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Environmental Management at the Miravalles Geothermal Field After 20 Years of Exploitation

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ABSTRACT

The great biological diversity of Costa Rica represents one of their main resources and is a focal point of the country's policies on environmental protection. The environmental authorities need to find ways to reduce the environmental impacts and for this reason the geothermal resources development is necessary. The low environmental impacts in the geothermal projects contribute in reducing the impacts related to the energy production, which help keep the natural balance between human well-being and conservation. This document discusses the different environmental aspects related to the exploitation of the Geothermal Fields in Costa Rica, how the environmental management has been carried out, and the results of this management so far. The conclusion shows the feasibility of the sustainable development of geothermal projects, and also shows how this project can contribute to the recovery of the environmental quality in areas that have been previously affected by the human activities.

1. INTRODUCTION

The Miravalles Geothermal Field is located at the Miravalles Volcano in Bagaces Guanacaste between the Blanco and Cuipilapa river basins. The Miravalles I and Miravalles II power plants are located at the coordinates 298 000 N-405 700 E at 610 m a.s.l and the Miravalles III power plant at the coordinates 300 150 N-407 050 E at 720 m a.s.l. This field is a high-temperature liquid-dominated reservoir with temperature of about 240 °C. The proven reservoir area is about 12 km^2 and it is encountered at 700 m depth and the estimated thickness is between 1000–1200 m. The field is an active hydrothermal area confined to a Caldera-type collapse structure with 15 km diameter.

Total dissolved solids in the range of 7000-8000 ppm characterize most of the fluids from the Miravalles geothermal wells. These fluids are sodium chloride type water with a pH of about 8 in surface. The geothermal non-condensable gases emitted to the atmosphere are CO2, H2S, N2, CH4, O2, H2, Ar, He and other ones in tracer quantities.

The environmental impacts assessment (EIA) for Miravalles was made in 1988. Since it was the first EIA ever done in Costa Rica at that time it would change the way models for any new large projects in Costa Rica, which would be presented in the future. In order to obtain financing, the Costa Rica National Congress made the exigency to complete an EIA to demonstrate the environmental feasibility of the project. As a result of this study, the most important environmental aspect to monitoring was established.

Brief comments on the management and monitoring of some of these environmental aspects are presented in this paper.

2. ENVIRONMENTHAL MANAGEMENT SYSTEM

The environmental management at the Miravalles Geothermal Field had been going on since 1987, before the beginning of the field utilization in 1994. The main purpose was to create a background that allowed comparison of environmental quality before commercial utilization and the assessment of any future impact due to the utilization.

The environmental geothermal management is focused on the EIA requirements and to ensure a systematic way to accomplish the EIA requirements the ISO 14001 Environmental Management System implemented at geothermal projects in Cost Rica since 2002. In March 2002, the ICE directive council established the environmental policy for the organization and ten principles to define it. The ICE policy is as follows: The Instituto Costarricense de Electricidad (ICE) plans and develops its activities with the principle of sustainable development; the management is done in accordance with the attitude of conservation, protection, recovery and adequate use of the environment.

In Miravalles, the Environmental Management System is used as a tool of continual improvement to administrate environmental issues and can be used successfully to ensure the EIA requirements. The Environmental Management System improves the EIA programs because it ensures the continual actions' reviewing and allows the detection of new impacts. The Environmental Management System that has been used in Miravalles has 8 environmental procedures to ensure adequate environmental management and additional procedures to control the system.

With the Environmental Management System it is possible to systemize and improve the control of impacts in a continuous way (continuous improvement). It is necessary because the process changes as well as the organization, the environmental conditions and legal requirements. And this means that the environmental programs and the actions also need to change continually. Public relations are very important because the people may be against the organization and can complain. For this reason the Environmental Management System has to ensure public participation and a fast response to all complaints. The organization and

the people have to ensure compliance with the law. The Environmental Management System has to allow a fast identification of any changes of law so as to take it into account.

The main objective of any Environmental Management System is to improve the environmental performance of the organizations to protect the environment, improve their public image and reduce costs. Firstly, try to prevent all kinds of negative impacts. If it is not possible, it will try to reduce the negative impacts and if any of these solutions are possible, then it will focus on to mitigate the impacts.

The actual laws in Costa Rica and in most of the other countries penalize environmental pollution, in most of the cases it means high quantities of money to pay and use of time and resources reversing the damage. All these problems can be prevented if the organization implements an adequate Environmental Management System. Finally, it has to be taken into account that the communities have a lot of power. If they are against the project it will mean a lot of problems that can be prevented and solved by a correct Environmental Management System implementation.

The Environmental Management System also increases the sense of responsibility with nature and thereby improves the personal satisfaction among all of the members of the organizations.

The environmental management in the geothermal projects in Costa Rica is focused on six main aspects, air and water quality, evolution of the rainwater pH, environmental education, field management and communities' relationships.

The monitoring is done using a system of control stations located around all the influenced area. Figure 1 shows the location of the stations (air, water and rain). The meteorological conditions have also been monitored.

