Salt Water Intrusion Risk Assessment in the Boca Abierta Valley, Sonora, Mexico.

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ABSTRACT

Keywords: abandoned wells, geophysical measurements, balance equation, ground water quality

Three elements are considered in qualitatively assessing the salt water encroachment risk in the Boca Abierta Valley, in northwest México: the hydro-stratigraphic conditions, the ground water quality and the estimation of some terms in the ground water balance equation.

The existence of a basaltic aquifer was pointed out by some well lithological sections. It was found out that this aquifer has the same water type as the, higher, sedimentary aquifer. The limited extension of the basaltic aquifer as well as the absence of any geological impermeable barrier obstructing the pass of salty water through the central section of this aquifer, was established with geophysical measurements. Also, the geophysical study, pointed out the ways for the salty water to reach several wells in an area up to seven kilometers from the sea shore.

The wells for water supply to Guaymas-Empalme and those for irrigation located at more than eight kilometers from the coast, have excellent physicochemical water quality, until today. Although in the closest area to the sea shore, up to seven kilometers, the shallow water samples don’t show any ion or any ratio related to sea water, two abandoned wells due to salinity and two more with electrical conductivity up to 3500 µmhos/cm were found in the area.

Several terms of the ground water balance equation are now in the process of being assessed. The static levels show a clear descendent tendency and the pumping extraction from wells for all uses is about four times the vertical recharge as estimated by the rainfall.

The risk weighting factors assigned to each of the three mentioned elements in the assessment were: high risk for the lack of geology boundaries and the results from the geophysical measurements; medium risk for the sampled groundwater quality and medium-high risk for the balance equation terms already estimated. Hence, it can be said that there is a medium-high risk of getting a severe salty water intrusion in the groundwater pumping area of the Boca Abierta Valley.

INTRODUCTION

The northwest of México is a part of the arid zone of the country, in this zone, a great productive activity develops, still when the superficial flow are scarce. This has provoked that the supply of water, generally for irrigation and human consumption, gotten of the groundwater pump.

Some years ago, the aquifer of the Guaymas Valley was the principal fountain of supply for the cities of Guaymas and Empalme, but due to the overexploited of the aquifer the piezometric levels go down under sea level, inducing sea water coming into the Guaymas aquifer and going up salt water concentrations that makes it unacceptable for human consumption neither for irrigation.

At present, the cities of Guaymas and Empalme, Sonora, satisfy their demands of potable water from two sources of supply; one located in the Boca Abierta Valley with seven wells that pumping 390 lps, and the other supply from wells in the Alluvial Valley of the Yaqui River, long away 130 km from Guaymas city with a discharge of 550 lps (Osorio, 2000).
The Boca Abierta Valley is located in the south of Sonora, to the east of Guaymas Valley between the ranges San Francisquito and Bacatete, bounded by Guásimas Bay, to the south as it’s show in Figure 1. The study area has an average nine kilometers width 35 km long from the coast. The geographical situation of this aquifer, near to the coast as well as his neighborhood the aquifer of Guaymas Valley, it makes necessary to know the behavior of the Boca Abierta aquifer with high precision, for managing current and future extractions and preventing high risk of salt water intrusion

OBJECTIVE
The general objective of this investigation is the estimate the risk of saline intrusion in the Boca Abierta Valley, considering three element in the analysis: the hydro-stratigraphic conditions, with the possibility of finding geological impermeable barrier; the groundwater quality; with the possibility of identifying sea water in monitoring wells; the assessment of the balance equation terms; considering the scarce information in the zone of study.

HYDROSTRATIGRAPHYC CONDITIONS
Herrera, et. al. (1985) show that the stratigraphic conditions of sedimentary unit actually know is relatively simple: there is a superior stratum with a thickness of 80 to 100 m of alluvial and lagoon deposits, with
gravels, sands, eyeglasses of clay and calcium carbonate compounds, under these deposits there are diverse marine fine sediments with a thickness between 20 m in the north to 180m in the south part of the valley, continue down there are straining probably basaltic origin coming out from granitic basement fracture with thickness over 100m as it can see in Figure 2.

According to Boca Abierta aquifer stratigraphic there are two types of stratums: in the upper part alluvial sedimentary layers and fractured basalt rock under. Also, it was found some connection between both aquifers, based on analyzing the types or water release of each aquifer, as well as water coming from mixing both water aquifers. (Martínez, 1999).

