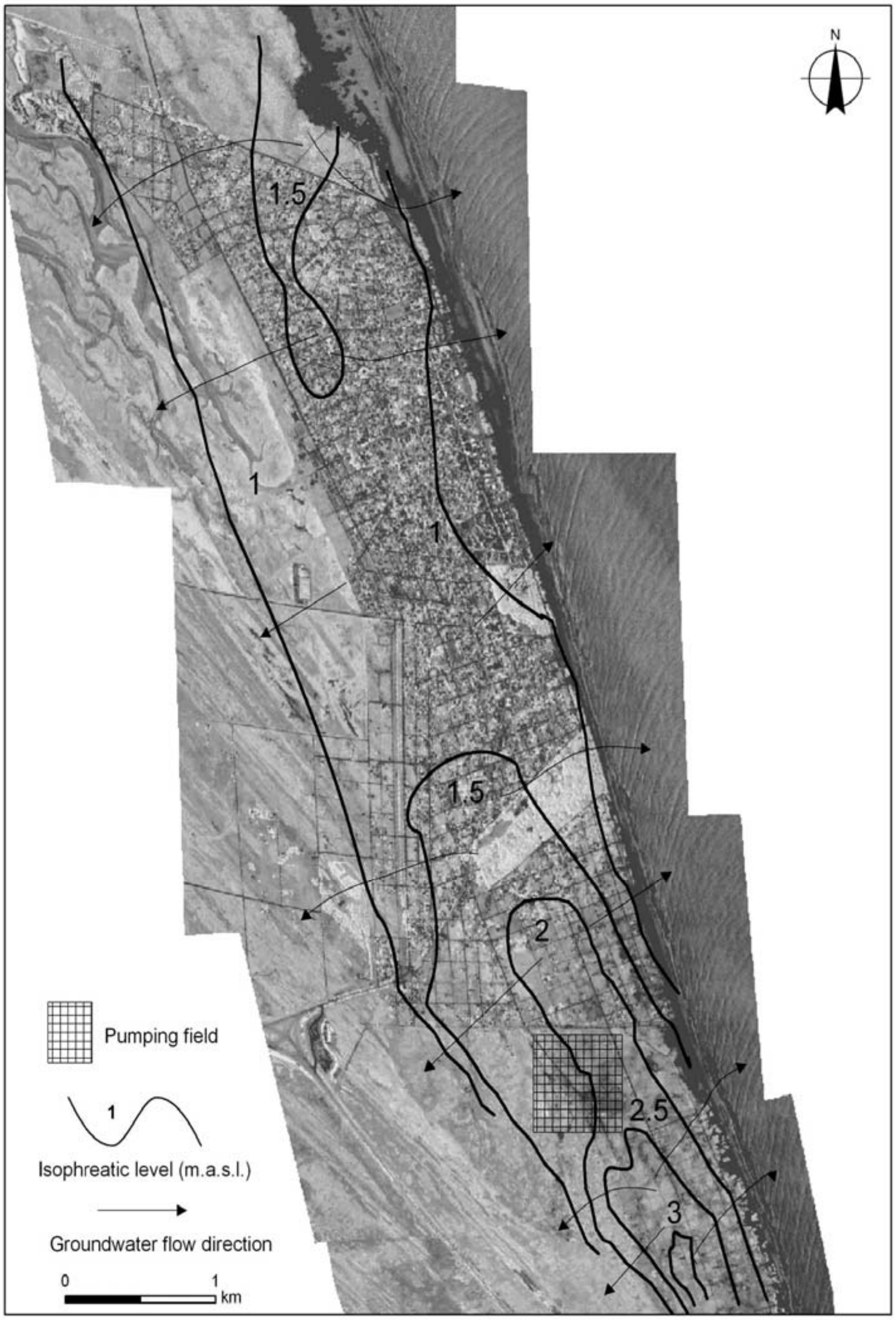

Figure 5. Isophreatic map

5.3 Phreatic Level Analysis

According to the analysis of the groundwater flow map (Figure 5), a high area in the phreatic morphology is observed, which coincides with the highest elevations in the dune. Locally, a hydraulic gradient in two opposing directions is recognized, one towards the east (sea), and the other one towards the west (continental plain). In the southern sector of the town, where the area of exploitation is located, the isophreatic curves oscillate between 1.5 and 3 m.a.s.l. On the other hand, in the northern area the values can reach, at maximum, 1.5 m.a.s.l. in the months with abundant precipitation, while periods of less rain will show curves of about 1 m.a.s.l. During the humid periods, the observed phreatic level depths reach 2.5 m, with some waterlogged in the west where topographical depressed areas exist. However, in the dry season the values are between 0.5 and 3 meter below ground level (m.b.g.l.).

The phreatic level in the pumping field has been measured since 2002; the location of the borehole is shown in the Figure 4 as NE. It is important to note that the measures have been taken when there are no nearby pumping wells working, therefore, is the static water level which is considered for this analysis.