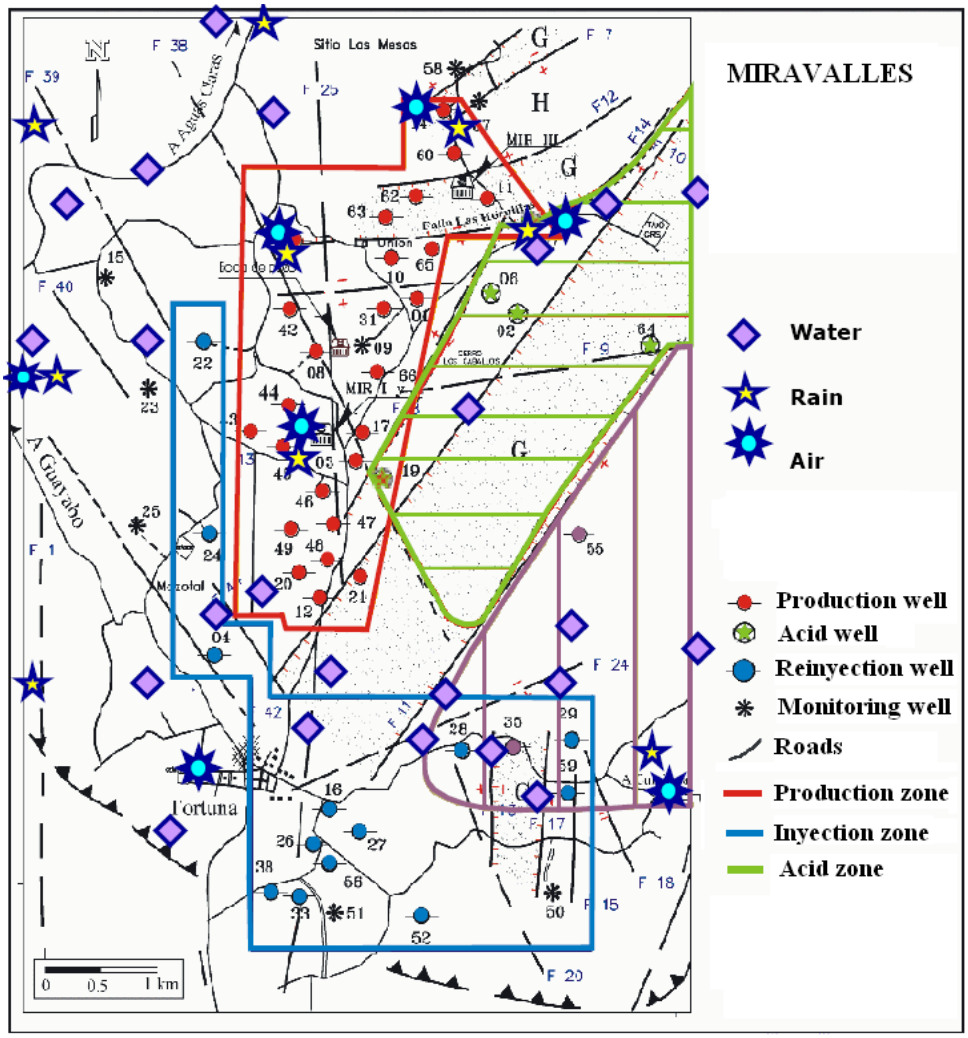

Figure 1: Environmental monitoring system.

Considering the Environmental Management System requirements, it is necessary to analyze all the project activities to determinate possible changes in the environmental conditions that can produce new environmental impacts. As was mentioned the processes of the development and commercial exploitation changes in a continual way and then new impacts can appear. For these reasons, continuous studies are important and involve the persons working directly at the project activities. It means that the analysis will consider all small details and potential problems probably not detected during the EIA process. This detailed analysis allows reviewing and valorizing the process and then classifying the impacts by relevance as shown in Figure 2 and also what environmental parameters are most affected by different processes as shown in Figure 3. In this way it is quite easy to determine how to use the resources of the organization in an efficient way.

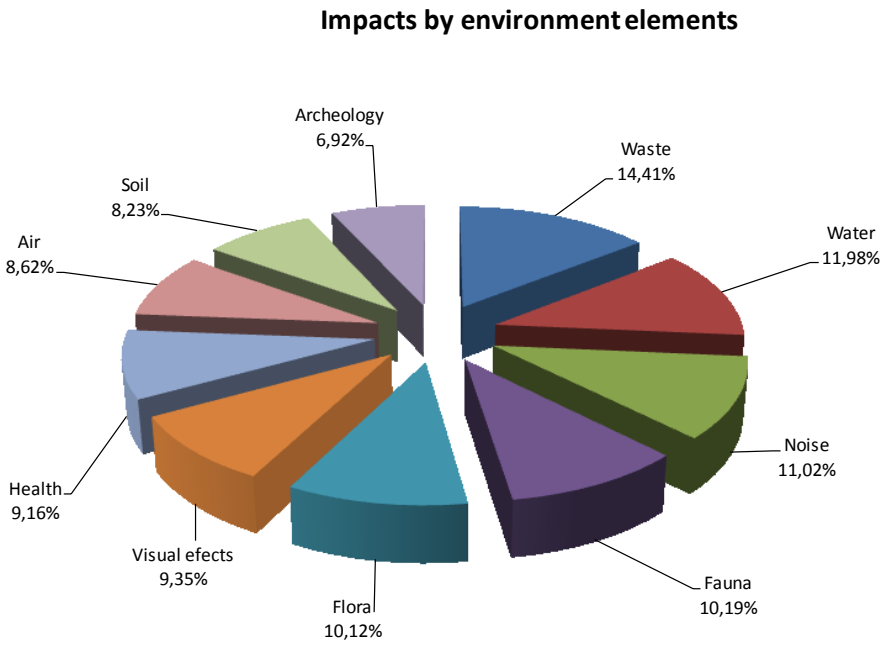

Figure 2: Environmental impacts.

