Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Water Quality of the Victoria River Basin in the Pailas Geothermal Field, Guanacaste, Costa Rica (2007-2008)

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Keywords: Water Quality, Geothermal Field, Curubande, Pailas, Victoria Basin, co-management, surface water.

ABSTRACT

Water quality of the Victoria River basin, located in the Pailas Geothermal Field, Guanacaste, Costa Rica, was evaluated during the dry, rainy and dry-rainy seasons of 2007-2008. A total of 15 sites, from the spring to the drinking water extraction area Curubande were, sampled and analyzed for their bacteriological and physicochemical characterization, which can be used as a baseline for monitoring the environmental impact of geothermal fluids on surface water in the basin. Point and non-point sources of contamination were identified and related to water quality parameters and indices. Water of the Victoria River was found to be adequate for drinking after treatment and disinfection. Statistical analysis of the data showed significant differences in color, turbidity, silica, fecal coliforms and *Escherichia coli* during the three sampling periods. The major effect on the water quality was runoff from pasture areas and soil discharges, which were provoked by erosion and the slope of the river banks. A co-management action plan was elaborated in conjunction with local communities and government authorities according to the results generated in this research. The plan is made up from four components, which include activities addressed towards the main problems of the basin; it was delivered to the local stakeholders concerned with water resources and environmental management.

1. INTRODUCTION

Water is essential for life and ecosystems. All water contains natural contaminants, particularly inorganic contaminants that arise from the geological strata through which the water flows and, to a varying extent, anthropogenic pollution by both microorganisms and chemicals (Fawell et al., 2005). Globally, more than two million annual deaths are due to diarrhea related diseases, which can be attributed to water sanitation and hygiene risk factors, 90 percent of them among children under five (UNESCO, 2003).

The contamination of drinking water by pathogens causing diarrhea related diseases is the most important aspect of drinking water quality. This problem arises as a consequence of contamination of water by fecal matter, particularly human fecal matter, containing pathogenic organisms (Fawell et al., 2005). Microorganisms such as *Shigella* and *S. flexnneri*, were identified in drinking water during the outbreaks of diarrhea in Costa Rica in 1999 and 2001 (Valiente et al., 2002).

Chemical water quality is partly responsible for the ill-health related to drinking water supply (UNESCO, 2003). These chemicals include inorganic compounds such as fluoride and boron, which may either occur naturally in aquifers used for drinking water or in spills from geothermal fluids.

“Rincon de la Vieja” is the only active volcano in the Guanacaste Volcanic Range. Its Crater Lake temperature is 39ºC (Kempter et al., 2000). High-flux fumaroles were observed in the southern inner flank of the active crater, whose western outer were the majority of the thermal emissions, including Pailas, Borinquen, Azufrales and Santa Maria (Tassi et al., 2005). At the south-western part of the volcano is located the Victoria River and the Pailas geothermal field, which is being developed by the Costa Rican Electricity Institute (ICE, for its acronym in Spanish) since 2007.

The environmental issues involved in geothermal development include surface disturbances, physical effects of fluids withdrawal, noise, thermal effects, chemical pollution, biological effects and the protection of natural resources (Kristmannsdóttir et al., 2003; Dogdu et al., 2005; Simsek et al., 2005). The directly influenced area of the Pailas geothermal field is the Victoria River, whose surface water is used for drinking by Curubande people.

Surface water is vulnerable to pollution, which may occur through point and non-point sources. Examples of point source pollution are effluents from industry, sewage-treatment plants and untreated domestic sewage. The main sources of diffuse sources may be anthropogenic activities, such as applications of agricultural fertilizers or geo-chemical origin, such as natural contamination of groundwater by fluoride and dissolved salts (Rao et al., 2004). Although there are no known cases of either chemical intoxication or epidemic of diarrheas in Curubande (ICE, 2005), an exhaustive evaluation of the quality of drinking water provides a quantitative baseline to elaborate a co-management action plan for improving and monitoring water resources in the basin.

2. MATERIALS AND METHODS

2.1 Study Area

The Victoria River basin is located at the south-western area of the Rincon de la Vieja and Santa Maria volcanic complex, between Lambert coordinates 3850000 N. Long., 307000 W. Lat. (Figure 1). The Victoria basin, which has an area of 4.14 km^2, drains towards the Colorado River and then to the Tempisque River in the Pacific Ocean. The Victoria River basin elevation ranges from 460 to 840 m above sea level.