It was carried out 20 time domain electromagnetic geophysical sounds in the zone of study, with a net of variable distances 1 to 4 km, as it’s showed in figure 3.

It worked the time domain electromagnetic method, (TDEM) logging resistivities of several stratums been located from zero until 250 m of depth, the method consisted of utilizing a reel formed of a square of cable with dimension of 100 m for 100 m, with the arrangement named "Coincident Loop" with a resistance of 2.6 ohms in the circuit, with these characteristics of the arrangement an intensity of current between 7 and 7.5 amperes, which it was necessary in order to fulfill the 250 m depth of investigation.

It was demonstrated that this technique is capable of logging the resistivity with very high resolution, still where the land introduces problems of contact resistance (CIGSA, 2000).

With the electromagnetic method (TDEM) is intended to show the stratigraphic distribution in terms of resistivity. Resistivity maps of were made for elevations of 0, -10. -25, -50, -75, -100, -150, -200 and- 300 m below mean sea level and six sections parallel or perpendicular to the line of coast.

Follow the analysis of these maps:

Resistivity map for –50 m below sea level it can see low restivity less than 6 ohms-m, in a big extension, witch means sea water coming into the aquifer until 7 to 8 km from the sea coast.( Figure 4)
For lesser elevation i.e. –10m and –25m.b.s.l. the resistivities smaller 6 ohms.m or high conductivity bodies are related with sea water in similar areas to the precedent; in some cases there are associated to old buried ditches.

For bigger depths i.e. –100, -200 m.b.s.l. the intruded area of low resistivity is reduced with respect –50m.b.s.l. map already mentioned. At the west boundary a high resistivity area is related to consolidated and without fractured rocks which act as impermeable barrier to the sea water inlet through the aquifer.

The resistivity profiles with values less than 6 ohm m like that of figure 4 are related to high conductivity water from sample wells (Figure 5).
FIGURE 4 RESISTIVITY AT –50 mbsl

FIGURE 5 RESISTIVITY PROFILE 02
WATER QUALITY

A study was carried out about hydrochemistry of the groundwater, getting chlorides, sulfates, bromides, calcium, besides some important relationships of ions that are useful for saline interface determination, as SO$_4$/HCO$_3$, Cl/HCO$_3$, Mg/Ca, these indicate that Boca Abierta area, in its coastal fringe, it shows possible saline intrusion (Esquer, 2000).

In Figure 6 it can be seen isolines of electric conductivity (EC), which means that in the neighborhood of potable water wells EC is less than 1500 µmhos/cm this is there is not sea water, according to Snoeyink and Yenkins (1987); however closer to the sea coast the phenomena of intrusion begins to be evident, since in Mesteña well has a conductivity of 3650 µmhos/cm. In the north part of Boca Abierta Valley is observed a isoline where it can be seen the well 43 has a high EC, which requires detailed study.

FIGURE 6 ELECTRICAL CONDUCTIVITY in µmhos/cm
In Figure 7 chloride isolines are similar to the previous figure. Custodio and Llamas (1976) give 250 mg/l as a limit for potable water. In this area of study all wells are beyond or around that limit.

Figure 8 displays the Cl/ HCO₃, this is one of the most important relations for detection of saline intrusion. Custodio and Llamas (1976) give 0.1 at 5 Cl/ HCO₃ as an interval for potable water. With this relationship could be said that the Boca Abierta area doesn't meet polluted for the phenomena of saline intrusion.
The Figure 9 shows Mg/Ca, for this relationship Guardian and Flames (1976) cited by Esquer (2000) say that a fresh water has from 0.2 until 1.5 Mg/Ca, on the other hand in the sea water this index is around 5. In this figure the coastal zone presents relations overcome that interval, as wells 7 and 138, which it makes evident the possible intrusion of sea water. Well number 43 most be study in detail.
FIGURE 9  MAGNESIUM / CALCIUM

ASSESSMENT OF THE BALANCE ECUATION TERMS

With this information and with the location and inventory of wells in the Boca Abierta Valley, the area was determined where it will application the balance equation, as well as the considerate sections like entrance and exit for groundwater flow.

