

DESIGN OF A NETWORK FOR MONITORING THE INJECTED POLLUTANTS IN THE YUCATAN AQUIFER.

S. Gaona<sup>\*°</sup>, M. Villasuso<sup>°</sup>, J. Trejo<sup>°</sup>, T. Gordillo<sup>°</sup>, J. Pacheco<sup>°</sup>, A. Cabrera<sup>°</sup>.

<sup>°</sup>Fac. de Ingeniería, Universidad de Yucatán; ap. pos. B-1423, Mérida, Yucatán, México.

<sup>\*</sup>Instituto de Física, UNAM; ap. postal 20-364, México D.F., México.

ABSTRACT

The sewage of the City of Merida, cannot be carried to the sea economically owing to the low gradient of the land surface. A proposed solution to this problem is the underground injection of waste water through a deep well below an impervious layer (shale). Due to the possibility of pollution at the fresh water aquifer, it is necessary to have a monitoring system around each injection well.

Natural hydrochemical variation from the aquifer at different depths were studied.

Assuming the simplest monitoring system to be injection well surrounded by four observation wells tapping different depths, the results obtained from this work be used as a control reference, in order to know when a sewage leak from an injection well will be present there.

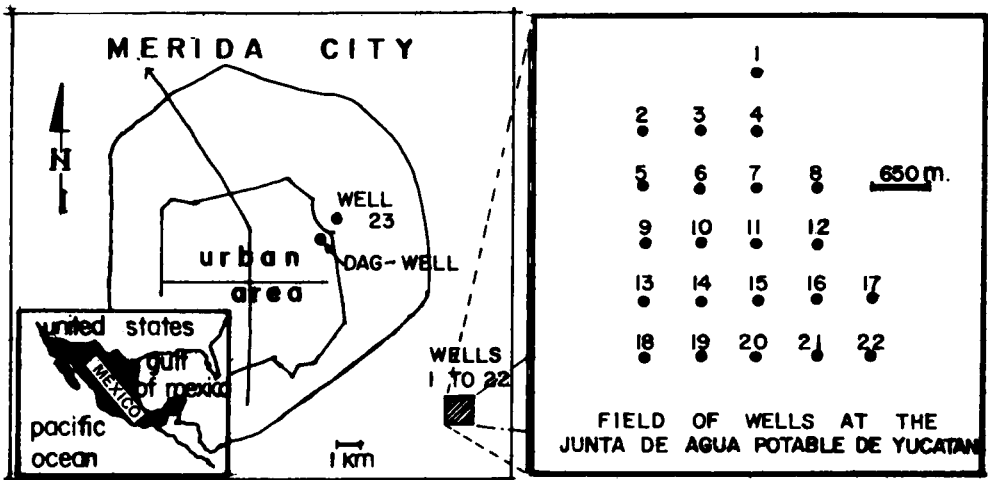


Fig. 1. The location of the Merida City and the studied wells.

## INTRODUCTION

The Peninsula of Yucatan is located in the eastern part of Mexico. It is surrounded to the north and west by the Gulf of Mexico, and to the east by the Caribbean sea.

The low gradient of land surface and the absence of an impervious layer close to the surface make difficult to carry the industrial and municipal waste water to the sea, for this reason some public institutions have been thinking that the injection of this sewage into the aquifer can be a solution.

The aquifer is almost pure calcium carbonate in horizontal layers from ground level to 200 meter below the surface where there exists a shale layer which is pointed out (Lesser J.M., 1976) as impervious.

The matrix of the aquifer above this shale presents a well defined karsticity (Gaona S., et al 1980); this means that a leak in the injection system would be dispersed very fast.

The network that we have in mind is the simplest; an injection well surrounded by four observation wells. To operate this network we need to know when the observation must be done and also which are the natural variations of the chemical parameters used as control. Here is presented the way the data has been analyzed and the conclusions drawn from these analyses.

