Hydrogeological Assessment for the Use of Groundwater in the Subcatchment Lauricocha, Huanuco, Peru

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ABSTRACT

The Geological, Mining and Metallurgical Institute – scientific and technical institute which belongs to the Energy and Mines Ministry-makes studies to find and propose of new sources of drinking water supply for local people established in the surrounding of mining projects. The hydrogeology studies consist in investigation and evaluation of backdrop level and situational diagnostic of the aquifer, through an intense field trip campaign and representative network of water sampling.

The place of study is the Lauricocha micro-basin, which presents an area of 173.4 km2, between 3,893 and 5,593 meters, located in Huánuco region. This micro-basin extends transversely to the morph-structural dominium of Occidental Mountain in the Andes.

The hydrogeology mapping was developed in June and July of 2013. This consisted in the characterization of the geological formations, identification of aquifers, inventory of 85 springs, evaluation of the condition of discharge, taking of hydraulic and physic-chemistry parameters and the water sampling of 39 springs. The water quality analysis has the objective to know the chemistry composition and the interaction of groundwater and rocks in the surrounding.

The hydrochemistry showed that the water has an ionic predominance of calcic bicarbonate water, of local flow, young water considered for its short pathway of transit contact time between the soil and rocks. The quality of the water was contrasted with the Peruvian guidelines of water quality (as referential), given 11 springs that overcame the values of aluminum, arsenic, iron, manganese, lead, antimony and cobalt. The analysis of flows showed a total discharge of 499.30 L/seg in the sum of springs.

The evaluations allowed selecting 13 ideal springs that was proposed as future direct spring catchments, being part of the drinking water system for the local communities. Finally, this proposal could help to solve the concern of the communities about the alternative sources of drinking water.

INTRODUCTION

The zone of the study was Lauricocha sub catchment, located in the department of Huanuco, Peru. The objective was to develop the hydrogeological characterization and to provide new water sources for drinking water and agriculture use in a zone with mining activity. A secondary objective was to provide new alternative for water sources for the lack of water quality in order to avoid social conflicts.

The study surged as a request from the local communities, who were concerned about a possible mining pollution of their water sources because the exploitation activities of the Raura mining company. During the public consultation conducted by public Peruvian institutions the water resource was determined as a serious concern for the health and environment, consequently this research conducted the geological and hydrogeological assessments, that included hydrogeological characterization, hydrochemistry, analysis of groundwater and developing plans to use the groundwater as water supply.

DESCRIPTION OF THE ZONE OF STUDY

LOCATION

The area of study is located in the district of San Miguel de Cauri, Province of Lauricocha and department of Huánuco in Peru. The water drainage is defined by three sectors, the main drainage comes from tributary lakes: Nieve Ucro; Caballococha; Santa Ana; Niño Cocha; Niño Perdido and Tinquicocha (where the area of influence is located in Raura mining company).The others two water drainage sectors have a series of interconnected lakes breaking through the Jaico and Chaucas stream, these three networks of surface waters join together at Antacallanca river forming the river that flows into the lagoon Lauricocha (ANA, 2014).

The Lauricocha sub catchment has an area of 173.4 km^2, and the elevation is between 3893 (Lauricocha lake) and 5593 meters (Raura mining company level).

The study area has a cold climate, typical of the Sierra region (highlands). There are two well-defined seasons in the year, winter and summer. The average temperature reaches between below 0 to 11 ° C. The rainy season occurs between November to March months, although sporadically in September to October, the other months are usually cold and dry, distinguishing cold in June and July (**Figure 1**).

The vegetation usually consists of ichus and pastures, and due to cold weather; the animal husbandry (goats and llamas) is the most important activity.

Figure 1 Extremely cold weather, to laguna Caballococha and population center Raura (north view).

