

Development and Protection of Geothermal Sources in Peru

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ABSTRACT

The project entitled "Development and protection of geothermal and mineral water sources in Peru" focused on the development of general rules for the protection of water resources in various parts of Peru between 2005 and 2007. Two case regions (Cajamarca and Churín) were studied from the points of view of geology, hydrogeology, climatology, geochemistry, and hydrology etc. to obtain the data required to make an assessment of the region and to establish basic rules of geothermal resource protection including the maximum extraction volumes, sustainability of the resources, and hazards etc. Mathematical modeling of geothermal resources, an economic assessment and a sociological survey were other important parts of the study.

This paper will present the technology used for the assessment of data and its application on pilot studies and will summarize the key results of the study with possible relevance for other locations in different countries with different geological, economical and ecological conditions.

1. INTRODUCTION

The environmental consultancy company AQUATEST a.s., along with the Czech Geological Survey participated on the project which was performed in the framework of the Czech Republic Foreign Aid Program. The Peruvian Ministry of Foreign Trade and Tourism (MINCETUR) was the project beneficiary while Peruvian Geological Survey (INGEMMET) was the local project coordinator. Cajamarca, Churín, Chivay and Candarave were locations selected for an introductory study of thermal and mineral waters (Figure 1).



Figure 1: Location of assessed sites.

After a SWOT analysis of all four locations, two locations (Cajamarca and Churín) were selected for further detailed assessment.

The following strengths were highlighted for Cajamarca:

- spring discharge (138 l/s), temperature (68-71°C)
- altitude
- tradition in balneology and good history of curative effects (pre-Inca and Inca periods)
- airport and good bus connections
- active support of local authorities, existence of additional resources, possibility of development in the area

The following strengths were highlighted for Churín:

- spring discharge (80 l/s), temperature (32-34°C)
- altitude
- tradition in balneology and good history of curative effects
- relatively short distance to the capital Lima, good bus connections
- active support of local authorities, existence of additional resources, possibility of site development

2. DESCRIPTION OF CAJAMARCA

The Cajamarca region was chosen in this paper as an example of data assessment. The capital of the region, also called Cajamarca, lies in a valley of western edge of Peruvian Andes between 7° and 8° south. The valley spans up to 8 km and the surrounding mountains are up to 4000 m high. Six km to the west of Cajamarca there is a village called Baños del Inca, which is well known for its thermal springs.

Cajamarca is a city with a long history. The most significance event was the killing of the Inca chief Atahualpa in 1533. This event opened the way for the Spanish conqueror Francisco Pizarro to annex Peru. This is reflected in many historical monuments and together with the thermal sources has brought tourism to the area.

2.1 Climatic Data

The very attractive position of Cajamarca valley and an altitude between 2660 - 2750 m provides for a comfortable climate. A stable temperature and long dry season are very important parameters for the exploitation of an area's balneal potential. Temperatures are constant during the whole of the year (Table 1). Although the rainy season is relatively long (from October till April), temperatures stay pleasant and the number of rainy days do not exceed 50% each month. The dry season is characterized by hot days and cold nights. Humidity is moderate and contributes to the comfortable climate.

2.2 Geological Characteristics

Geologically, the area of Cajamarca consists of Triassic, Jurassic, and Paleozoic sediments. Major outcrops form a thick series of Upper and Lower Triassic sediments. The Upper and Lower Tertiary are represented by sediments and thick sequences of volcanic rock. The folded structure of post-cretaceous age is the dominant structure in the region.

An axis of folds and extensive slip-on planes are oriented towards 'andino', i.e. in WNW-ESE direction.

Table 1: Meteorological data of Cajamarca area

Month	Temperature [°C]		Relative Humidity [%]		Average precipitation [mm]	Rainy days
	min	max	am	pm		
Jan	9	22	85	38	91	13
Feb	9	21	88	45	107	17
Mar	9	21	92	46	117	17
Apr	8	21	90	42	86	14
May	7	22	86	41	43	9
June	6	21	81	37	13	4
July	5	21	86	33	5	2
Aug	6	22	81	29	8	2
Sep	7	22	85	38	58	9
Oct	8	22	81	34	58	9
Nov	8	22	79	33	48	8
Dec	8	22	86	37	81	11

2.3 Conceptual Hydraulic Model

The springs in Banos del Inca are created by a unique thermal mineral water source which is why their further development is considered. The sources consist of two independent groups, Tragadero at 2695 m a.s.l. and Perolitos at 2689 m a.s.l. Besides these two major sources there are springs scattered in the alluvial sediments as far as Río Chonta.

