Salt water intrusion in the Pedro Gonzalez-El Salado aquifer, Margarita Island, Venezuela

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ABSTRACT

This work presents a model of Salt Water Intrusion from the Caribbean Sea to the Pedro Gonzalez-El Salado Aquifer located in the northeast of Margarita Island, Venezuela. Since 2001, the northern part of the aquifer has shown a continuous increase in salinity. A model has been developed to show how the salt water has moved toward the inner aquifer and allowed the identification of its potential position. The salt wedge can reach a maximum of 300m depth if a maximum penetration of 2500m is assumed (where the majority of pumping wells are located). The maximum discharge that can be extracted per well can be calculated and depends on its location within the aquifer. Over production of water from most coastal wells could be the reason for the advance of the salty water wedge landward. The final aim of the project is to create sufficient evidence from which governmental institutions can control and manage the aquifer life cycle.

Keywords: *Aquifer, Saline intrusion, Salt wedge*

INTRODUCTION

The supply of fresh water has become a serious worldwide problem; Margarita Island in Venezuela is no exception to this. The Aquifer located in Pedro Gozalez-El Salado on Margarita has experienced an increase in salinity over time; this has had a marked effect on the production capabilities of this aquifer. The main economic activity in the region is agriculture, which is dependent on the supply of fresh water for irrigation. Using hydrogeological field parameters from measurements taken in 21 wells within the study area, it has been possible to determine the position of the salt water wedge intruding into the aquifer. This has been calculated by implementing the Ghyben-Herzberg equation. The aim of this investigation is to try and identify the approximate position of contaminated ground water within the aquifer. In the northern areas of Margarita, the presence of contaminated water within the aquifer has made wells unfit for irrigation.

Background

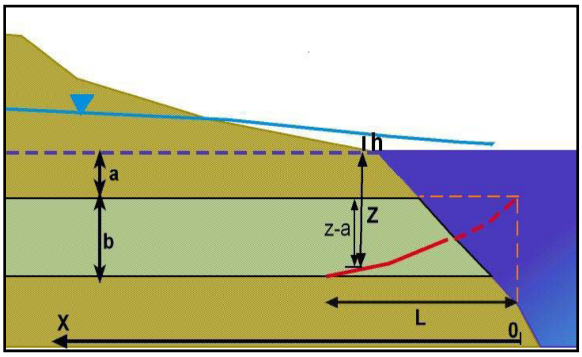
The island of Margarita is located in the Eastern part of the Venezuelan Caribbean Sea. The Pedro Gonzalez-El Salado aquifer is situated to the northeast of the isle and it is constrained by the Caribbean Sea to the north and by The Metamorphic Juangriego-Paraguachi complex to the east and south. M. Uzcategui *et al.* in 2007 completed the hydrogeological model of the aquifer stating that it is composed of two major units. The top unit was identified as 10m of very fine grain mud and clay layers that confine the aquifer, whereas the bottom layer contains fluvial and alluvial deposits (sands and gravels). The total discharge calculated was 22.76l/s, from which the infiltrated recharge is 37.57l/s, the extracted flow rate from wells is 22.44l/s and the natural discharge from in the area is 0.32l/s. The aquifer transmissivity is 63,85m^2/d with an estimated storage coefficient of 1E10^{-4}.

METHODS

Salt Water Intrusion Calculation: The salt water intrusion was calculated using Ghyben-Herzberg equation. In this equation (1), the flow rate per area unit is:

$$q_o = k\frac{\Delta h}{\Delta L}E \qquad (1)$$

where *k* is the aquifer permeability, $\frac{\Delta h}{\Delta L}$ represents the hydraulic gradient in the coast. *E* is the average aquifer thickness, taken form the difference of maximum depth in wells and the base of the confining layer.



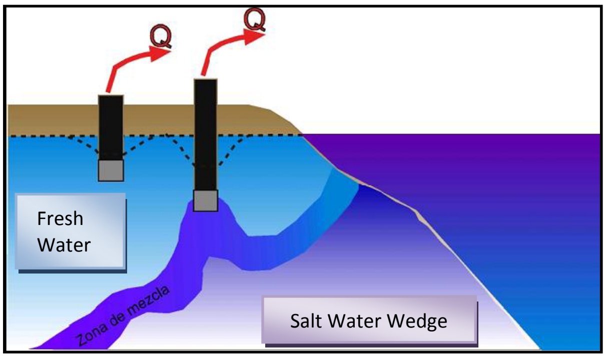


Figure 1: Salt Water Intrusion wedge model (left), Cone generated by ascended salt water levels. (after Custodio & Llamas, 2001)

The maximum penetration of the salt water wedge *"L"* (figure 1: left), was obtained from the following equation (2):

$$L = \frac{kb^2}{2q_o\alpha} \qquad (2)$$

where *b* is the average thickness, q_0 is the flow rate per unit of area and *α* is the density difference parameter.

Having *L*, the wedge depths were obtained by the following equation (3); from *x* equal cero to the maximum *L*:

$$(z-a)^2 = \frac{2q_o\alpha}{k}x \qquad (3)$$

a is the average difference of the top limit of the aquifer and the sea level for each well.

Salt water wedge thickness: The semi-amplitude of the horizontal displacement of the interface is calculated by using the equation below (4):

$$a = \frac{kh_o}{\phi}\sqrt{\frac{t_oS}{2\pi T}}\exp\left(-x\sqrt{\frac{\pi S}{t_oT}}\right) \qquad (4)$$

where h_o is the semi-amplitude of tide oscillation.