GEOMORPHOLOGY AND PHYSIOGRAPHY

The study area has moderate to abrupt slopes, as a result of glacial and fluvioglacial modeling processes in stable natural conditions. It is extended transversely to the morphological -structural domains of the western Andes, evidencing variable topography, from moderate to abrupt. This peculiar landscape is the result of different erosion processes associated with the uplift of the Andes beginning in the Miocene, and later covered by the volcanic deposits from upper tertiary and quaternary; forming the mountains, plateaus and valleys terrains (Romani, 1983; Jaillard, 1986; Cobbing, 1996; Angeles, 2004; Uribe, 2012)

The watershed consists of wetlands and streams which contribute to the major rivers, valleys and glacial cirques, varying the elevations between 3800 to 4600 meters, and active glaciers with 5700 meters. Due to the deglaciation process and rains, there were formed staggered lagoons; also, by the process of denudation and erosion there is extensive areas covered with moraine material. The common drainage collector of the watershed is Lauricocha lake, which is surrounded by eastern foothills of the Occidental Andean. The altitude lake is 3900 meters in Raura mountain, with an approximately length of 7 km., wide of 1.5 km., deep of 75 m and a total area of 160.7 km^2 (ANA, 2014).

METHODOLOGY

The investigation was developed in three stages: two in office and one in field. The first stage was in office corresponding to the planning and coordination with the table of dialog, authorities from the Huanuco regional government and Raura mining company, further, the were made the recompilation of information and elaboration of maps of field work. The second stage, was the hydrogeological mapping, where were collected the major quantity of information and samples, which allowed to develop a situational diagnostic of Lauricocha Sub catchment. The third stage, the office, it was elaborated the hydrogeological characterization, the database of source inventory, the interpretation of chemistry results and the elaboration of thematic maps focusing in the proposals of intervention.

RESULTS

HIDROGEOLOGICAL DESCRIPTION

Considering the geological mapping at 1:25 000 scale, where it is zoned the main types of rocks, soils and structures (faults, fractures and joints that influences the groundwater percolation), giving importance to lithology (Figure 02). The hydrogeological mapping, characterized each geological formation, differentiating their permeable and impermeable properties and zoning rocks reservoirs with their capacity to store and transmit groundwater, called aquifers. In the field trip was developed seven specific Lefrance permeability tests for fissured aquifers, these tests helped to obtain a hydrogeological correspondence through hydraulic conductivity (Custodio, 1983).

The hydrogeological characterization considered as basic information the geological mapping, with a lithological and structural analysis, the permeability tests and the inventory of sources, identifying the upwelling of groundwater, with their respective discharge conditions and physicochemical properties (Table 1). This characterization served to prepare the hydrogeological map, zoning rocks and soil conditions with storage characteristics and movement of groundwater, as well as rocks and soils with waterproof properties.

Figure 2 Outcrop of carbonated layered folds of those members 3 (a) and 4 (b) Jumasha geological formation, located in the southeast of the Añaspampa Lake.

Table 1 Hydrogeological classification of geologic units

Geological Formation / unit		Simbology	Hydrogeological Formation
Colluvial Deposits		Q-co	sedimentary aquitard
Alluvial Deposits		Q-al	unconsolidated porous aquifer
Fluvioglacial Deposits		Q-fg	unconsolidated porous aquifer
Moraine Deposits		Q-mo	unconsolidated porous aquifer
Calipuy Group	Volcanic Rocks	Nm-ca	volcanic aquitard
Casapalca Formation		KsP-ca	sedimentary aquitard
Celendín Formation		Ks-ce	Fissured sedimentary aquifer
Jumasha Formation		Ks-ju5	Fissured sedimentary aquifer

		Ks-ju4	Fissured sedimentary aquifer
		Ks-ju3	Fissured sedimentary aquifer
		Ks-ju1/ju2	Fissured sedimentary aquifer
Pariahuanca Chulec y Pariatambo Formations		Ki-phchpt	sedimentary aquitard
Goyllarisquizga Group	Santa Carhuaz Formations	Ki-saca	sedimentary aquitard
	Chimú Formations	Ki-ch	Fissured sedimentary aquifer
Intrusive Rocks		Nm-to	intrusive aquitard
		Nm-mz	
		Nm-gd	
Subvolcanic Rocks		Nm-da	sub volcanic Aquitard

HYDROCHEMISTRY AND ANALYSIS OF GROUNDWATER QUALITY

The fieldwork was conducted from 24th June to 8th July, 2013. It was recorded the groundwater discharge generally of low flow, although there were found sporadic sources with considerable flows, these discharges corresponded to dry season , ideal for identify the true flow from aquifers (Custodio, 1982).