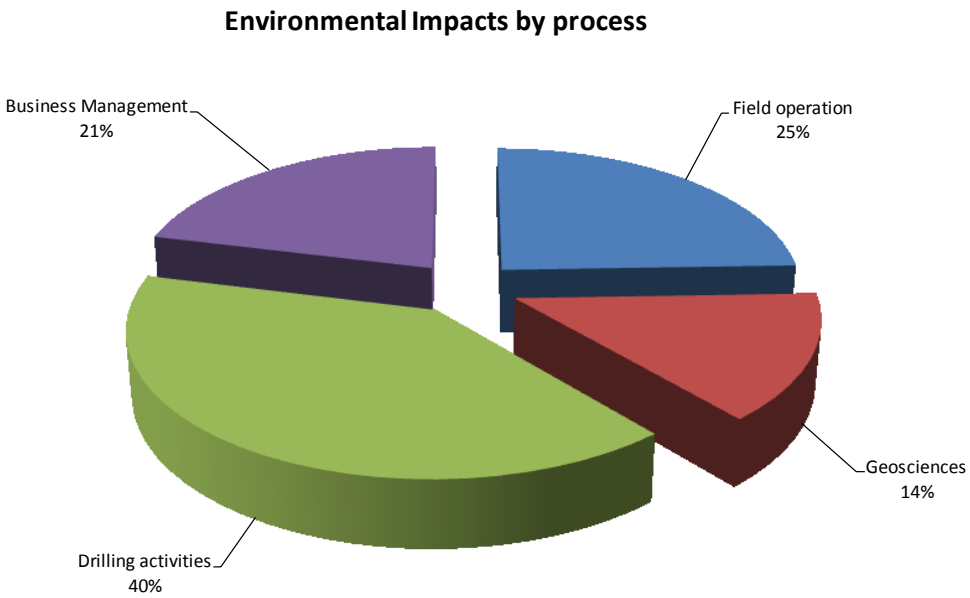

Figure 3: Impacts at the productive process.

This information allows attending at first to the most significant impacts and then the others. The information obtained using this Environmental Management System tool can be used as input information in the elaboration of the EIA at new geothermal development, can ensure more accurate impacts identification and increase the enterprise credibility against the environmental authority and the communities.

2.1 Air Quality Management

In Miravalles there are different ways the gas is disposed into the atmosphere. The gas can be released from the silencer when the wells are out of production. In the centrifugal separators the waste water is sent to injection wells and the steam towards the turbine. In the power plant the gas ejector system extracts the non-condensable gases from the turbine condenser. This gas is cooled and discharged into the atmosphere through the cooling tower. Of these gases, CO_2 (96-97%), and H_2S (less than 1%) are the most important because of possible effects on environment and human health.

2.1.1 Carbon Dioxide (CO_2)

CO_2 is a heavy gas naturally present in air at a concentration of 0.03 – 0.06 percent. It is odorless and acid taste. In a concentration higher than 5% it will produce mental confusion, headaches and eventually a loss of consciousness and a concentration of higher

than10% produces a loss of consciousness in few minutes and larger concentrations cause death due to an alteration of blood pH (Brown, K., 1995).

CO_2 is also one of the principal greenhouse gases (GHGs). It is estimated that, due to the accumulation of greenhouse gases the global surface temperature will have risen between 1.5 to 3.5 ^oC by the year 2100 (WHO, 1997). There are international standards to control the maximum quantities emitted into the atmosphere. This climate change has indirect effects over ecosystems and over the distribution patterns of vector populations. Table 1 shows some different international standards for CO_2 emissions.

TABLE 1: Different standards for CO2 emissions

Norm	Standard
OSHA[(a)]	5 000 ppm, 8 hour TWA
NIOSH[(b)]	10 000 ppm TWA; 30 000 Ceiling (10 min)

a) Occupational Safety and Health administration (OSHA); b) regulations and National Institute for Occupational Safety and Health (NIOSH)

2.1.2 Hydrogen Sulfide (H_2S)

H_2S is a poisonous gas. It can come from natural sources like volcanic gases, geothermal springs and decaying organic matter, from manmade sources and also from industries. It is a colorless flammable gas with vapor density of 1.189 and soluble in water, alcohol ether and glycerol. The presence of H_2S in the atmosphere increases health risks. Low concentrations can produce human health problems, effects on flora and fauna and damages to human constructions by corrosion and higher quantities may cause death. Due to the toxic characteristics of the hydrogen sulfide different health and environmental organizations have established exposure standards for work areas and for populated areas. Table 3 shows different international standards for H_2S concentrations.

TABLE 2: Different standards for H_2S emissions

Norm	Standard
TWA PELs OSHA [a]	28 000 μg/m^3 acceptable ceiling; 70 000 μg/m^3, 10 minutes maximum ceiling.
RELs NIOSH [a]	14 000 μg/m^3 ceiling 10 minutes on exposures up to ten hours
ACGIH [b]	14 000 μg/m^3 like 8 hour average and 40 hour per week to workers
Italy [c]	42 μg/m^3 as 24-hour averaging time in urban areas.
California [d]	42 μg/m^3 like 1-hour averaging time.

a: OSHA and NIOSH, 1986; bBrown, 1995; c: ICE, 1996 d: California air resources board, 1999

