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## Extended Abstracts

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# Estimation of hydraulic conductivity by applying slug test in a volcaniclastic-deposits aquifer

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## INTRODUCTION

The study was carried out in an aquifer called Las Sierras located in Managua Nicaragua, an area where water supply issues are becoming increasingly important. In the study area pumping tests had been used previously to calculate hydraulic properties. However, the purpose of performing these measurements had not been aquifer characterization but rather calculation of the specific capacity of the production wells. This study attempts to investigate the applicability of slug tests as a well-testing method for use in Managua, where lack of data is a main problem.

According to JICA & INAA (1993) the study area is mainly composed of volcanic rock and volcanic sediment ranging in age from plio-pleistocene to recent. Three principal water–bearing formations are present: a). Alluvial deposits with Quaternary pyroclastic materials (Qal) consisting of mixed sediments of volcanic ash (scoria and pumice) and debris; b) Masaya Group Volcanic (QvM) composed of basaltic lavas and pyroclastic materials (volcanic breccia, scoria and ash), c) Middle Las Sierras Group (TQpsM). This last group consists of massive and compact basaltic to andesitic agglomerate with tuffbreccia (lapilli tuff) and tuff. The groundwater flow is mainly domain by the topography. The thickness of the aquifer varies between 100 m in the recharge zone and 300 meters in the discharge zones, which are close to the shore of the Xolotlan Lake. The depth from the ground level to the water table is in the range from 3 m to more than 230 m. In total five study sites were tested by carrying out multiple slug tests in each of them.

## METHODS

The study was based on the evaluation, analysis and interpretation of data collection on hydraulic parameters from Las Sierras Aquifer. New data was acquired for this purpose by applying slug tests and then comparing them with hydraulic parameters obtained from previous pumping test performed by the national water supply company, ENACAL. This company manages more than 110 wells distributed over the entire Managua area and also controls the production and location of private wells. Most of the wells located in the Managua area were drilled during the 70s and 80s. Consequently, some of them are out of service, thus providing accessible places for carrying out slug testing. For the processing of the data, additional borehole information was collected regarding well completion and lithological description. The availability of such information was an essential consideration when selecting field study sites (Ciudad Sandino, Altamira, San Cristobal, Las Mercedes, Managua Fase II) see figure below.

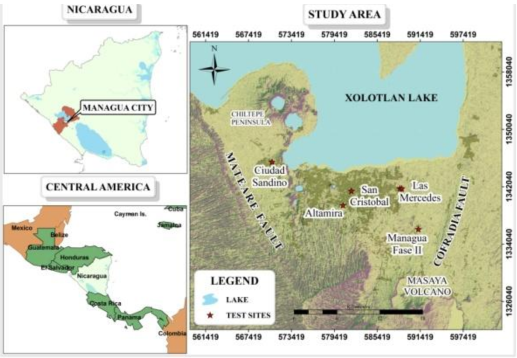

**Figure 1.** Location study area and tested sites.

From the five above-mentioned study-sites, the hydraulic conductivity of seven wells were assessed using a hydraulic method commonly known as a slug test. This method, introduced by Hvorslev in 1951, has many advantages: it is low-cost, both in terms of manpower and equipment, simple to carry out and relatively rapid to execute, see Butler (1998). Its mechanisms consist of generating a sudden change in the water level and subsequently measuring the return to static condition.