The Pailas geothermal field is located in the medium and upper Victoria basin. Its reservoir has temperatures from 205 to 250ºC and its geothermal fluids are characterized as the sodium chloride type (Chavarria et al., 2006). The

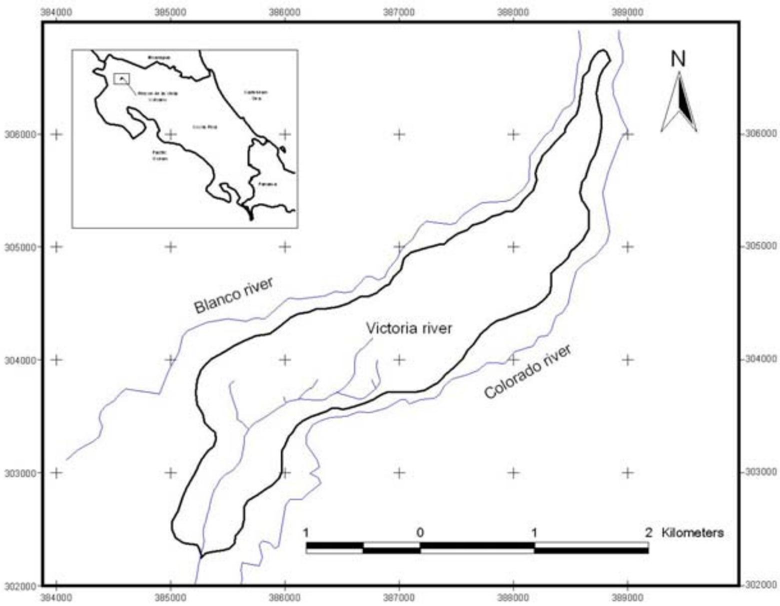

Figure 1: Location of the Victoria River basin, Guanacaste, Costa Rica, Central America.

directly and indirectly influenced areas of Las Pailas geothermal field are the Victoria River and the village of Curubande, respectively. A drinking water extraction area for Curubande is located in the lower basin of the Victoria River. Six springs discharge their water into this area. Curubande lies four kilometers south-western from the Victoria River and has a population of 1812 people (INEC, 2002). There is a school, a church, a park, a few groceries and some restaurants (ICE, 2005).

Victoria basin´s relative humidity is 75 to 82%. Its annual temperature is 24ºC. From 2002 to 2008, its mean annual precipitation was 2528 mm with annual variations from 1600 to 4100 mm (ICE, 2005).

2.2 Site Selection

Sampling sites were selected after a preliminary reconnaissance survey in October 2006 and February 2007. A total of 15 samples sites located in the Victoria River basin composed the monitoring network (Figure 2).

2.3 Sampling and Analysis

Sampling and analysis were carried out following procedures of Standard Methods (Eaton et al., 2005) and IAEA (2003). Sampling was carried out during the rainy season (September 11 and November 6, 2007), the dry season (January 29 and February 26, 2008) and the dry-rainy transition (June 3, 2008).

2.3.1 Collection of Samples

Temperature, pH and electrical conductivity were measured *in situ* using portable meter (WTW 330i). Flow was recorded within 48 hours after collecting samples using a hydrometer (Seba D-87600, Kaufbeuren F1 2169).

Samples for physicochemical and bacteriological analysis were collected from downstream to upstream. Samples for bacteriological analysis were stored at 4ºC. Samples were treated according to the type of analysis: 100 mL were fixed with manganese basic solution immediately after collection to test for dissolved oxygen; 100 mL were acidified with nitric acid (50% V/V) for detection of metals; 100 mL were acidified with hydrochloric acid (50% V/V) and stored in a dark bottle for ammonium analysis; 100 mL were stored in a borosilicate bottle for bicarbonate analysis; 2 L were degassed and stored at 4ºC for a five-day biochemical oxygen demand test; 500 mL for HPLC chromatography and remnant analysis; and 500 mL for storage as a control.

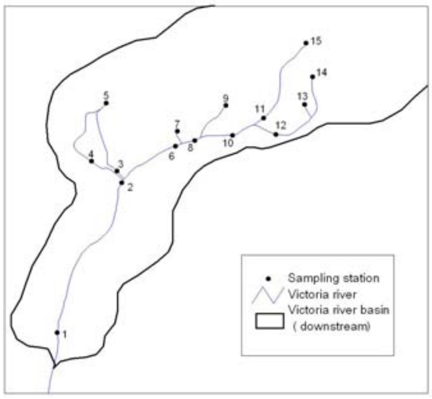

Figure 2: Sampling sites of the Victoria River basin, Guanacaste, Costa Rica. Sampling station 1: drinking water extraction area for Curubande, sampling station 15: spring of the river.