## THE DATA

Several official institutions and private companies have been gathering information about the behavior and the characteristics of the Yucatan Peninsula aquifer, but each of them with a different approach to ours. We choose the more reliable and complete among them. We have been doing chemical analyses every two months for a year of the water from each of the 22 wells (30 meter depth) that are the supply of potable water of Merida City, located in an area of 845 hectares. Comision Federal de Electricidad get chemical analyses every day of the water extracted from a well 23 located in their thermoelectrical plant, which they give us. Also available were hydrochemical values (Durazo J., et al 1980) of samples at different depths from "cenote Ucil" (Gaona S., et al, 1980).

Water level measurements were desirable but unfortunately they were not available; instead of that, careful measurements were done several days in a dug-well located at the university campus. A sketch of the studied wells is presented in the figure 1.

The source, sampling frequency, period and types of measurements are summarized in table I.

To unify the information, from the well 23 were used only the analyses corresponding to the months in which the wells 1 to 22 were measured.

Daily values of the chemical parameters from well 23 were monthly average ( $\bar{x}_m$ ).

The yearly average ( $\bar{x}_y$ ) of each of these parameters ( $\bar{x}_y = \sum \bar{x}_m/n$ ) was taken as a hundred percent, and the percent difference was calculated between the yearly average and the monthly average ( $(\bar{x}_y - \bar{x}_m) 100/\bar{x}_y = \delta$ ) as well as their range of uncertainty ( $(\sigma \times 100)/\bar{x}_y = u$ ). The results of each sampling in wells 1 to 22 were also average for each ion ( $\bar{x}_s$ ). The yearly average of these samplings ( $\bar{x}_a = \bar{x}_s/k$ ) were used as a hundred percent, and monthly difference with their uncertainties were transformed like above. The resultant percentage and range of uncertainty of each point were plotted in figure 2, where spatial mean are showed by  $\square$  and temporal mean by  $\odot$ .

Figure 3 shows for some of the different hydrochemical parameters the percent difference between yearly average from well 22 and each one of the other well, versus distance between them. Uncertainties were plotted in percent. Here was fitted a curve of the type  $y=mx$  to the average differences (full line), with their range of  $1 \sigma_a$  (dash line) (where  $\sigma_a = \sum \sigma_i/n$ ,  $n=21$ ). Yearly  $\sigma$  is pointed out here as  $\sigma_{22}$ .

Average and standard deviation from hydrochemical values of "cenote Ucil" were calculated for each depth. Each standard deviation was expressed as related percentage to its corresponding average value in table II.

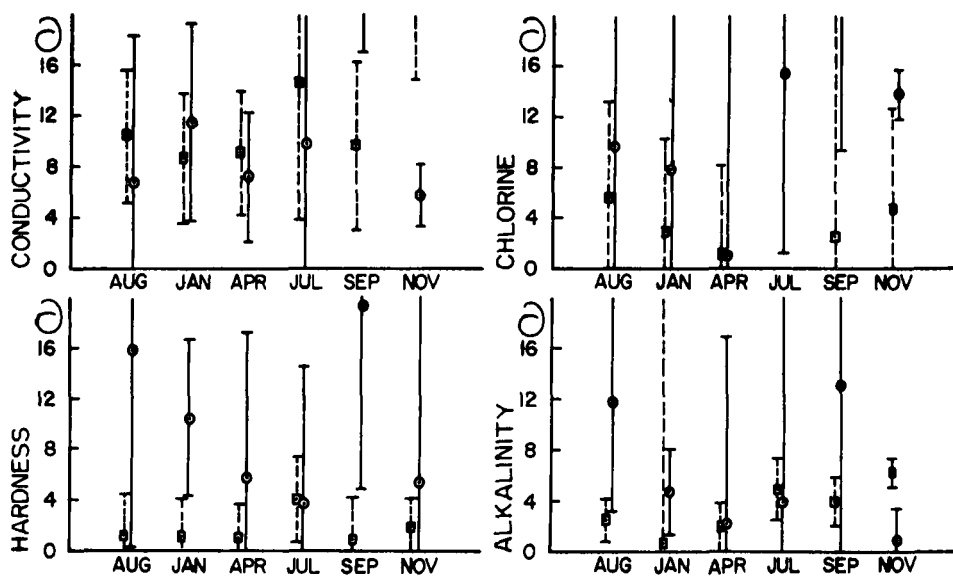


Fig. 2. The resultant percentages as well as the range of uncertainty of each point have been plotted. The mean spatial and the mean temporal are showed by  $\square$  and  $\odot$  respectively.