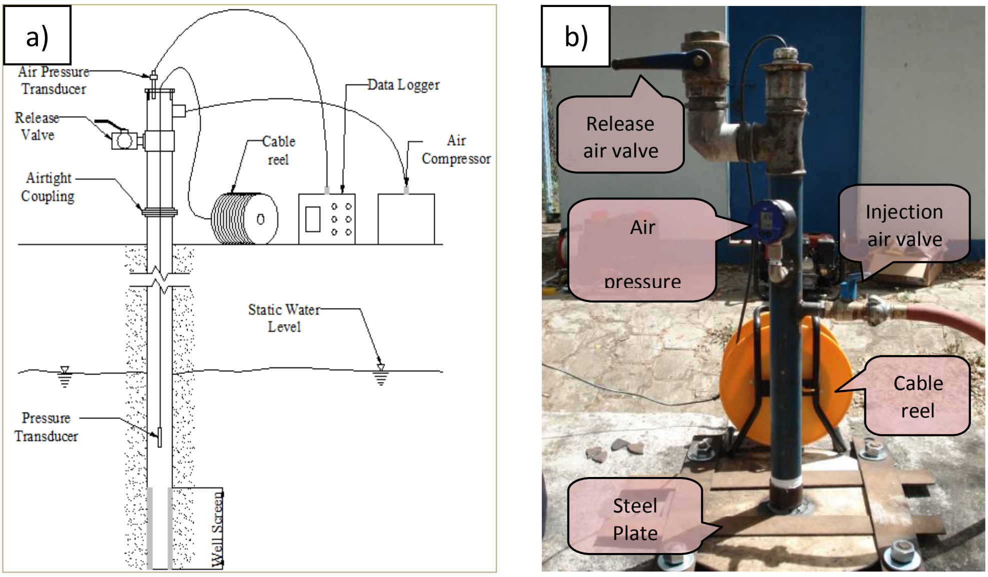

**Figure 2.** a) Pneumatic Method (Butler, 1998); b) Slug test equipment.

The slug test in this study was initiated by applying the pneumatic approach (Fig. 2a). This approach involves pressurizing the air column in a sealed well by the injection of air; the pressurization produces a depression of the water level, as water flows out of the well in response to the increased pressure (Prosser, 1981). Two pressure transducers are needed: one that measures the pressure in the air column and the other one which records the change of pressure in the water column. The advantages of the pneumatic slug test are: no water needs to be handled and a rapid test initiation can be performed, see Butler (1998). An issue when conducting the pneumatic approach in our study was the need for an air-tight coupling between the casing wells and the slug test equipment. Such a device was constructed by welding steel plates, and rubber rings were required (Fig. 2b).

## RESULTS AND DISCUSSION

The lithological description reveals that a combination of three geological units constitutes the water-bearing formations in the tested places. Such formations yield the different values of the hydraulic conductivities obtained for each study site (Table. 1). The accuracy of the slug test data was checked by comparing the values with hydraulic parameters obtained from previous pumping tests. The results demonstrate that slug test can provide consistent and viable data regarding hydraulic conductivities for volcanic environments. Hence the information acquired during this investigation provides valuable data that is required for developing future studies such as numerical modelling and groundwater flow simulations.

**Table 1.** Estimated Hydraulic Conductivities (K).

| Test site | Total tests | Total casing (m) | Water table (m) | Screen length (m) | Well Diameter (cm) | *Geological deposits | K (m/sec) |
|---|---|---|---|---|---|---|---|
| Las Mercedes | | | | | | | |
| 12 | 8 | 131.1 | 21.82 | 32.02 | 20.32 (8") | Qal + QvM + TQpsM | 1.4E-4 |
| 13 | 8 | 164.63 | 20.42 | 35.37 | 20.32 (8") | | 1.5E-4 |
| San Cristóbal | | | | | | | |
| 2008 | 7 | 152.44 | 49.86 | 58.96 | 30.48 (12") | TQpsM | 8.1E-6 |
| 2009 | 5 | | 50.83 | | | | |
| Managua Fase II | 4 | 200 | 45.68 | 68 | 30.48 (12") | QvM + TQpsM | 1.2E-5 |
| Altamira | 5 | 204 | 92.27 | 33.54 | 30.48 (12") | QvM + TQpsM | 1.3E-5 |
| Ciudad Sandino | 8 | 125 | 52.58 | 28.58 | 25.4 (10") | Qal + QvChiltepe | 5.2E-5 |

*Geological description proposed by JICA & INAA 1993. Qal —Sand clay sediments with pyroclastic material, debris deposits; QvM — Basaltic andesitic agglomerate, tuffbreccia, tuff, fossil soil, tuffaceous sand and silt; TQpsM & QvChiltepe — Pyroclastic flows and pyroclastic fall deposits.

**Las Mercedes well field**: eight slug tests were performed in two wells (Las Mercedes 12 and 13) by lowering the water level.