There were inventoried 85 sources (74 springs, 4 captured springs, 4 control points and 3 piezometers), as manifestations of the presence of groundwater reservoir in the subsurface that outcrop at surface. These sources arised mostly conditioned by structures such as faults and fractures within limestones from the Jumasha and Celendin geological formations; in other sectors the impermeable rocks and covering unconsolidated materials are material of upwelling conditions.

Considering the flow, lithology, font type and physicochemical parameters, 39 sources were selected for sampling in order to know their chemical composition, the possible geochemical source, the interaction of groundwater with the surrounding materials and the analysis for reference purposes comparing the results with environmental water quality standards: “Waters that can be treat drinking with disinfection” (ECA – A1) and "Water for irrigation and animal waterer (ECA-A3)", which were applied to assess surface water. It is important to mention that Peru does not have standards for groundwater; however, according to the latest water law and its regulations, there is a standard refereed to the springs considering these as points or outcropping areas of groundwater and shall be considered as surface waters for the purposes of evaluation (Class I). Consequently, with the objective to assess the water quality the results of groundwater were contrasted with these two guidelines ECA-A1, ECA-A3 and Class I.

In the analysis of the physicochemical parameters, the sources had values of low temperatures with a neutral pH value, which lie between the limits of 6.5 to 8.5, for Class I, when compared referentially with environmental quality standards, only 2 points had a slight tendency to pH basic. The Huascacocha control point (4989991-018), pH = 8.61, and Jaico 2 (4989991-044) spring that had pH = 8.57, this lightweight trend is due to the presence of limestone outcrops, which provide calcium concentrations in groundwater, which controlled the processes of precipitation and dissolution in the carbonate - bicarbonate system.

In this evaluation was observed that 98% of conductivity in the inventoried sources, are between 150 and 500 mS /cm, below the standard limit (ECA A3= 2000 µS/cm and Class I= 1500 µS /cm) except the piezometer 02 (4989991-085) whose value reaches 2673 µS / cm. This high electrical conductivity value is attributed to the geological factor, the percolated water had contact with altered sedimentary rocks (limestones and volcanic) containing mineralization and the presence of carbonates, since this source is located very close to the mineralized zone, which contributes to increasing sales.

The analysis of total metal, based on the results of the sampled sources, selected and evaluated the concentrations of the major ionic components in groundwater, as cations (Ca, Mg, Na and K) and anions (carbonates, bicarbonates, sulfates and chlorides), allowing the geochemical analysis of sources represented by Stiff diagrams, which are displayed on the hydrochemical map (Figure 03).

The diagrams showed the main chemical characteristics of water, facilitating their classification according to their ionic predominance. As a result the water was characterized as calcium bicarbonate type (HCO3-Ca), distinguishing three groups of graphics, differing in the ranks of their limit values (2, 4 and 6 meq / L, represented in diagrams of yellow, orange and red color respectively on the map), which indicates the proportional change in chemical concentrations, which are interpreted as shallow water infiltration and short haul.