The base aquifer is formed by a Chimu geological layer, where geothermal sources for both spring groups are formed (Figure 2). The geological profile shows that the Chimu aquifer elevates in the south of the Cajamarca basin and is infiltrated at an altitude of 3000 – 3500 m. The infiltrated water flows through fissures in quartzites located at the base of the aquifer. The underlying layer is formed by very low permeable sediments of Jurassic Chicama, which direct the groundwater to the centre of the Cajamarca basin. The upper aquifer boundary is also formed by an aquitard of Santa and Carhuas. Above there is a higher aquifer in sandstone Farrat, filling a substantial fraction of the southern part of the Cajamarca basin.

Spring sources of thermal water in Tragadero and Perolitos are connected with an interference of two important structural elements: the Banos del Inca anticline and a N-S fault. A conceptual geological model assumes that the fault is deep and has been active since before the orogenesis. Current activity is confirmed by high temperature flux, gas inflow from depth and a high concentration of chloride anions. Hot groundwater under high pressure comes through the aquitard and the alluvial sediments and forms two spring groups. In the alluvial sediments (about 30 m thick) the thermal water is partially diluted by groundwater of low circulation.

2.4 Numerical Hydraulic Model

The mathematical model was set in the code *Flow123D*, developed by the ARTEC (TUL) research center. The program applies Darcy's law and a continuity equation in each element of the model mesh. The mesh is composed by

a combination of 3D, 2D and 1D elements. Details on the model are included in [1].

The model was calibrated based on the present situation taking into account the estimated infiltrations rates and measured sources of thermal water. The major aim of the model is to assess the possibility to increase water consumption by the drilling of an abstraction well. The model simulates different scenarios of water abstraction from the well situated about 1 km from the existing springs.

Results of the simulation show significant consequences of water abstraction from the new well. Discharge of exiting springs would be reduced and infiltration ratio in the Chimu outcrop would be increased. In the case of 100 l/s of water being abstracted, the spring water discharge would be

reduced to 1/3 of the present amount. An increase of the discharged water in the springs would have a subsequent negative effect in increasing mixing of thermal water with shallow groundwater and therefore an influence on the resulting spring water quality and temperature. From all these aspects, the maximum extracted volume in the well should not exceed 15-20 l/s, which is sufficient to supply a newly planned spa complex. Additionally, better water management of existing springs would spare this water quantity by reducing the existing consumption.

2.5 Socio-Economic and Cultural Assessment

Assessments of socio-economic and cultural factors are made to eliminate the any negative impacts of the prepared project on the region. The district of Baños del Inca has an area of 33 317 km² and 277 443 inhabitants.

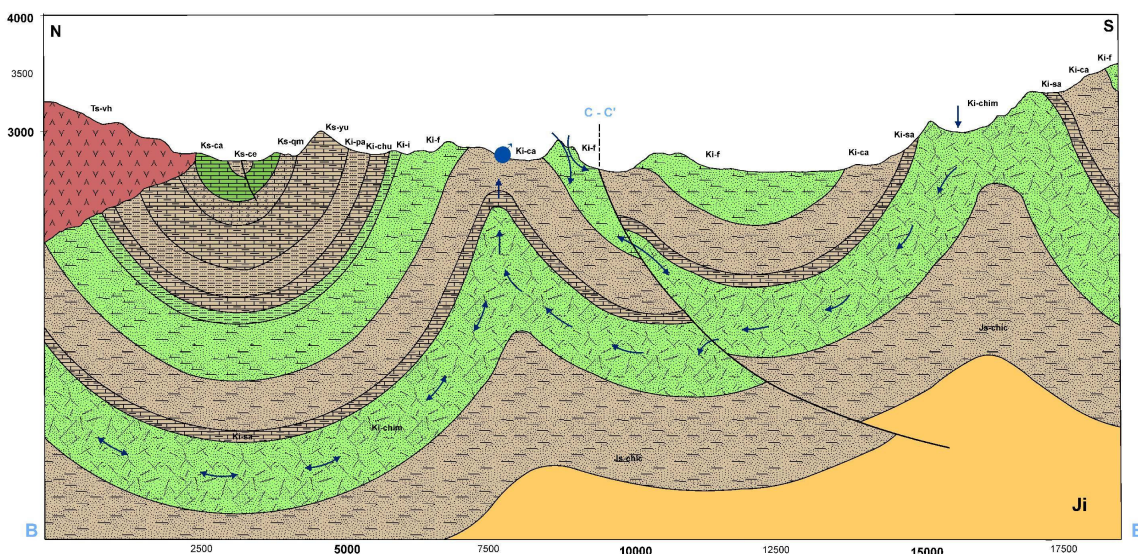


Figure 2: Hydrogeological profile of Cajamarca basin.