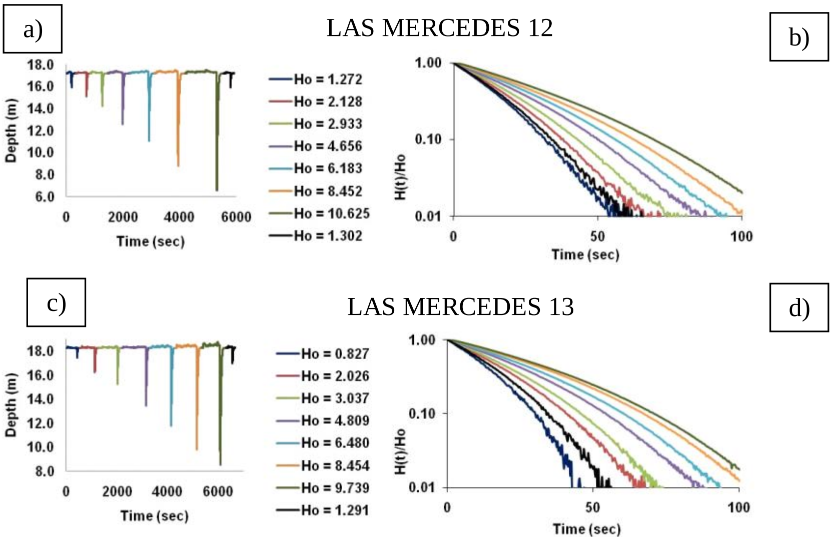

**Figure 3.** a) Measurements at Las Mercedes 12 b) Normalized head from Las Mercedes 12, c) Measurements at Las Mercedes 13 d) Normalized head from Las Mercedes 13.

Measurements of the normalized head versus the time are plotted in Fig. 3b and 3d for Las Mercedes 12 and Las Mercedes 13 respectively. As can be seen the plots present a concave downward curve characteristic of a nonlinear flow, as discussed by McElwee and Zenner (1998). This means that the data is not adequate for analysis with the linear models. The best fit was achieved by using the McElwee-Zenner (1998) solution. By doing this separately for each of the eight tests performed, the average hydraulic conductivity (K) was found to equal 1.4E-04 m/s and 1.5E-04 m/s for Las Mercedes 12 and Las Mercedes 13 respectively. These values were compared with the ones obtained from previous pumping tests performed by ENACAL in others wells located in the well field. It can be said that the K are in good agreement. The average K estimated from previous pumping test data is around 1.4E-04 m/s.

**San Cristobal study site**: The data were acquired during two periods. Seven tests were performed during February 2008, in this case the data were obtained from the slug tested well (San Cristobal 2) and an observation well (San Cristobal 3). Others 5 tests were carried out during April 2009 (measuring only in the tested well). The purpose was to check the accuracy of the data, the reproducibility of the method and the subsequent reliability of the results. The logarithms of the normalized heads versus the time are plotted in Fig 4b and Fig 4d for 2008 and 2009 respectively. There is clearly seen the double straight line effect discussed by Bouwer (1989). Almost the same values were obtained by plotting the data measured in the tested well one year later. In the case of San Cristobal 2, the estimated K = 8.1E-06 m/s, which includes the results gathered from the two dates. Regarding San Cristobal 3 in the upper part in Fig. 4a it can be seen an evident influence created by the tests carried out 15 meters away. This contributes to the findings of previous researchers that slug tests affect greater areas in the formation than just those in the vicinity of the well.

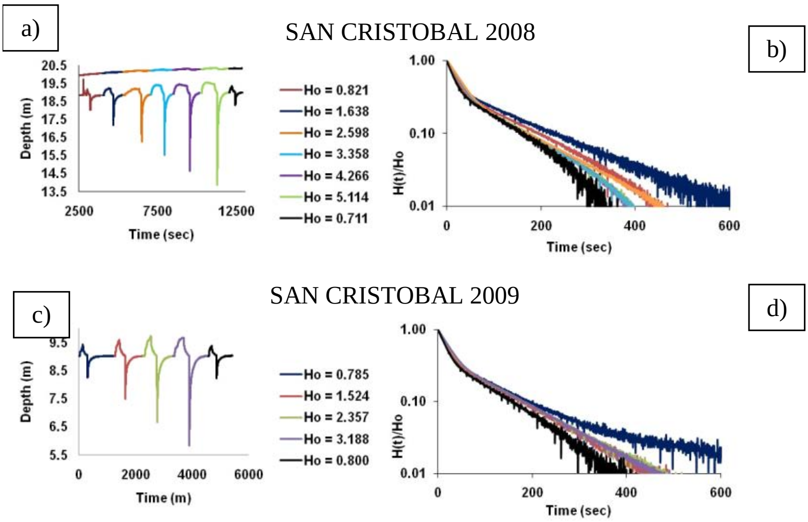

**Figure 4.** Measurements at San Cristobal a) during 2008, b) Normalized head obtained in 2008, c) during 2009, d) Normalized head obtained in 2009.

