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Estimating Low-Enthalpy Geothermal Potential for District Heating in Santiago Basin (33.5°S), Central Chile

Pablo Garat[1,2], Mauricio Muñoz[1,2], Valentina Flores-Aqueveque[1,2], Sofía Rebolledo[1], Gabriel Vargas[1,2], Diego Morata[1,2], Miguel Ángel Parada[1,2]

[1]Departamento de Geología, FCFM, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile

[2]Centro de Excelencia en Geotermia de los Andes (CEGA), FCFM, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile

E-mail: maumunoz@ing.uchile.cl

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ABSTRACT

This work shows results of a regional scale estimation of low-enthalpy geothermal resources in Santiago basin (33.5°S), located between Coastal Range, and Andean Range in central Chile. The purpose of this work is to identify promising areas for the development of the direct use of this non-conventional renewable energy. The estimation is based on soil thermal properties, and hydrogeological parameters using Geographic Information System (GIS). To estimate the low-enthalpy geothermal potential for district heating, a Borehole Heat Exchanger (BHE) coupled with Heat Pump is assessed to supply the energy demand equivalent to the required to heat a standard Chilean house. The main barrier for this direct use of geothermal energy is the depth to be drilled to implement a BHE. The depth to be drilled is estimated based on specific Heat Extraction (sHE) of sediments in watt per meter. Results show that the most important parameters controlling the meters to be drilled to implement a BHE are static level depth, and groundwater flow velocity. In our case the meters to be drilled range from tens of meters to a little more than one hundred meters.

1. INTRODUCTION

Soil can naturally store energy from atmosphere and heat flow coming up from rock basement. The energy stored in the ground can be extracted with a Borehole Heat Exchanger (BHE) that uses the heat stored in soil to supply power to a heat pump that supplements the power needed for heating a space (Florides and Kalogirou, 2007).

Ground source heat exchanger coupled with heat pump is the most popular direct use of low-enthalpy geothermal energy. By 2010 the installed capacity was 68.3%, and the use capacity was 47.2% of direct use of geothermal energy (Lund et al., 2011). This is a widespread type of acclimatization system, because it can be used for heating or cooling, and can be developed anywhere, and anytime with a very low environmental impact (Florides and Kalogirou, 2007).

In this work a decision support map is created to evaluate the favorability of installing a BHE coupled with heat pump in Santiago basin. The BHE is the most common type of ground source heat pump, which consists of a U-shape pipe, usually made of high-density polyethylene, inserted in vertical boreholes. A fluid, usually water, optionally with antifreezes, circulates throughout the pipe exchanging heat with the ground. Depth of the BHE depends on the soil thermal properties, groundwater flow and its velocity. Generally to heat a house with a BHE it must be drilled from tens to a few hundreds of meters (e.g. Ondreka et al., 2007, Gemelli et al., 2011).

In Chile the use of a BHE coupled with heat pump is limited, because of the lack of information about the advantages offered by these systems and their high initial cost. A high drilling cost may be the result of an oversized design of BHE, caused by lack of reliable hydrological information.

2. STUDY AREA

The interest area is the Santiago basin in central Chile, with more than 6.5 million inhabitants, which represent *c.a.* 40% of the country's population (XVIII Chilean Population Census, 2012). The Santiago basin is located between Andean Range and Coastal Range (Figure 1). According to Peel et al. (2007) the climate of Santiago city is subtropical tempered with dry and warm summer. The annual mean temperature is 13.6°C ranging from 0°C in winter to 34°C in summer (Santibáñez and Uribe, 1990). The annual average rainfall is about 300 mm per year, principally concentrated from May to August.

3. HYDROGEOLOGICAL SETTING

3.1 Sedimentary Infill

The Santiago basin sedimentary infill was defined based on 785 sedimentary borehole descriptions. The sedimentary facies correspond mainly to alluvial, and fluvial facies. In addition, there are colluvial, and lacustrine facies of reduced areal extent, and volcanic pyroclastic deposits of Pleistocene age, which outcrop in western and southwestern part of the basin. In the central and southern part of the basin there are alluvial fans of high-energy depositional environment. In the northern and southwestern part of the basin there are alluvial fans of lower-energy depositional environment. The main difference between these alluvial fans is the fine sediment content in matrix. Close to rivers there are fluvial deposits, with depositional energy decreasing westward. In the basin margins, there are colluvial deposits, which correspond to debris flows and foothill deposits. There are lacustrine deposits located northwestern and southwestern of the basin. Finally, pyroclastic deposits (reworked in some cases), outcrop western and southwestern of the basin (Wall et al., 1999; Sellés y Gana, 2001).