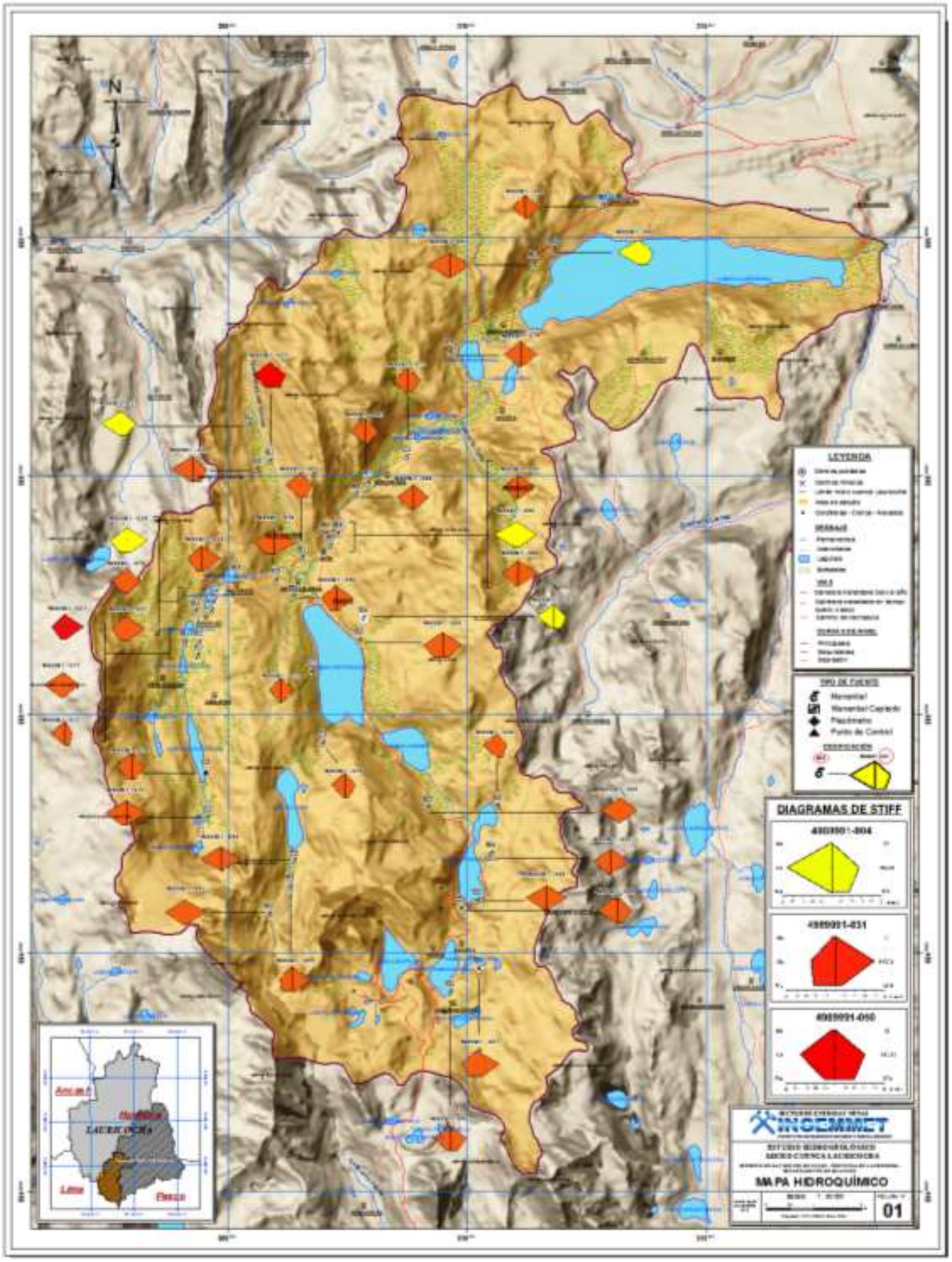

Figure 3: Hydrochemical map Lauricocha watershed.

Figures 4, 5 and 6 showed diagrams of Piper and Scatter for 3 sample groups in the upper, middle and lower zone respectively. The graphs gathered the sampled sources, 11 in the top part (Figure 4), 14 in the middle part (Figure 5) and 12 in the lower part (Figure 6) of the subcatchment.

Piper diagrams showed that water sources are within the calcium bicarbonate facies; further Scatter diagrams showed that the waters belong to a local stream, considered young short path water, with a transient contact time with the soil and rocks of the study area.