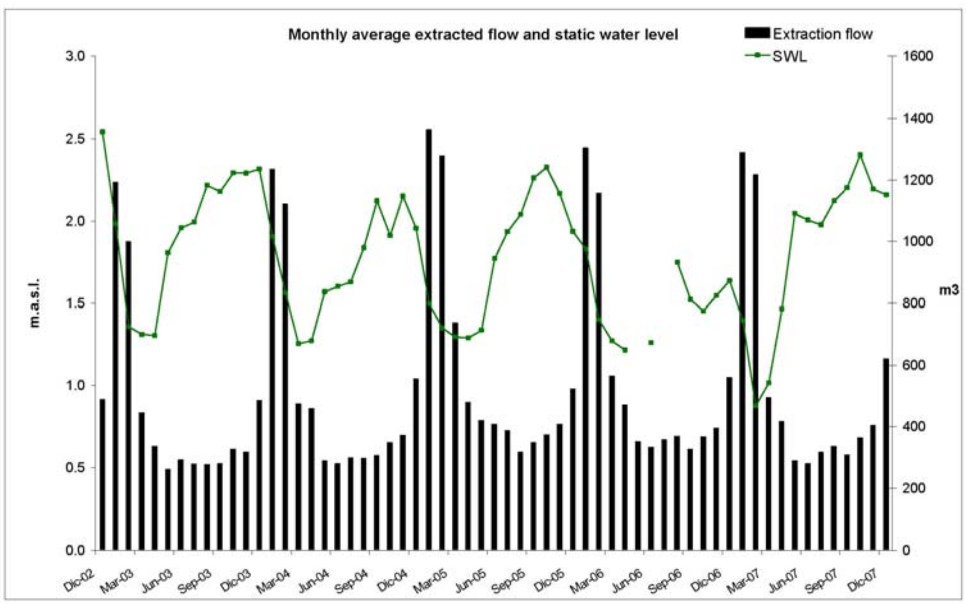

Figure 6. Monthly average extracted flow and phreatic level in the pumping field

As for the phreatic levels in the pumping field, during the analyzed period the registered values of depth are between 0.4 and 2.8 m, with a statistical mode of 2.2 m, presenting a general tendency towards deepening. An inverse relationship between phreatic level and the extracted flow is observed, since in the minimum extraction period a recovery of groundwater levels is manifested while they are significantly deepened in summer months with the increased demand (Figure 6).

Figure 7. Phreatic level behavior in the pumping field (2002-2007).

Given the methodology of exploitation, the levels do not deepen below 0 m.a.s.l., oscillating between 0.7 and 3.1 m.a.s.l. (Figure 7). The extracted flows are in the range of the regulating reserves and therefore there is not a substantial modification of the natural water cycle.

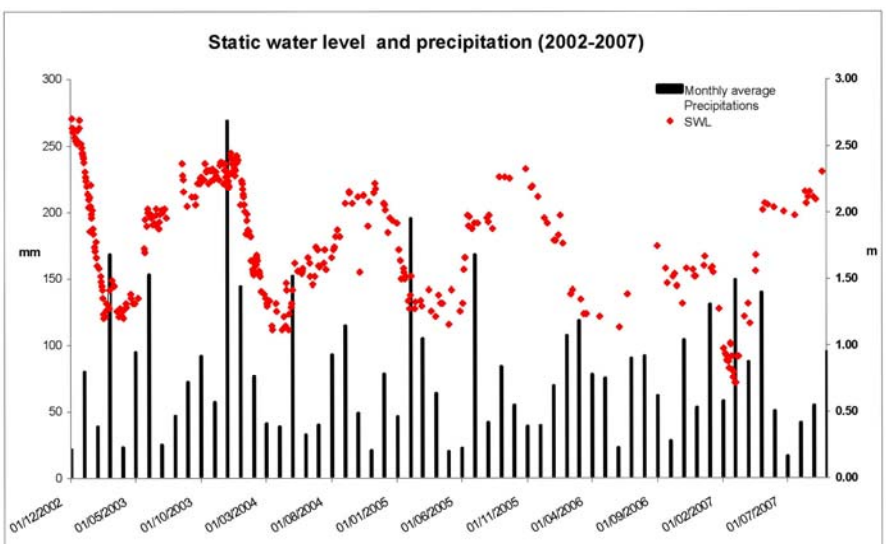

Figure 8. Relationship between static water level and monthly average precipitation during the period 2002-2007.

5.4 Relationship between Surplus Water and Phreatic Level

The water surplus has been determined by hydrological balances (diary) according to Thornthwaite and Mather (1955) methodology, based on precipitation data (2002-2007) of Santa Teresita station of the Meteorological National Service. The daily average of ETo (reference evapotranspiration) was estimated according to the Penman-Monteith (FAO, 1998) method. The system recharge only takes place from the precipitations (1000 mm/y), while the natural discharge is by the evapotranspiration (640 mm/y), with water surplus of 360 mm/y. (Carretero et al, 2007).