The human body does not accumulate H_2S, it is excreted in the urine, intestines and expired into the air (Brown, 1995). H_2S smells like rotting eggs and the smell is perceptible in concentrations less than 42 μg/m^3. When people have exposure to low concentrations of H_2S, it can cause lacrimation, photophobia, and irritation of the nasal mucosa it also has a profoundly irritant effect on the cornea producing pain and blurring of vision and keratitis. The concentration of 500 μg/m^3 H_2S has a clearly perceptible odor and begins to cause damage to delicate plants. In the range of 280 000 and 700 000 μg/m^3 it will produce intoxication and above 840 000 μg/m^3 it can produce rapid death by asphyxia. Aluminum conductors in substations and on transmission lines will usually take on a protective coating of black sulphide which inhibits further attack. However instruments and relay contacts will almost certainly suffer if they feature exposed copper, as sealing is seldom perfect. Contacts and bare connectors of silver are advisable. Exciter commutators of copper can be very troublesome, not only because the copper itself is attacked by H_2S but also because the sulphide film causes sparking at the bushes which wear away at an alarming rate (Armstead, 1983).

The geothermal energy is a good example of how CO2 emission can be reduced in Costa Rica. The geothermal energy is used to substitute the production of fossil fuels power plants that release a lot of CO and NOx to the atmosphere. Using the emission in Miravalles the reduction of CO_2 emission is about 1 138 800 tons per year. Figure 4 shows the different emissions by technologies.

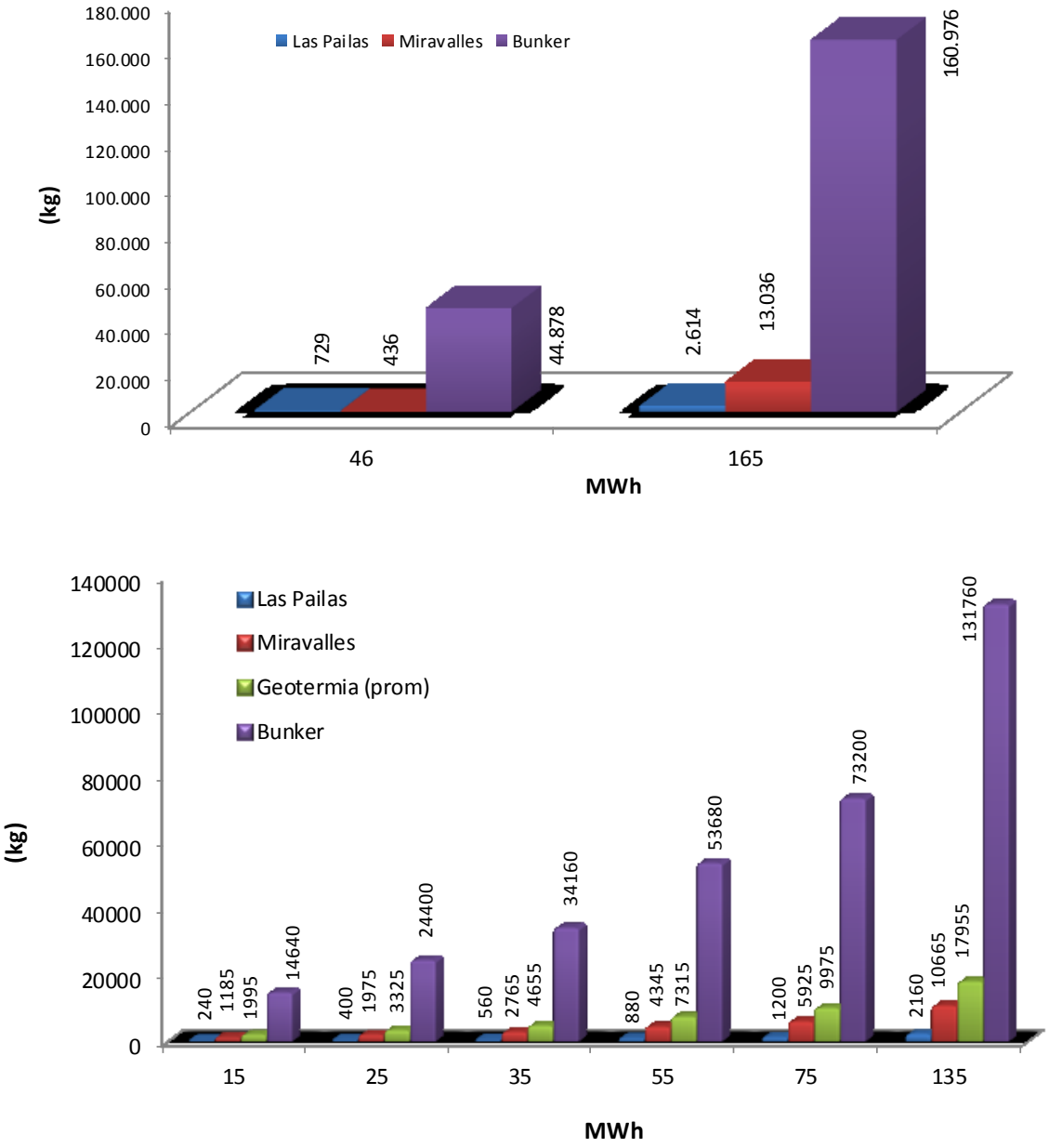

Figure 4: Emission of CO_2 by technology (kg/MWh).