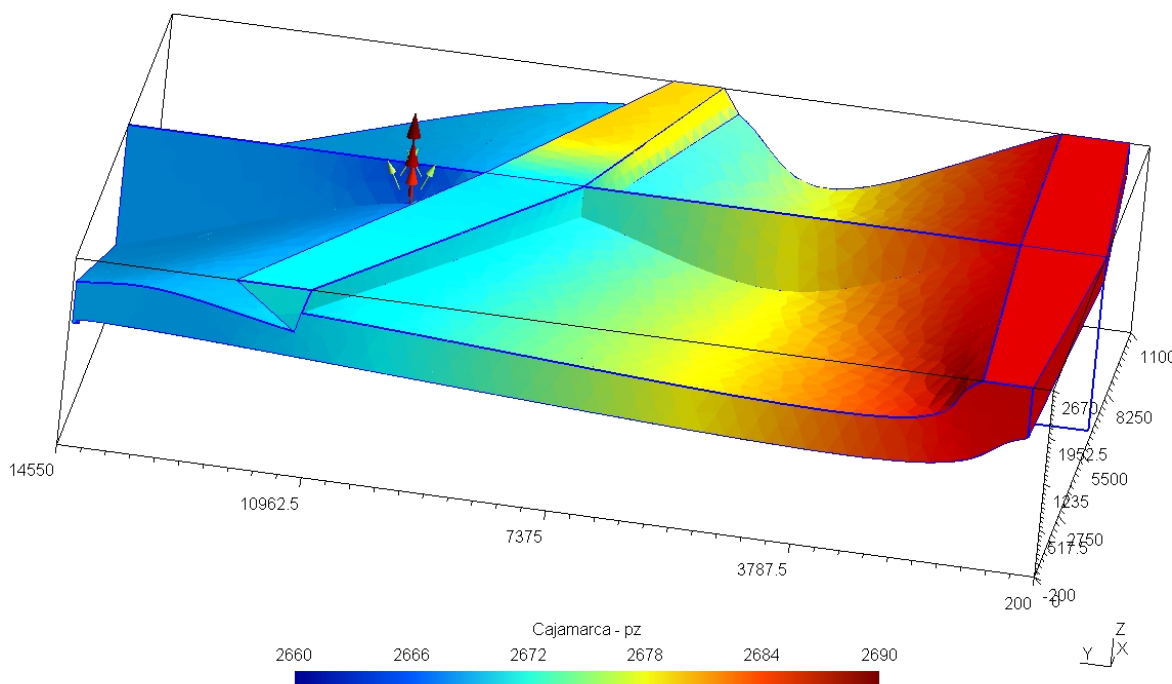


Figure 3: Distribution of piezometer heads for resulting simulation (in meters).

The project would improve the infrastructure (road connections, potential of new services connected with the balneology complex, increase in local product sale) and increase in the employment rate due to the new work opportunities. The need for qualified labor would improve education standards in the region and consequently labor costs. Guests at the balneology complex would also bring a significant amount of money, which would be spent in the region. Close cooperation between the facility owners and the local authorities is required for successful completion of the project and launching of related activities (tourist routes, airport reconstruction, publicity, maintenance services) including management and protection of the springs and thermal water resources.

During the planning stage the local authorities should aid in the acquisition (purchase) of land for the thermal bath complex and in declaration of spring protection zones, which are yet to exist. These zones should be laid out based on the present study (geological, hydrogeological and social-economic parameters).

2.6 Environmental Protection

For qualified management of the springs (and wells), and the spa complex, issues of environmental protection should be addressed. From the point of view of environmental protection the project has the following issues:

- program of precautionary measures for elimination of direct and indirect impacts to environment (technical, economical and social measures),
- monitoring program (periodic evaluation of selected components of environment including socio-economic and cultural indicators) with the

aim to provide objective and actual information for the authorities,

- program of training and education of employees in environmental protection (workshops, information leaflets, banners, audio-visual devices),
- procedures to correct damages with the aim to remedy them to a stage which is better than before the damage, in the case of environmental deterioration.

3. RESULTS AND CONCLUSIONS

The project "Development and protection of geothermal and mineral water sources in Peru" proved the feasibility of balneology complex developments in Baños del Inca (Cajamarca) and Churín. The complexes would provide economical profitable services for national and international customers mainly in balneology but also wellness and sport. Both sites have significant thermal resources and have been used for thermal bathing for many centuries. These renewable sources have to be protected and preserved for water quantity and quality and protection zones should be declared. For this, geological, climatological and hydrogeological data have to be assessed using a conceptual mathematical model. If the data permits it, alternative water management scenarios could be evaluated by a numerical model.

REFERENCES

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