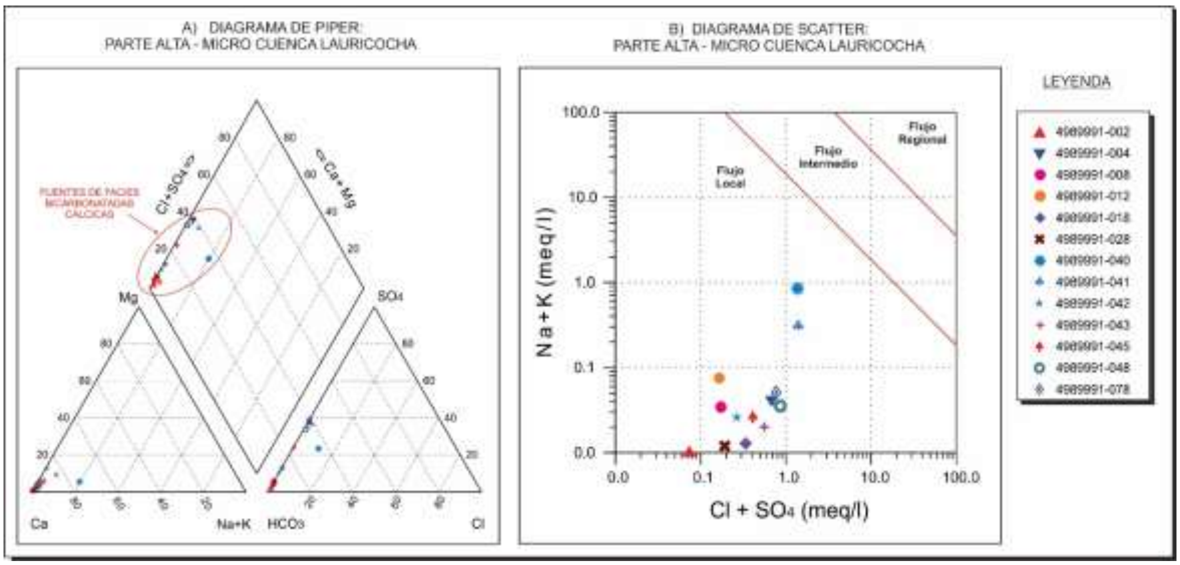

Figure 4: Scatter and Piper diagram for groundwater sources located on the top of the Lauricocha Subcatchment.

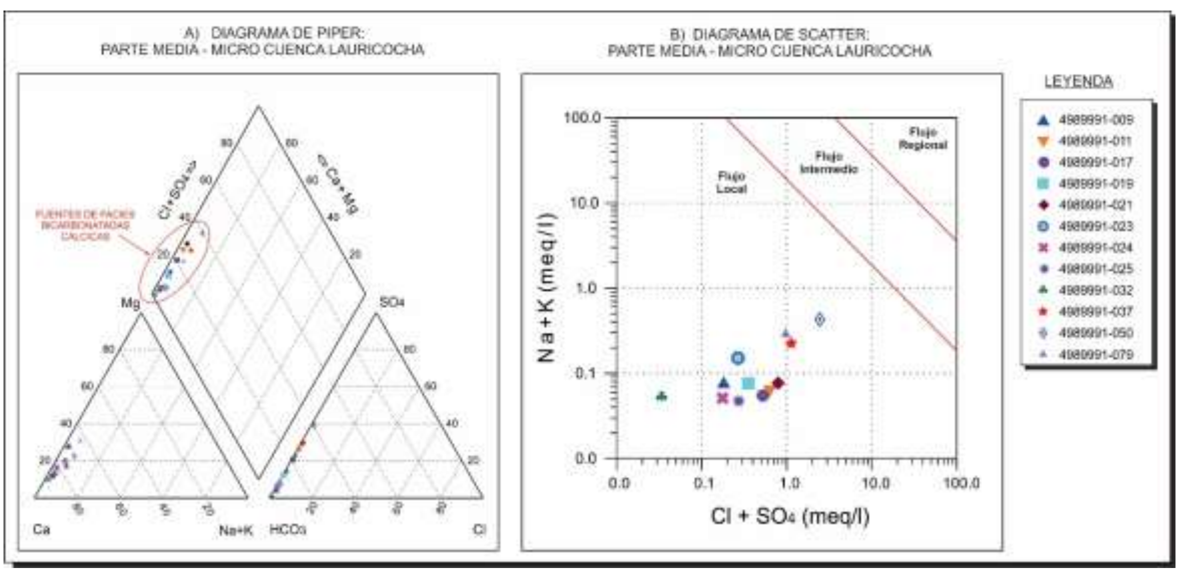

Figure 5: Piper and Scatter diagram for groundwater sources located in the middle of the Lauricocha Subcatchment.