The Miravalles environmental impact assessment (ICE, 1996) established the maximum concentration as 42 µg/m^3 in populated areas and 938 µg/m^3 one kilometer from the power plants. In Miravalles the hydrogen sulfide emission was modeled (ICE, 1988 and 1996). The models estimated H_2S concentrations under 42 µg/m^3 in towns and less than 938 µg/m^3 at one kilometer from the power plants (Guido, 999). In order to study the H_2S evolution, the Instituto Costarricense de Electricidad (ICE) operates seven stations for H_2S monitoring. For the measurements of hydrogen sulfide, electronic equipment with the capacity to measure H_2S concentrations from 4.2 µg/m3 is used. CO_2 is measured using equipment with the range of 0 ppm to 10 000 ppm. Figure 5 shows the concentration in representative stations.

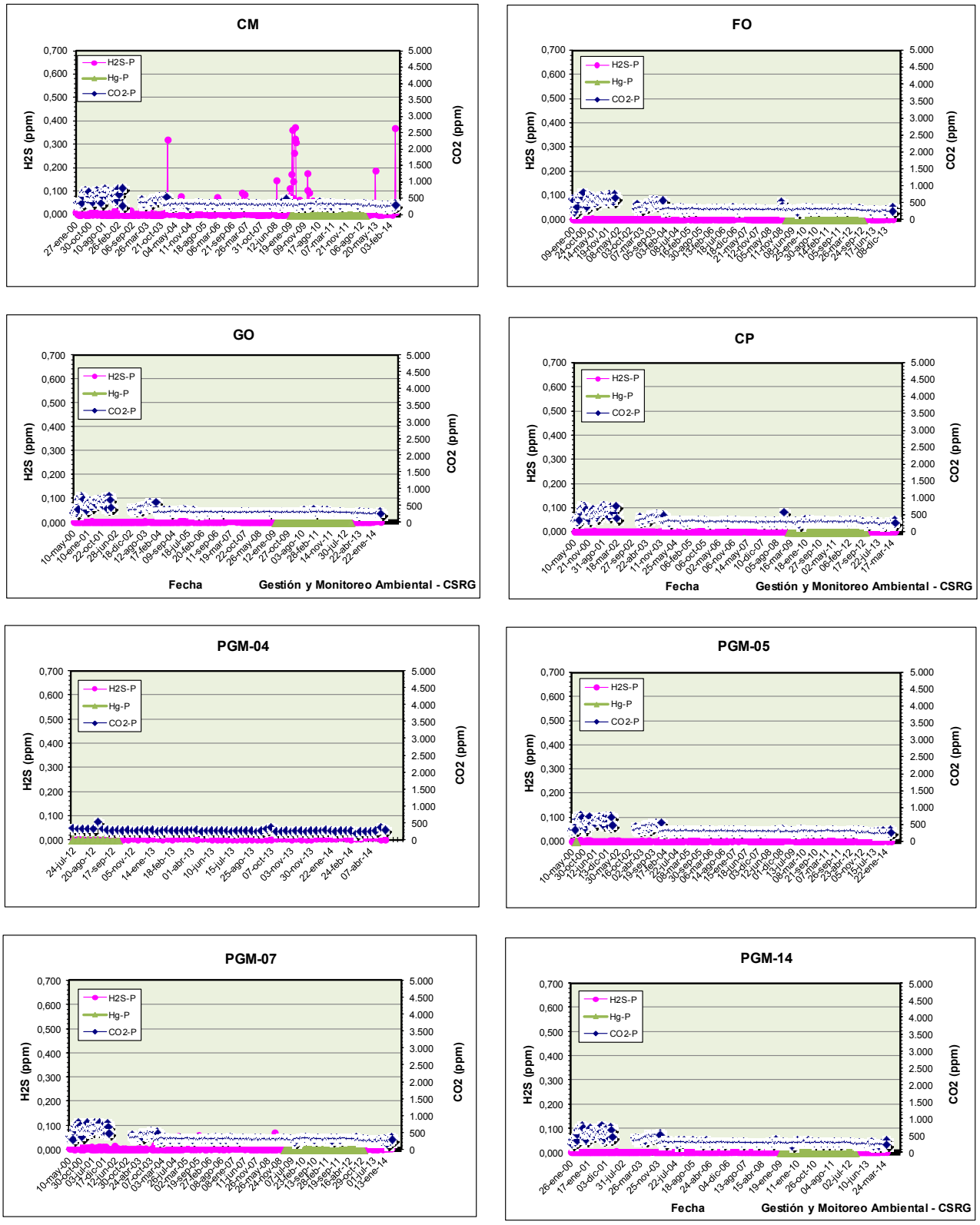

Figure 5: Concentration of H_2S at Miravalles.

2.2 Water Quality Management

In Miravalles, the hot geothermal water is re-injected into the reservoir using deep wells. It therefore does not represent a pollution problem to the groundwater system. In some cases it is necessary to store the geothermal water in surface ponds prior to injection and due to possible leakage the groundwater can become contaminated. The physical and chemical characteristics of the Miravalles geothermal fluids do not allow wastewater disposal at the soil or into the springs or rivers in the area.

The water quality monitoring program in Miravalles was established in 1987 and it includes 26 points around the project area with the objective of detecting possible geothermal water pollution. At the beginning the study there was more detailed (pH, Cl. B, As, Li, Rb, Cs), but after many years it was decided to reduce the number of chemical species. Actually, the monitoring includes Cl, pH

and conductivity, because they can be used to indicate the presence of geothermal and fresh mixed water. Figure 6 shows the result of the monitoring in representative monitoring sites in Miravalles.