**Managua Fase II study site**: four slug tests were carried out at this site by lowering the water level 0.72, 2.19, 1.39 and 0.65 m. Plots of the data in a semi logarithmic format are shown in Fig. 5. It is clear that the variation in the response of the well is negligible. Very good matching was obtained by applying the Hvorslev (1951) solution. Thus the average transmissivity was T = 8.7E-04 m2/s, which resulted from multiplying the aquifer thickness by the hydraulic conductivity. The average K was 1.2E-05 m/s, which was much lower than the hydraulic conductivity in Las Mercedes.

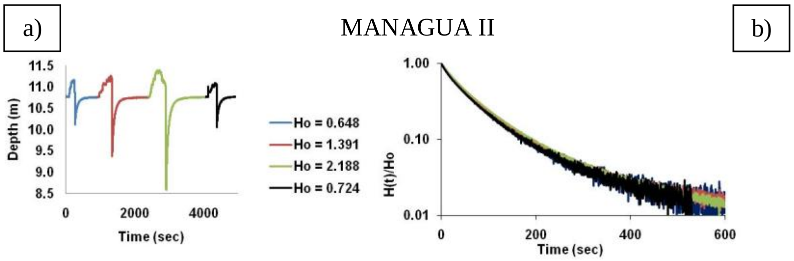

**Figure 5.** a) Measurements at Managua II, b) Normalized head.

**Altamira study site**: as can be seen in the Fig 6b, the plots present a similar behavior to the obtained at San Cristobal site. The double straight line effect is evident. The estimated K = 1.3E-05 m/s, which is relatively close to the values obtained from a previous pumping test: K = 1.1E-05 m/s, thus demonstrating that the two methods provide similar results.

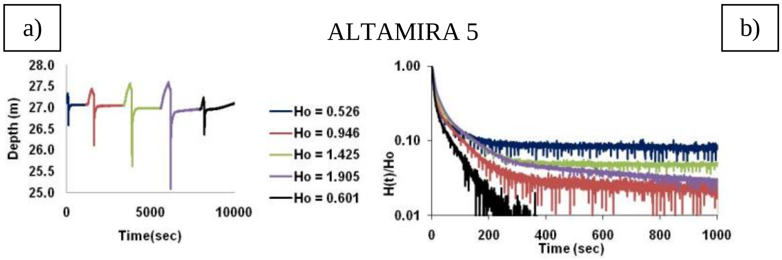

**Figure 6.** a) Measurements at Altamira , b) Normalized head.

**Ciudad Sandino study site**: the same behavior (Fig.7) as the one in the Las Mercedes well field was obtained from the tests performed in this well. The plots present a concave downward curve if plotted in a semi-logarithmic format and K = 5.2E-05 m/s was obtained by using the McElwee-Zenner (1998) solution. The value is in good agreement with the obtained through a pumping test carried out in another well, in which K was equal to 5.6E-05 m/s.

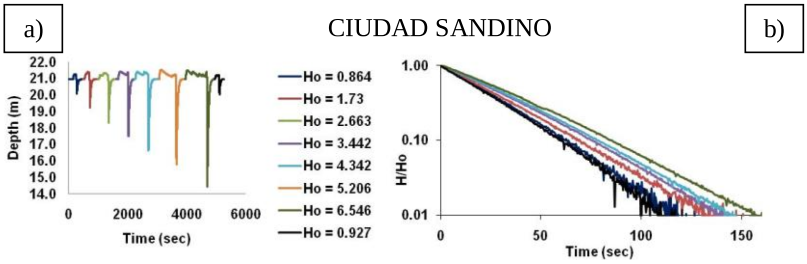

**Figure 7.** a) Measurements at Ciudad Sandino , b) Normalized head.

## CONCLUSION

The results obtained for each study site show that slug tests can provide consistent and viable data regarding hydraulic conductivities for volcanic environments such as the one studied. The hydraulic conductivities have been effectively compared with the results from pumping tests and a good agreement has been demonstrated between the two methods. In addition, the K values estimated are closely related to the different type of deposits (the tree water bearing formations) that were found in the study sites. Finally, due to its ease of implementation and low cost, this method provides an effective alternative for application in developing countries, where lack of data and economical resources are part of the problem.

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