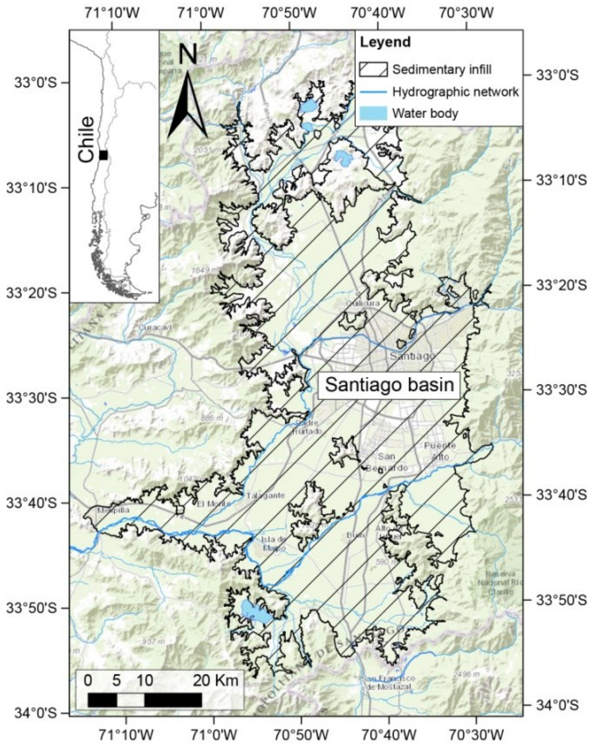

Figure 1: Location of Santiago basin.

3.2 Static level of groundwater and piezometric elevation

A surface for the depth of static level is determined by interpolating more than 2.000 control points with information including data from the last 5 decades using a circular model with anisotropy of ordinary kriging interpolation tool with Geostatistical tool of ArcMap. To consider the effect of lower recharge and maximum extraction of groundwater in the aquifer, the maximum static level depth for each control point is considered. The piezometric elevation surface is estimated by subtracting the static level to the topographic height.

3.3 Velocity of groundwater flow

The groundwater velocity is calculated from Darcy's Law as follows:

$$V_{Darcy} = \lambda \cdot i \quad (1)$$

Here λ is the hydraulic conductivity, and i is the hydraulic gradient. Hydraulic conductivity values are obtained from literature (Custodio and Llamas, 1983) whereas hydraulic gradient is estimated as the slope of the piezometric elevation surface.

4. METHODOLOGY

In order to obtain an estimation of direct use of low enthalpy geothermal energy, the performance of a Borehole Heat Exchanger (BHE) to supply a fixed energy demand of 2.7 kW was evaluated in the Santiago basin sedimentary infill. This energy demand is equivalent to energy needed for heating a Chilean standard one-story house of 50 to 71 m^2 with thermal insulation (Romero, 2012). The performance of the BHE depends on the soil thermal properties, and hydrogeological parameters that have been implemented in a geodatabase with the aim to be managed and analyzed in a Geographic Information System (GIS). The statistical and geostatistical analysis have been also performed using GIS and Kriging algorithm.

The BHE consists of a borehole with a U-shape pipe inside, which exchanges heat with the ground. The energy that can be exchanged depends on thermal properties of sediments, groundwater, and its velocity. The power that can be exchanged per meter by a BHE is defined as specific Heat Extraction (sHE) in watts per meter (W/m). The sHE values of sediments were defined according to the German VDI guideline 4640 (Table 1), whose values are based on 2.400 operating hours (Ondreka et al., 2007).

Table 1: Values of specific Heat Extraction for sediments (German VDI guideline 4640).

Soil type	Specific heat extraction sHE (W/m)
Gravel, sand, dry	<20
Gravel, sand, water saturated	55-65
Gravel, sand, with strong groundwater flow	80-100
Clay, Silt, mud	30-40

As the sHE is variable in each layer and is strongly dependent of the water content, and its velocity, for each borehole with stratigraphic information, an upper specific Heat Extraction for dry sediments (sHE_d), and a lower saturated specific Heat Extraction for saturated sediments (sHE_S) are determined as follows:

$$sHE_d = \frac{1}{Th_d} \sum_{i=1}^{k} \left(sHE_i \times Th_i \right) \quad \text{If } \sum (Th_i) < \text{static level depth} \tag{2}$$

$$sHE_S = \frac{1}{Th_S} \sum_{i=k+1}^{n} \left(sHE_i \times Th_i \right) \quad \text{If } \sum (Th_i) \geq \text{static level depth} \tag{3}$$