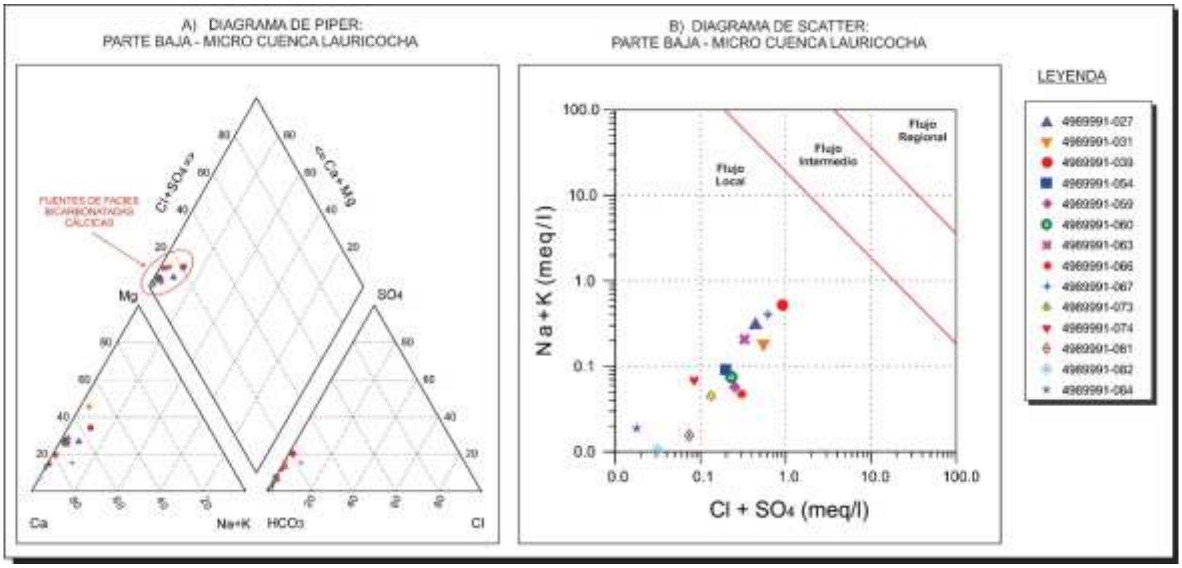

Figure 6: Piper and Scatter diagram for groundwater sources located in the lower part of the Lauricocha Sub catchment.

The quality analysis, considering the most important total metals, compared referentially with ECA-A1 and ECA-A3, was detected 11 sources with values that exceeded the limits of the standards, being 9 springs and 2 piezometers. Metals in exceeding the ECA -A1 and ECA-A3 varied at least on one of the elements of aluminum, arsenic, iron, manganese, lead, antimony or cobalt.

The variations of metals in the springs, are because the groundwater flows were in contact with the reservoir, where is located the mineralized zone. In case of the piezometers, which have greater variation in the elements, the sources must represent groundwater in depth, not emerge to the surface, which are removed by suction, which has more residence time in the basement area and influenced by polymetallic deposit with pyrite and chalcopyrite mineralization, and in contact with oxygen that can generateacidity (Custodio, 1982).

Table 2 shows the groundwater sources variation with the ECAs, the shaded cells with different colors indicating exceedances, according to the category or subcategory.

Table 2 Summary of elements of groundwater sources exceeding environmental quality standards (RCT) in the Sub catchment Lauricocha.

RCTs			ECA-A1																ECA-A3						
N°	CODE / SIMBOL		A1						A2					A3				BA			RV			
			Al	As	Fe	Mn	Pb	Sb	Al	As	Mn	Pb	Sb	Al	As	Pb	Sb	As	Mn	Pb	As	Co	Mn	Pb
1	4989991-004																							
2	4989991-008																							
3	4989991-011																							
4	4989991-017																							
5	4989991-019																							
6	4989991-021																							
7	4989991-023																							
8	4989991-043																							

9	4989991-045	♂																						
10	4989991-040	⌖																						
11	4989991-041	⌖																						

CATEGORY 1 : POPULATION AND RECREATION, WATER TO ENCOURAGE THE PRODUCTION OF DRINKING WATER	RCT 1 - A1 : Waters can be potabilized with disinfection.
	RCT 1 - A2 : Waters can be potabilized with conventional treatment.
	RCT 1 - A3 : Waters can be potabilized with advanced treatment.
CATEGORY 3 : IRRIGATION AND ANIMAL WATERER	RCT 3 - BA : animal waterer
	RCT 3 - RV : Irrigation
♂ Springs	⌖ Piezometers

Table 2, It is used for ECAs in category 1, considering the subcategories A1 (Waters can be drinking water with disinfection), A2 (Waters can be drinking water with conventional treatment) and A3 (Waters can be drinking water with advanced treatment); and, in the case of category 3 it was analyzed separately for animal waterer (BA) and irrigation (RV).