Bacteriological samples were sent to the Costa Rican Aqueducts and Sewers Institute (AyA, for its abbreviation in Spanish) within 24 hours, whereas physicochemical samples were sent to the Geochemistry Laboratory of the Costa Rican Electricity Institute.

2.3.2 Sample Analysis

Fecal coliforms and *Escherichia coli* were analyzed using the Most Probable Number method and *Salmonella* with the API-20E identification system. Samples for metal analysis (sodium, potassium, magnesium and silicon) were filtered and the filtrate analyzed using the flame absorption spectrometry (Thermo Solaar 600). Nitrite, nitrate, phosphate, chloride and sulfate were analyzed using the HPLC techniques (Agilent Hp1100). Ammonium and fluoride were determined with ion selective electrodes, boron and iron with spectrophotometry (Thermo Evolution 600), bicarbonate by volumetric titrimetry, total dissolved solids with gravimetry and dissolved oxygen and five-day biochemical oxygen demand with the Winkler method (Eaton et al., 2005).

2.4 Sources of Contamination

Point sources of contamination were registered with a global positioning system (Garmin 12XL) through systematic observation from the lower to the upper basin. Non-point sources of contamination were determined by a geographic information system (Arcview 3.3, ESRI, 2002) combined with verification in the field.

2.5 Co-management Action Plan

Members of Integrated Development Association, Aqueducts and Sewers Administrator (ASADA, for its abbreviation in Spanish), the School of Curubande, local government and the Environmental Management Department of the ICE were identified as the local stakeholders.

Three activities were carried out at the Curubande Lodge in order to elaborate the plan: an Open Meeting (November 28, 2007) for presenting the goal of the study; a participated meeting (August 7, 2008) with stakeholders in which the results of the evaluation of the water quality of Victoria River were discussed in order to obtain their suggestions; and a final Open Meeting (September 3, 2008) for validating the co-management action plan, which was delivered to the participants.

3. RESULTS AND DISCUSSIONS

Data of samples were analyzed to characterize the water of the Victoria River in order to provide a quantitative baseline for defining the co-management action plan in the basin.

3.1 Composition and Analysis of Water Samples

Physicochemical and bacteriological data of water of the Victoria River during the three sampling periods are listed in Table 1.

The physical composition of the Victoria River samples were characterized as lightly acidic (annual mean pH of 5.67, 3.85-7.51 range); an annual mean temperature of 25ºC (22.5-27.3ºC range); an annual mean electrical conductivity of 217.5 µS/cm (87.5-285 µS/cm range); and an annual mean total dissolved solids of 213 mg/L (120-268 mg/L range).

According to the Ludwing Langelier diagram analysis, Victoria River water has the following geochemical facies during the dry season: calcium-sulfate (stations: 3, 4, 5 and 7), calcium-magnesium sulfate (stations: 1, 2, 6, 8, 9, 10 and 11), calcium-magnesium-sulfate-bicarbonate (station 13), calcium-magnesium-bicarbonate-sulfate (station 15), calcium-magnesium-sodium-sulfate-bicarbonate-chloride (station12) and calcium-magnesium-sodium-bicarbonate-sulfate (station 14) types. In addition, geothermal wells (number 1 and 3) have sodium-chloride types (Figure 3).

According to the Kruskall-Wallis test (Table 2), data of samples (n=75) showed significant differences ($p<0.05$) in five parameters: color, turbidity, silica, fecal coliforms and *Escherichia coli*, during the three sampling periods.

Table 1: Physicochemical and bacteriological composition of water of the Victoria River basin, Costa Rica, 2007-2008.