Extraction cones in wells: The ascended water level of cones (figure 1: right) from continuously pumping water from wells at the coast (3 relevant wells) was obtained by using the following equation (5):

$$\xi(r,t) = \frac{Q}{2\pi k_h d}\left(\frac{1}{\sqrt{1+R^2}} - \frac{1}{\sqrt{(1+t')^2 + R^2}}\right) \tag{5}$$

where $R = \frac{r}{d}\sqrt{\frac{k_v}{k_h}}$ and k_h= 1m/d and k_v=k_h/10, *r* is well radius and *d* is the thickness from the well depth to the interface which depends on the well horizontal distance to the coastal line. $t' = \frac{k_v}{2\phi\alpha d}t$ where *t* is the pumping time on which the average flow ratio is extracted (84.67 m^3/d). The maximum ascended level is then calculated using the equation below (6):

$$\xi_{\max} = \frac{Q\alpha}{2\pi k_h d\beta} \tag{6}$$

where the critical? ascended level β (dc) is d/3. Taking into account that the maximum ascended level depends on the flow rate (*Q*), the maximum flow rate for each well is determined by using the following equation (7):

$$Q_{\max} = \frac{2\pi k_h d_c}{\alpha} \tag{7}$$

RESULTS

Salt Water Intrusion

The flow rate per area unit is: $q_o = 0{,}36 m^2/d$; *L*= 32,70m. As these values depend on the aquifer thickness (taken from the wells depths), it is possible that the thickness used might not be the actual total aquifer thickness. An assumed maximum wedge penetration of 2500m from the coast to where the majority of wells are located in the Pedro González-El Salado area was used. The wedge depths (z) from 0 to 2500 are shown in table 1 along with the saline wedge thickness *a* and the illustration of the salt water wedge is shown in figure 2.

Extraction cones in wells

Table 2 shows the values for the selected wells that were used for the calculation and the maximum ascended level and the maximum flow rate for each well.

DISCUSSION AND CONCLUSIONS

Using the Ghyben-Herzberg equation it is possible to determine the Salt Water Intrusion geometry in the Pedro Gonzalez-El Salado aquifer. The confined nature of the aquifer allows the acceptable application of this process. For the aquifer thickness established as the wells depths, the salt water intrusion does not penetrate deeper than *L* 32,70m; however, this measured thickness might not represent the true thickness under the subsurface; assuming a maximum penetration of 2500m, where the majority of the pumping wells are located, the salt water wedge can reach 300m deep. Figure 2, shows the maximum wedge penetration versus its maximum depth, where the increase in depth is related to the increase in penetration. It is possible to calculate the maximum flow rate that can be pumped from the wells before this extraction causes the water level to rise to contaminate the consumable water. Examples from coastal wells in table 2 show that, in the worse case a maximum of 41,27m^3/day can be extracted. Further investigation is recommended to determine the exact aquifer depth and to control the volume of water that can be extracted from the aquifer in order to inhibit the advancement of the salt water wedge.

Table 1: Salt Water Wedge depths and interface thickness

X(m)	Z(m)	Interface *a* (mm)
0	36.83	3.12
2	44.42	3.10
4	47.56	3.08
6	49.98	3.06
8	52.01	3.05
10	53.80	3.03
12	55.42	3.01
14	56.91	2.99
16	58.30	2.97
18	59.60	2.95
20	60.83	2.93
22	62.00	2.92
24	63.12	2.90
26	64.19	2.88
28	65.23	2.86
30	66.22	2.85
50	74.78	2.68
100	90.50	2.29
200	112.72	1.69
400	144.16	0.91
600	168.28	0.49
800	188.62	0.27
1000	206.54	0.14
1500	244.68	0.03
2000	276.83	0.01
2500	305.16	0.00

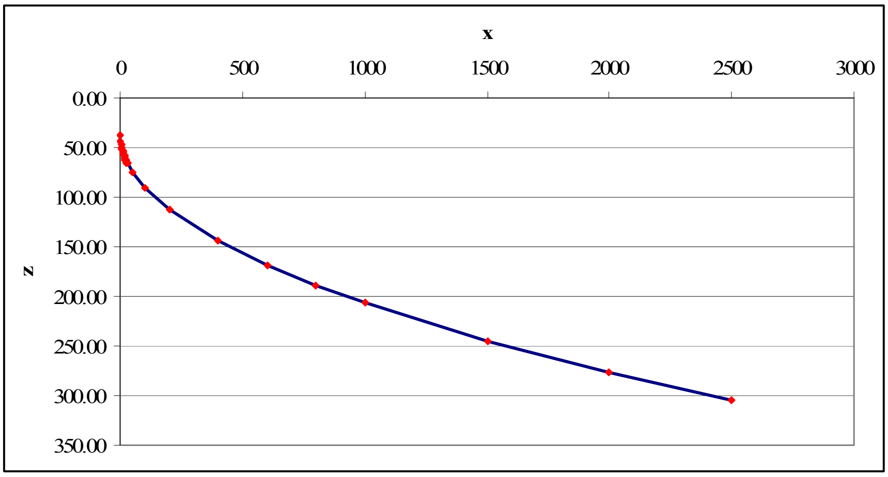


Figure 2: Modeled Salt Water Intrusion Wedge assuming a maximum *L*=2500m.

Table 2: Ascended water levels and Maximum Flow rates for coastal wells.

Well	Depth	Dist. x (m)	Interface depth (m)	ξ(r,t) (m)	ξ max (m)	Qmax m^3/day
C1-24	70	177.06	108.24	1.31E-05	1.11	76.53
C1-25	45	181.63	109.16	4.64E-06	0.39	215.40
C1-30	50	59.09	78.08	2.42E-05	2.05	41.27

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