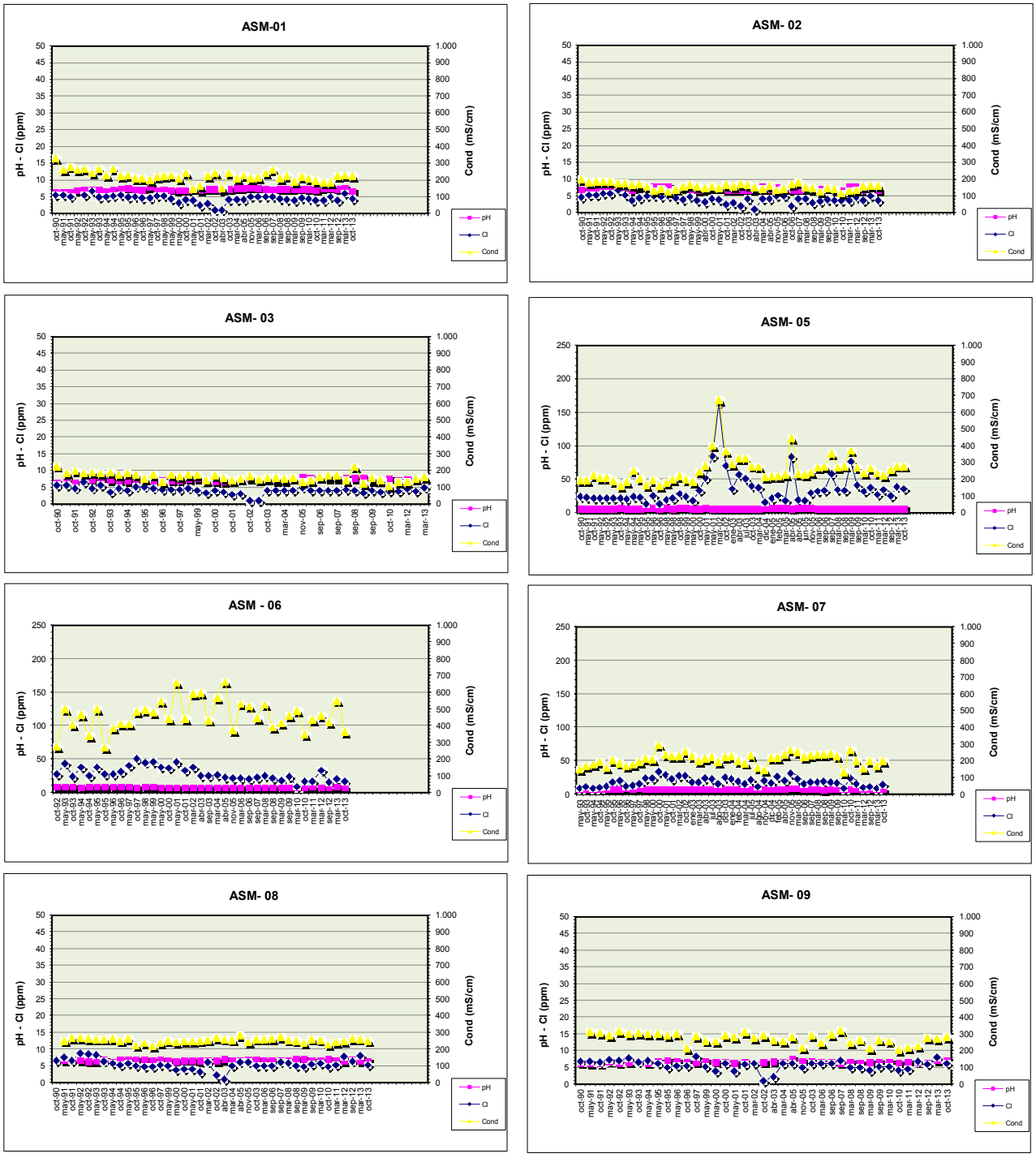

Figure 6: Water quality monitoring at Miravalles.

2.3 pH of Rain

The possible changes of pH in the rain because of geothermal utilization has been monitored and studied in Miravalles since 1987. One continuous monitoring was established in ten points around the project area. Figures 6 and 7 demonstrate the location of the rain monitoring points. The objective of monitoring is to determinate the pH background, and use it as a comparison line that allows identifying any pH changes after the start of the field operation. The commercial field operation started in 1994, and demonstrated no operational effects over the pH range of values. Figure 7 shows the results of the pH rain monitoring at the Miravalles Geothermal Field.