Eight springs (4989991-008, 4989991-011, 4989991-017, 4989991-019, 4989991-021, 4989991-023, 4989991-043, 4989991-045) showed exceedances for aluminum, arsenic and iron, to ECA-A 1, either in the three subcategories (A1, A2 and A3), at least one element. The spring 4989991-004 (Jurahupampa 2) exceeded the limit for cobalt (0.128 mg/l) for irrigation, ECA-A3.

At the end of the table, we could locate the 02 piezometers (4989991-040 and 4989991-041, the same with variations in ECAs, for aluminum, arsenic, iron, manganese, lead and antimony, surpassing all the categories.

CONCLUSION

Finally, after the hydrogeological diagnosis, the intervention proposals on groundwater resources were developed, finding new sources of water for human and irrigation use, this source selection was based on defined technical criteria, based on the inventory map sources, hydrogeological characterization of rocks, evaluation of flows, supplemented with hydrochemical analysis of the main sources, evaluation of water quality and the spatial distribution of the sources, considering also the proximity of population centers.

The evaluation of flow was performed considering only sampled sources, this group did not consider the sources that where upper of the environmental standards, classifying a total of 27 springs, same that in total sum a discharge flow rate of 281.00 L / seg.

Under the criteria to capture in areas near populations, and its potential in the flow, 13 springs were classified for direct uptake, five were qualified as 1 priority, benefiting the communities of Raura and Antacallanca, eight as 2 priority, located near to homes scattered in the watershed.

For the direct uptake should apply a water system consisting of the direct feedback from the spring, including works by spoilers, line pipe, storage reservoir, intake pipe and domestic distribution system water. (Figures 7 and 8).

One of the selected sources is the Shuplamachay 1, 4989991-067, considered as the most important because of its constant flow throughout the year, approximately 80 L/seg.

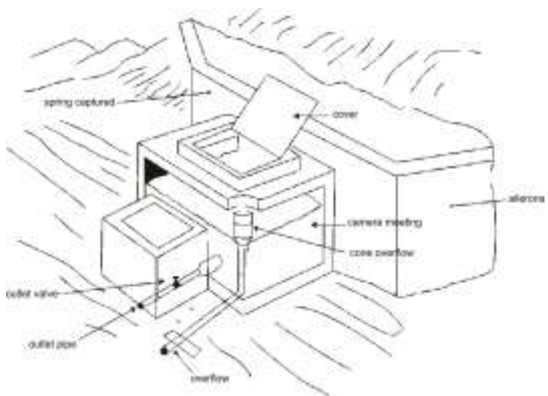

Figure 7 Design canvassing springs by spoilers, this design can be applied to all selected springs of the watershed; the measures will be applied according to the production rate of the spring

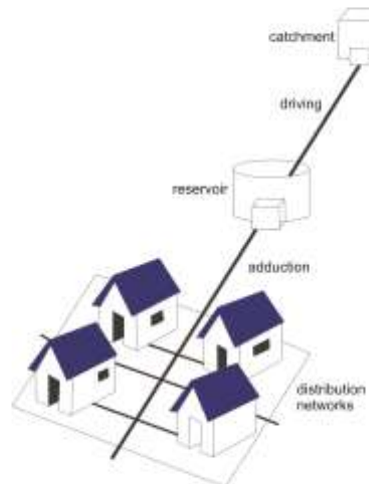

Figure 8 Design of water host for consumption, from catchment in the spring, the pipe line to the reservoir and adduction home before connecting major population centers located in the Sub catchment Lauricocha.

Figure 9 Shuplamachay one spring with 80 l / s flow, considered as the most important for their use and recruitment

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