The annual variations of rainfall for the studied period are shown in the Figure 8. In the current situation a direct relationship between the precipitation and the variation of the phreatic level is observed. This is an indication of a quick response following the recharge from the water surplus as a result of the rains. The same phenomenon is observed between the phreatic level and the water excesses which go directly to the recharge (Figure 9).

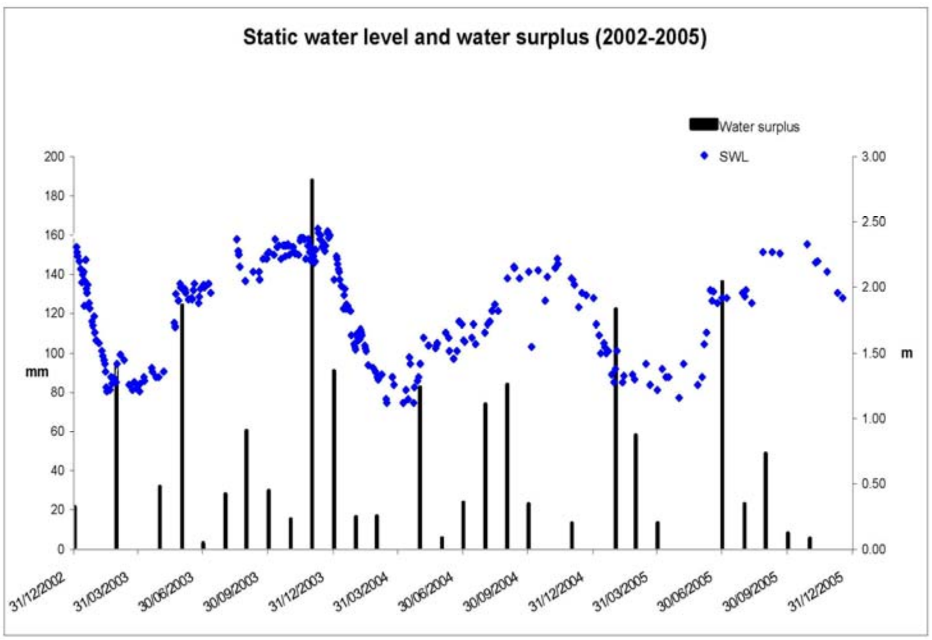

Figure 9. Static water level and water surplus for the period 2002-2005.

5.5 Water Supply

In the study area, the permanent population is greater than 10,000 inhabitants (INDEC, 2001). In summer, the region is subjected to a high rate of tourism which multiplies the population by 5.

Only a small percentage of the houses (approximately 2500) have water supply coming from the pumping field. This water has potabilization treatment before the distribution. Those people who are not supplied by the pumping field cover their needs by domestic pumps where the water does not have any treatment. As for the sewer service, an important percentage of the town housings are connected (80%).

From the data of the monthly average of daily exploitation for the years 2006 (542 m^3/d) and 2007 (522 m^3/d), with the consumption rate per inhabitant (200 l/d) and keeping in mind the tourist increase, the percentage of supplied inhabitants by the pumping field was calculated.

Although the production values for the summer months are greater, there is also an increased user demand. The percentage of the population supplied by the water treatment plant may reach 35% in January and February, but it stays between 15 and 17% for most of the remaining months.

The expansion of the drinking water service by means of the groundwater exploitation will require a sustainable management of this natural resource. It should be based on achieving a balance between the demand, the supply and the natural balance of the hydrological process. According to the obtained results, it is evidenced that the relationship demand-supply is not balanced. The current production values seem to be in harmony with the natural aquifer operation.

6. CONCLUSIONS

In the studied coastal environment, where the phreatic aquifer to exploit is a fresh water lens of scarce development and with risk of salt water intrusion for overexploitation, the extraction method used is horizontal wells, such as the Ranney or well point system type.

The regimen generated by the exploitation would be coincident with the natural hydrologic cycle. Naturally, in summer with smaller excesses the groundwater levels deepen (this coincides with the biggest exploitation). The excesses in winter are bigger and an increase in the water table level is produced (which coincides with the smallest exploitation).

Due to the methodology of exploitation the levels do not deepen below 0 m.a.s.l. The extracted flows are in the range of the regulating reserves and therefore there is not a substantial modification of the natural water cycle. There is a direct relationship between precipitation and the phreatic level behavior which has a quick response to the water surplus which get directly towards the recharge.

As increasing tourism levels exert greater pressure on water demand, these points must be considered when planning and implementing future summertime groundwater management plans.

It is necessary to increase the drinking water supply to cover the needs of a greater number of inhabitants. The management pattern should include the selection of new exploitation areas, including a detailed water input and output quantification of the hydrological system. It is also recommended an areal exploitation at scarce depth, and it is fundamental that the areas of use are declared reservation areas to conserve the recharge areas and to avoid all possible contamination of the groundwater. Besides, the installation of phreatimeters for evaluating the constant pumping field hydrodynamic behavior is proposed.

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