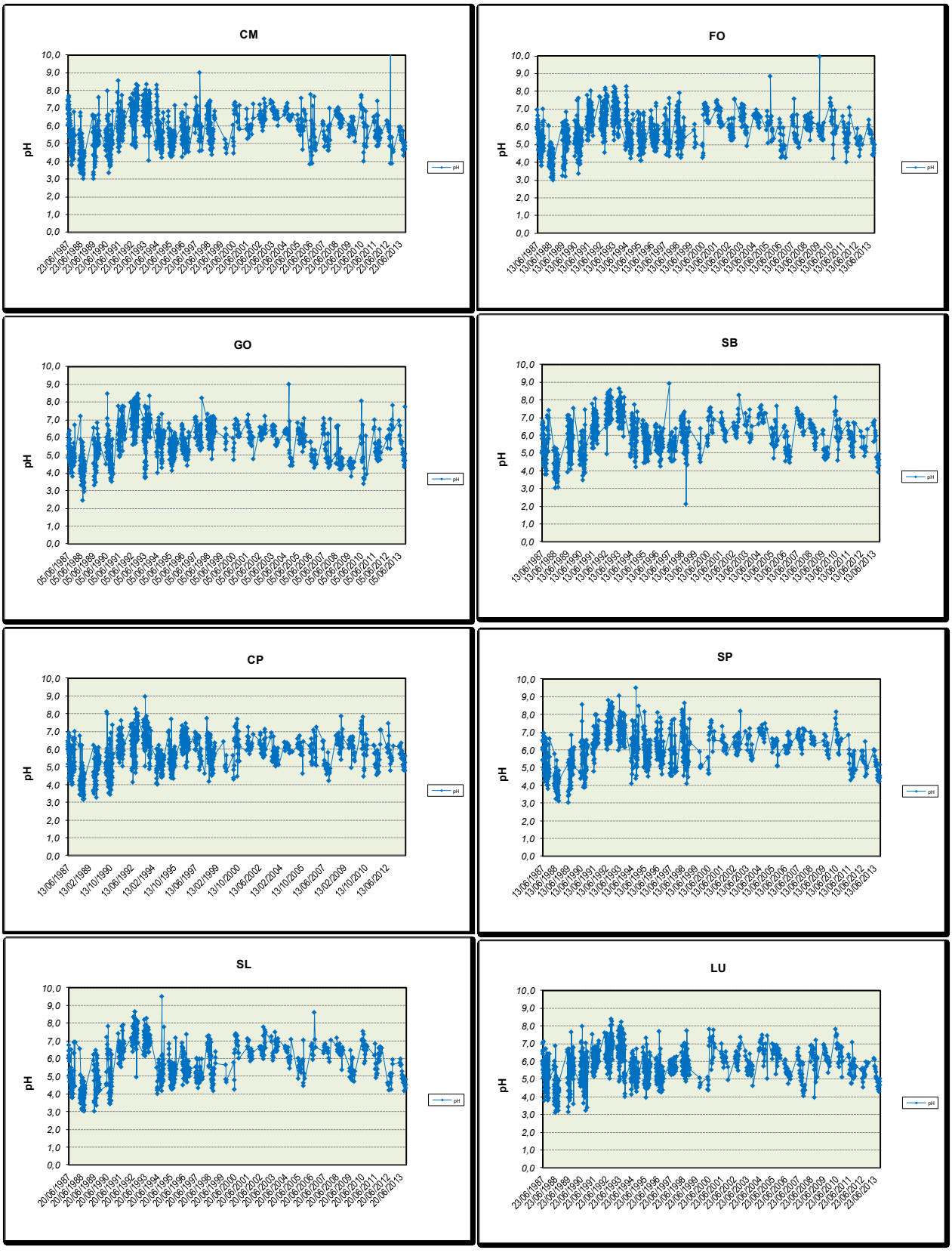

Figure 7: pH and annual Rain – Miravalles.

2.4 Effects on the Forest

In Miravalles most of the land acquired for geothermal utilization has been reforested by using local flora and promoting natural recovery. When the geothermal activities began, most of the land was used for grazing. ICE has recovered 800 hectares by planting 362,000 trees in the area. As a natural consequence it is now possible to see animals that were nearly impossible to find earlier. Figure 8 shows the forest coverage in 1987 and figure 9 shows the forest coverage in 2013. Due to the reforestation of Miravalles geothermal field area, now the total forest coverage has increased one hundred percent. These represent a positive impact over the fauna and over the environmental quality.