Parameter	Season		
	Rainy 2007	Dry 2008	Dry-rainy 2008
T (±0.1ºC)	24.9	25.1	24.7
pH (±0.01)	5.70	5.54	5.63
Cond. (±1 µS/cm)	203	208	229
Color (±1 Pt-Co)	2	1	5
Turbidity (±0.01 NTU)	3.39	1.72	7.38
TDS (±8 mg/L)	209	214	219
DO (±1%)	83	87	83
DBO_5 (mg/L)	<2	<2	<2
NO_2^--N (mg/L)	<0.09	<0.09	<0.09
NO_3^--N (±0.01 mg/L)	0.29	0.43	0.39
NH_4^+-N (mg/L)	<0.08	<0.08	<0.08
PO_4^{3-}-P (mg/L)	<0.09	<0.09	<0.09
Na^+ (±0.04 mg/L)	8.30	8.00	8.40
K^+ (±0.1 mg/L)	2.9	2.9	3.0
Ca^{2+} (±0.5 mg/L)	18.0	19.7	18.6
Mg^{2+} (±0.2 mg/L)	5.5	5.5	5.4
Fe (mg/L)	<0.07	<0.07	<0.07
HCO_3^- (±1 mg/L)	16	15	13
Cl^- (±0.1 mg/L)	10.7	10.1	11.1
SO_4^{2-} (±1 mg/L)	63	69	72
F^- (±0.01 mg/L)	0.34	0.29	0.25
B (±0.07 mg/L)	0.11	0.18	0.11
SiO_2 (±2 mg/L)	77	83	79
CF (MPN/100 mL)	380	253	691
E.coli (MPN/100 mL)	210	245	679
Salmonella	Absent	Absent	Absent
Flow (m^3/s)	0.231	0.118	0.167

*Cond.: conductivity; TDS: total dissolved solids; DO: dissolved oxygen; FC: fecal coliforms; results as mean of parameter of all stations (from 1 to 15).

Annual mean color of the Victoria River water was 2 Pt-Co with a minimum of 0 Pt-Co at springs (stations 5, 7, 13 and 15) and a maximum of 30 Pt-Co (station 14 during the dry-rainy season). Turbidity of this water showed a similar trend: annual mean of 3.52 NTU with a minimum of 0.05 NTU and a maximum of 31.50 NTU at the same stations.

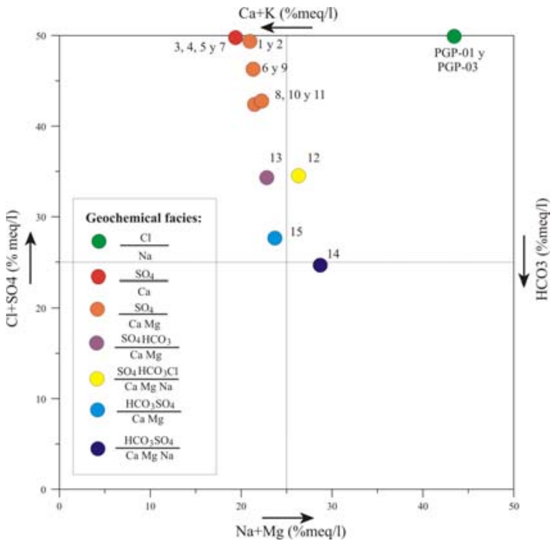

Figure 3: Ludwing Langelier diagram of the Victoria River water during dry season 2008 and geothermal wells in the Pailas geothermal field, Guanacaste, Costa Rica. Sampling stations from 1 to 15; PGP: number of geothermal well.

Table 2: Results of Kruskall-Wallis test.

Parameter	p-value
T	0.2045
pH	0.6275
Cond.	0.0635
Color	0.0335
Turbidity	0.0084
TDS	0.4430
DO	0.0450
Na^+	0.2225
K^+	0.5128
Ca^{2+}	0.0670
Mg^{2+}	0.9575
HCO_3^-	0.9694
Cl^-	0.2620
SO_4^{2-}	0.3745
F^-	0.2896
SiO_2	0.0001
CF	0.0414
E.coli	0.0328
Flow	0.0596

*n=75; calculations obtained with InfoStat (Universidad Nacional de Córdoba, 2002)

The content of silicate matter as silica in the water was characterized by an annual mean of 79 mg/L (65-91 mg/L range). Silica is a common compound of some aquatic plants such as diatomea, which captures and liberates it when decomposing (Chapman, 1996). During the dry-rainy transition season a strong increase of fecal coliforms and *Escherichia coli* was found (Table 1). Bacteria concentrations and water quality variables are associated. Oliver et al. (2005) have found a correlation between *Escherichia coli* and turbidity and flow. They concluded that *E. coli* is physically mobilized by water, and not diluted by the increased discharge volume in a similar manner to nitrate. The greatest fluxes of these bacteria from drained and undrained pasture were coincident with high rainfall. In addition, *E. coli* is able to persist in the soil for several months following the removal of cattle. In this way, the beginning of rains during the dry to rainy transition period may transfer fecal bacteria that persisted in soils to surface waters and highlights the potential for contamination. This is a possible explanation for the significant increase of fecal coliforms (from 253 to 691 MPN/100 mL) and *E. coli* (from 245 to 649 MPN/100 mL) as well as the flow (from 0.118 to 0.167 m^3/s) during the dry-rainy transition season (Table 1).