Daily variations for some hydrochemical parameters of samples from well 23 are presented in figure 4.

## DISCUSSION

Our goal was to find out the frequency of measurement of the hydrochemical parameters around the injection well, as well as to define when those variations are naturals or not.

Conclusions were made from more than one ion in order to reduce the possibility of error.

TABLE I

Available information

Well num.	Source	Sampling frequency	Period	Types of measurements
1-22	Junta de Agua Potable de Yucatan	bi-monthly	Aug.-1970 Nov.-1980	chem. Analy.
23	Comision Federal de Electricidad	daily	Jan.-1979 Nov.-1980	chem. Analy.
24	Fac. Ingenieria U. de Yucatan	daily	21 Jan.1981	piezometric
25	Fac. Ingenieria U. de Yucatan	each 4 months	Oct.-1979 Jul.-1980	chem. and Isotopic Analy.

It can be seen from Figure 2 that data dispersion around the temporal mean is greater than around the spatial mean; this means that a daily sampling will give us more information on the aquifer quality than samples of several wells at once each month. This fact can be assumed from observation in figure 2.

TABLE II

Variation of the hydrochemical values (in percent)

Depth	% of variation				
	E.C.	Alk.	Hardness	Chlorine	Sulfate
20	2.5	1.7	0.3	9.6	20.7
40	2.5	1.4	6.8	8.6	15.8
50	34.4	0.7	12.6	16.3	43.5
60	4.9	2.2	7.2	13.9	25.7
70	2.6	3.2	12.9	29.9	27.1
80	27.8	5.6	22.1	25.7	28.8
95	12.9	6.3	13.8	4.8	27.3

Table II shows that the aquifer has greater variation at its deepest part than at its surface, contradicting previous findings. With this result, it is possible to say that control samples must be taken at different depths, but using the same periodicity samplings.

Figure 3 has a confidence region in order to appreciate when the variation is natural or not. The way to do this, is to obtain the average of the water quality at the injection point. Taking this value to be 100%, the percent difference between the average injection and the observation well values must be calculated and to plot the value of this difference in figure 4 with the adequate ordinate. If the value falls

between the dash line and the ordinate axis of the figure 4 the value has a probability of 68% or more to be normal; if the value falls out of the dash line, perhaps it will be desirable to analyses other ion or to inspected the injection system.