Here Th_d and Th_S are dry and saturated thickness respectively, sHE_i is the specific Heat Extraction of layer i, Th_i is thickness of layer I, and k is the index of the layer just above the static level depth. Therefore, the depth to be drilled for a BHE implementation in each borehole with sedimentary information is calculated as follows:

$$Th = \frac{P}{sHE_d} \quad \text{If not necessary to reach saturated layers} \tag{4}$$

$$Th = Th_d + \frac{\left(P - \left(sHE_d \times Th_d \right) \right)}{sHE_S} \quad \text{If it is necessary to reach saturated layers} \tag{5}$$

Here Th corresponds to the meters to be drilled to supply a fixed power demand (P) and Th_d is dry thickness in equation (5).

5. RESULTS AND DISCUSSION

The depth to be drilled to supply a fixed demand of 2.7 kW with a BHE, was estimated for each borehole with stratigraphic information. A continuous surface using these results was estimated by interpolation using the Ordinary Kriging method (Figure 2). The best estimation was found with a circular model with anisotropy, which gave less than 5 meters of estimated error, where stratigraphic information is available.

The depth to be drilled to implement a BHE is in the range between 35 to 105 meters, with an average value of 58 meters. The southwestern sector of the basin is the most favorable part, where is necessary to drill less than 50 meters, whereas the central eastern area of the basin is the less favorable part, where is necessary to drill more than 80 meters.

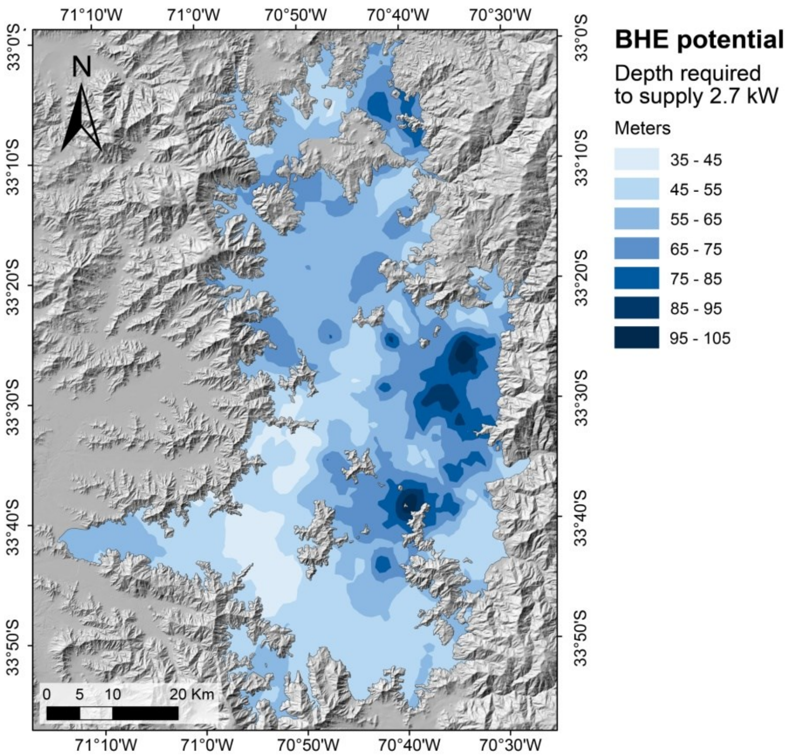

Figure 2: Depth to be drilled to supply a power demand of 2.7 kW using a BHE in Santiago basin.

The factors which control the favorability for the implementation of a BHE are mainly the static level depth, and velocity of groundwater flow. The groundwater flow is highly dependent of the hydraulic conductivity, which in the Santiago basin sedimentary infill is higher due to the presence of fluvial and alluvial facies of high energy depositional environments.

There are areas where, despite a shallower static level depth, are not part of the most favorable areas for the development of BHE because of the low hydraulic conductivity. These areas correspond to alluvial fans of low energy environment, lacustrine and pyroclastic deposits.

6. CONCLUSIONS

This work presents a regional evaluation for the use of a BHE as an alternative for heating a standard Chilean house, considering geological and hydrological parameters. It is expected that favorable places for heating a house are also promising for heating bigger buildings or another direct uses of low-enthalpy geothermal energy.

The main factor, which controls the favorability of BHE in the Santiago basin is the static level depth, because of the higher thermal conductivity of saturated sediments respect to dry sediments.

A higher hydraulic conductivity improves the groundwater velocity, and therefore improves the heat exchanging reducing the depth to be drilled for heating a space with a BHE.

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