Salmonella was absent during the three periods (Table 1). From a public health point of view, absence of this pathogen in drinking water is a good evidence of either low levels or absence in the water of the Victoria River. Salmonella has been detected not only in human beings but also in surface water and is associated with outbreaks of diarrhea (Valiente, per. com., 2009). For this reason, monitoring of drinking water must be permanently performed by users (Rojas, 2002).

Organic contamination was determined by evaluating five-day biochemical oxygen demand, nitrite, nitrate, ammoniacal nitrogen and dissolved oxygen. Low levels of biochemical oxygen demand (<2 mg/L, Table 1), nitrite (<0.09 mg/L), nitrate (0.29-0.43 mg/L range) and nitrogen ammoniacal (<0.08 mg/L) indicate no contamination. In addition, low levels of phosphate (<0.09 mg/L) indicates there is no water eutrophization in the Victoria River.

The concentration of fluoride in samples is 0.3 mg/L (annual mean, 0.06-0.57 mg/L range). According to the maximum permissible level of national standard (from 0.7 to 1.5 mg/mL, *Reglamento para la calidad del agua potable*, in Spanish, 2005), this level does not represent threat to health. Piris da Motta et al. (2003) have found a significant association between fluoride water and risk of tooth decay. The concentration found in the Victoria water may protect the population from fluorosis, especially in children.

Concentration of boron in samples was found to be low (0.11-0.18 mg/L range). High concentration of this element could lead to borism (Eaton et al., 2005). Due to the fact that geothermal fluids have high concentrations (50 to 60 mg/L), a monitoring program is a priority.

Parameters such as pH, electrical conductivity, temperature, turbidity and chloride must be minimized for monitoring impacts of geothermal fluids on surface waters such as thermal effects, possible chemical intrusion during drilling or production of wells.

3.2 Sources of Contamination

Point sources of contamination were identified as bridges, ballast roads, paths across and adjoining the river and pig farms. During the systematic observation in the field, surface runoff was observed after a rain event in station 9 and 14.

A possible explanation of the degradation of water quality parameters, such as color, turbidity and bacterial content, may be leaching of sediments and fecal matter from soils after a rain event. Two rain events such as Noel Tropical Storm in October 2007 and Alma Tropical Storm in May 2008 (Sánchez, 2007; Stolz et al., 2008) occurred during the sampling period. These events resulted, especially where surface cover was low, in surface runoff and leaching of sediments. Physical quality degradation in station 14 was observed during the dry-rainy transition contributing to increase of color (from 3 Pt-Co in the dry season to 30 Pt-Co in the dry-rainy transition) and turbidity (from 3 NTU in the dry season to 32 NTU in the dry-rainy transition).

Thoma et al. (2005) showed that a low runoff velocity on relatively flat landscapes (<3% slope) that have high clay content soils minimizes downslope movements of sediment. Station 14 had clay content soils and high slopes (from five to nine degrees), so its physicochemical parameters degraded, especially, after a rain event during the rainy or the dry-rainy transition seasons.

Non-point sources of contamination identified were grazing areas and depth wells and platform construction sites at the Pailas geothermal field (Figure 4).

According to the land use (Figure 4), pasture occupied 53% of the basin, secondary growth forest 24%, second growth and forest plantation 11% each, and coppice´s vegetation 1%. The Pailas Geothermal Field has a total area of 1.44 km^2, which represents 35% of the Victoria basin. In this area only 12% is destined to the construction of geothermal wells and power plant platforms.

An environmental action plan (ICE, 2005) is being implemented during the construction of wells and power plants. A prevention action includes reforestation with native plants in pasture areas. This action will reduce the pasture area from 53% to 24% and increase the area of forest plantation from 11% to 40%.

The construction of sedimentation lagoons in each geothermal well in order to collect the fluids during production tests is another prevention action. Due to the high flow (200 L/s) of geothermal wells during production, reinjection seems to be the most technically and economically suitable method for getting rid of used geothermal fluids. This will help maintaining reservoir pressures and extending the commercial life of the geothermal fluids (Simsek et al., 2005). Construction of reinjection wells is necessary for the sustainability of the geothermal field.