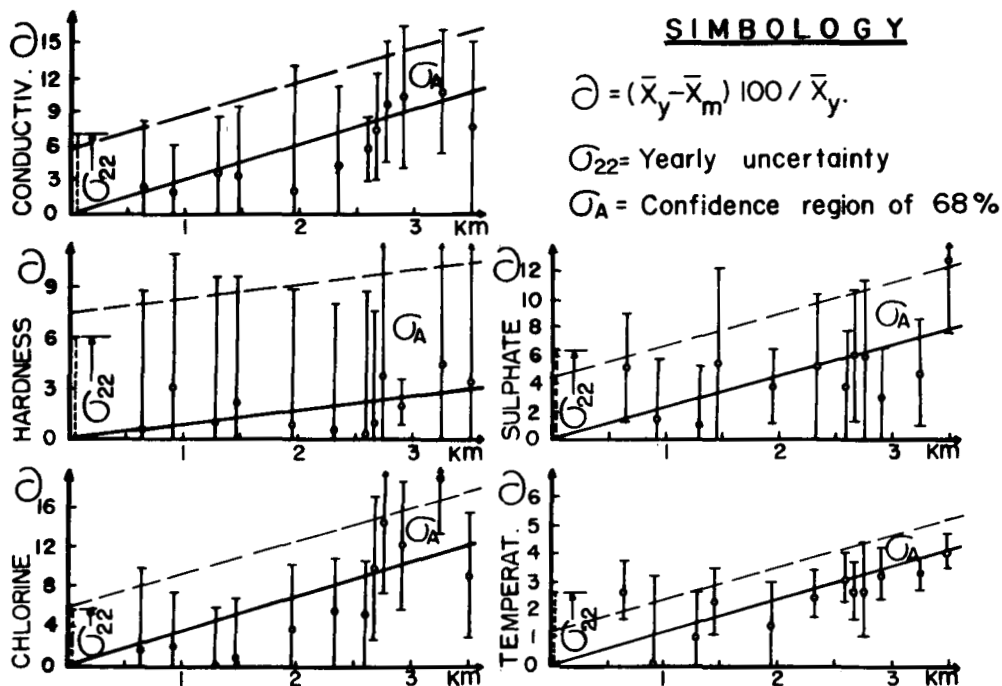


Fig. 3. For different hydrochemical parameters, the percent of the difference between the yearly average from well 22 and each of the others, versus the distance between them have been plotted.

Finally the available information and experience shows that only four parameters should be used as control, two of them must be easy of sampling and analysis; the other one is chosen from the more abundant parameter in the injection water, and the fourth must be the temperature because it remains very stable during the year and it changes appreciably, when hydrochemical reactions take place.

#### SUMMARY

To prevent a possible leak of pollutants to the aquifer of fresh water in the vicinity of an injection point, observation wells must be situated no more than two kilometers around the injection point since in this perimeter the differences among

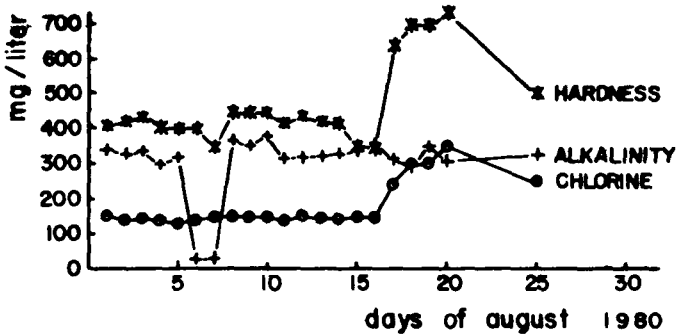


Fig. 4. Daily variations for some hydrochemical parameters of samples from the well 23

the measure parameters will be into the order of magnitude of the yearly variations that have the aquifer in its natural form; it must be chosen as control parameters those of easy sampling and analysis, temperature and another typical parameter of the particular injection. If the values are greater than  $\sigma_a$  it would be desirable to measure the other chemical parameters and in the case the variation persists for more than a day it will be necessary to do a careful review of the injection system. The control wells must be at least four, since there exists the possibility the direction flow in the injection point does not correspond to the general direction of the aquifer. The head of the aquifer must be measured with milimetric detectors and the interpretation must be done considering the daily rainfall in the study region.

#### REFERENCES

- Durazo J., Gaona S., Trejo J., Villasuso M., 1980. Observaciones sobre la interfase salina en los cenotes del Centro-Norte de Yucatán. XXIII Congreso Nacional de Investigación en Física, Guadalajara, Méx. (unpublished).
- Gaona S., Gordillo T. y Villasuso M., 1980. Karsticity in the Aquifer of Yucatan (Hypothesis of its Development) 3rd. International Symposium on Water-Rock Interaction, Edmonton: 16-17.
- Gaona S., Gordillo T., Villasuso M., 1980. Algunas Características del Karst de la Península de Yucatán, VI Congreso Nacional de Hidráulica, Mérida, Yucatán, México.
- Lesser J.M., 1976. Estudio hidrogeoquímico e hidrogeológico de la Península de Yucatán. Proyecto, SRH. CONACYT-NSF 704.
- Soto J J , 1980. Informe de Control Químico de la central termoeléctrica Nachicocon, Mérida, Yucatán, (unpublished).

We thank to Direction General de Investigacion Cientifica y Superacion Academica, SEP, by the economical support; the Comision Federal de Electricidad (Merida) and Junta de Agua Potable de Yucatan for the access to their hydrochemical information.