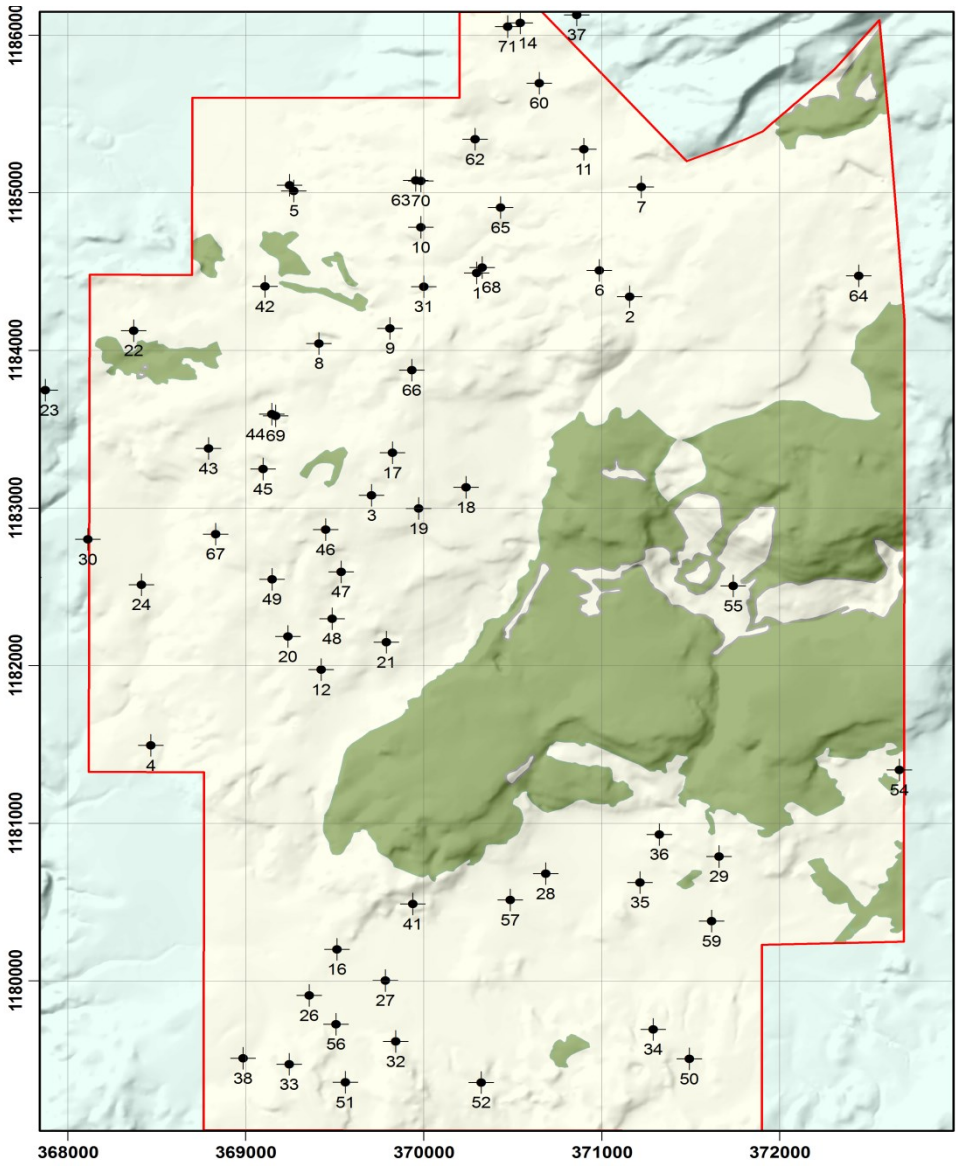

Figure 8: Forest coverage in 1987 – 600 Ha.

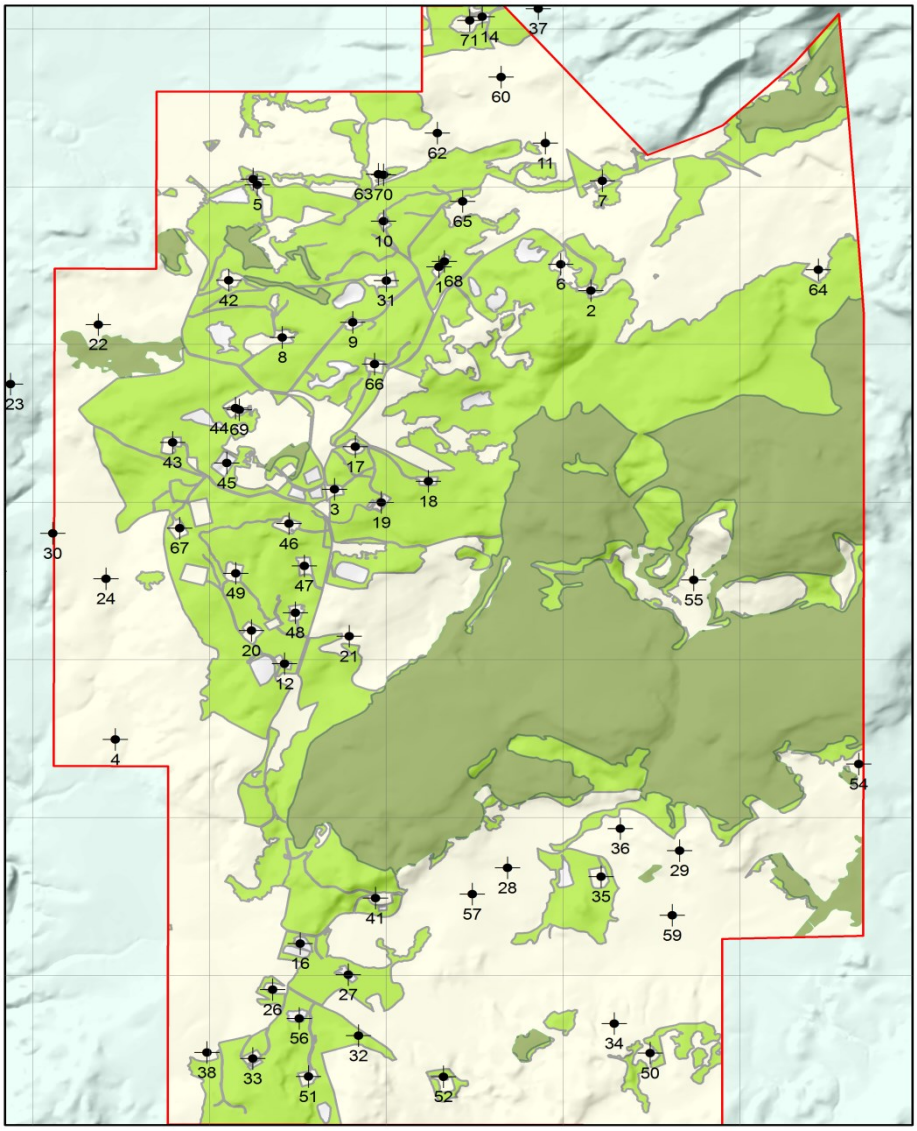

Figure 9: Forest coverage in 2013 – 1480 Ha.

3. CONCLUSION

The results of the environmental parameters show that the geothermal development in the Miravalles Geothermal Field is sustainable.

The natural recovery due to the presence of the Miravalles Geothermal Developments is extremely important over the vegetation and over the fauna.

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