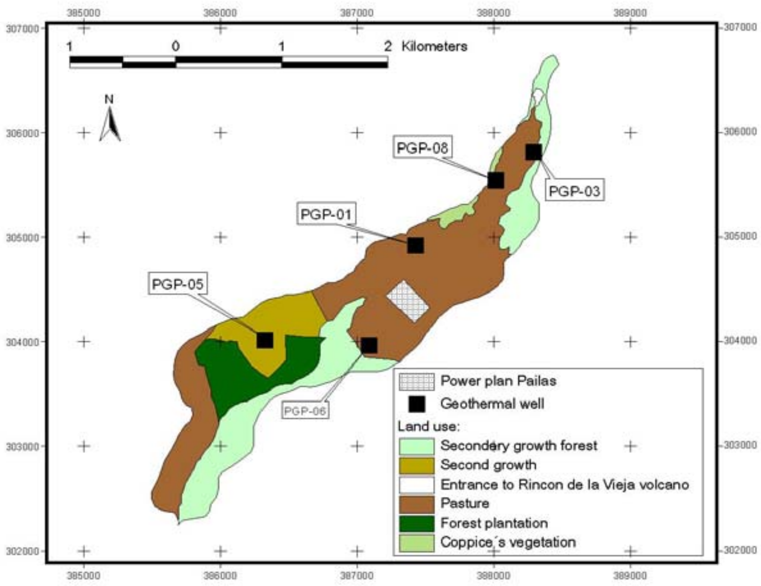

Figure 4: Land use of the Victoria basin, Guanacaste, Costa Rica, 2007-2008.

3.3 Water Quality Quidelines

According to Costa Rica´s Guidelines for the Classification and Evaluation of Surface Water Quality (2007), the Water Quality Index (WQI-CR) is based on three parameters: dissolved oxygen percent saturation, five-day biochemical oxygen demand (mg/L) and ammoniacal nitrogen (mg/L). The WQI-CR score of the Victoria River during the three sampling periods was four points, which corresponds to a level of incipient contamination (4 to 6 points) in the basin. This high score is attributed to the fecal coliforms (Table 1, FC: 253-691 MPN/100 mL). These records provide a baseline for monitoring temporal variations in water quality and determining trends in the basin.

The water of the Victoria River is adequate for drinking after treatment and disinfection (stations from 8 to 15; stations from 1 to 7 require adjustment of pH to a range between 6.5 and 8.5).

3.4 Management of Water Resources

Quantitative estimation of water quality and its relationship with management activities is a necessary step in efficient water resources management (Parparov et al., 2006). In this way, the evaluation of the water quality of the Victoria basin is the baseline for preparing a co-management action plan. Its long-term objective is to guarantee the water quality of the Victoria basin. Its specific objectives are to promote and to strengthen a participatory management of water resources in order to solve water resources related problems in the basin, to implement sustainable practices for protection and conservation natural resources and to monitor environmental impacts of natural causes and human activities, including geothermal developments.

The co-management action plan, which four components with activities oriented to solve the main problems of the basin, was delivered to stakeholders concerned with water resources and environmental management. Each component has its own objectives, strategies, target population, intervention and programs managed by a local coordinator, who is a member of the Victoria Basin Organism, with the main responsibility to coordinate and integrate efforts from local governments and private companies.

The four components of the action plan are: Environmental Education Program for the Sustainable Management of Water Resources, Water Quality Improvement Program, Springs and Water Sources Protection Program and Monitoring Water Quality Program in the Victoria basin.

4. CONCLUSION

The type of water that predominated in the Victoria River, during the period from rainy season 2007 to dry-rainy transition season 2008, was calcium-magnesium-sulfate (47% of sampling sites).

According to the Kruskall-Wallis test, water of the Victoria River showed significant differences ($p<0.05$) in five parameters: color, turbidity, silica, fecal coliforms and *Escherichia coli*, during the three sampling periods.

Physical quality degradation in sampling sites with clay soils and moderate slopes contribute to the increase in color and turbidity.

From a public health point of view, absence of *Salmonella* in the Victoria River water is a good evidence of either low levels or absence in the water.

According to the results of the five-day biochemical oxygen demand, nitrite, nitrate, ammoniacal nitrogen and dissolved oxygen parameters, there was no organic contamination.

According to Costa Rica´s Guidelines for the Classification and Evaluation of Surface Water Quality (2007), the water of the Victoria River is adequate for drinking after treatment and disinfection.

A co-management action plan for assuring water quality in the Victoria River was possible due to water resources related problems as a common element, which allowed to integrate local stakeholders and governments.

ACKNOWLEDGEMENTS

The study was supported by the Instituto Costarricense de Acueductos y Alcantarillados (AyA) and the Instituto Costarricense de Electricidad (ICE).

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