Pumping test

For the inflow section by groundwater, it was carried out a pumping test, utilizing like pump well 41-M with localization on N28°04´10´´ W110°34´34´´ and like observation well 147 with localization N28°03´40´´ W110°34´23´´. For interpretation of the pumping test, the following methods are used: Curved Type of Hantush, Neuman, Jacob, Point of Inflection of Hantush and Specific Discharge, utilizing
the drawdown registered in the observation well, except the Jacob’s Method that was utilized for both wells (Osorio, 2000). The outputs are show in the Table 1.

### Table 1 Results of Transmissivity

<table>
<thead>
<tr>
<th>Well # 41-M</th>
<th>Inflow Section</th>
<th>Method</th>
<th>T. Calculated</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C. T. Hantush</td>
<td>0.0289 m²/s</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. T. Neuman</td>
<td>0.01095 m²/s</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jacob</td>
<td>0.0157 m²/s</td>
<td>Satellite well, don’t satisfy the time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jacob</td>
<td>0.00394 m²/s</td>
<td>pumping well</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P.L. Hantush</td>
<td>0.0097 m²/s</td>
<td>Sm extrapolated gives outputs without verification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unconfined</td>
<td>0.0033 m²/s</td>
<td>for t = 2 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confined</td>
<td>0.0086 m²/s</td>
<td>for t = 2 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unconfined</td>
<td>0.0034 m²/s</td>
<td>for t = 10 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confined</td>
<td>0.0078 m²/s</td>
<td>for t = 10 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unconfined</td>
<td>0.0037 m²/s</td>
<td>for t = 60 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confined</td>
<td>0.0075 m²/s</td>
<td>for t = 60 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unconfined</td>
<td>0.0044 m²/s</td>
<td>for t = 24 hrs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confined</td>
<td>0.0076 m²/s</td>
<td>for t = 24 hrs.</td>
</tr>
</tbody>
</table>

For the outflow section by groundwater, the researchers with operators of the wells agree effect a pumping test in the well number 133. At 25 minutes of beginning the test, has a problems in the pipeline for irrigation fields, the test was suspended and no longer it was possible to restart it.

Subsequently, the irrigation district 084 facilitated the data of a pumping test made in the year 1968, with readings of drawdown and time only in the pump well PGB-12

For interpretation of pumping test to well PGB-12, it was utilized the Jacob’s method and Specific Discharge (Osorio, 2000), getting the outputs that are shown in the Table 2.

### Table 2 Results of Transmissivity

<table>
<thead>
<tr>
<th>Well PGB-12</th>
<th>Outflow Section</th>
<th>Method</th>
<th>T. calculated</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Jacob</td>
<td>0.11712 m²/s</td>
<td>pumping well</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unconfined</td>
<td>0.018 m²/s</td>
<td>for t = 2 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>confined</td>
<td>0.036 m²/s</td>
<td>for t = 2 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unconfined</td>
<td>0.021 m²/s</td>
<td>for t = 60 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>confined</td>
<td>0.038 m²/s</td>
<td>for t = 60 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unconfined</td>
<td>0.024 m²/s</td>
<td>for t = 60 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>confined</td>
<td>0.040 m²/s</td>
<td>for t = 60 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unconfined</td>
<td>0.025 m²/s</td>
<td>for t = 24 hrs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>confined</td>
<td>0.042 m²/s</td>
<td>for t = 24 hrs.</td>
</tr>
</tbody>
</table>
The transmissivity results accepted for balance equation in inlet section are:

Unconfined aquifer: \( T = 0.01095 \, \text{m}^2/\text{s} \)
Confined aquifer \( T = 0.0289 \, \text{m}^2/\text{s} \)

In outlet section:
Confined aquifer \( T = 0.11712 \, \text{m}^2/\text{s} \)

Several terms of the groundwater balance equation are now in the process of being assessed, as soon as the groundwater inflow and outflow besides getting the volume of pumping of study zone, starting from the year 1995 at 2000.

With the registrations of static levels, a descending tendency of these levels has been identified. In accordance with Félix, J. C. (1999), the pumping extraction from wells for all uses is about four times the vertical recharge as estimated by the rainfall.

CONCLUSIONS

Finally, the risk weighting factors assigned to each of the three mentioned elements in the assessment were:
high risk for the lack of geology boundaries and the results from the geophysical measurements; medium risk for the sampled groundwater quality and medium-high risk for the balance equation terms already estimated. Hence, it can be said that there is a medium-high risk of getting a severe salty water intrusion in the groundwater pumping area of the Boca Abierta Valley.

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