



## **GEO-ENVIRONMENTAL ASPECTS FOR THE DEVELOPMENT OF LAS PAILAS GEOTHERMAL FIELD, GUANACASTE, COSTA RICA**

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### **ABSTRACT**

Las Pailas is located in a very special zone where different social-economic activities, natural conditions, and an important geothermal resource converge. All the geoscientific environmental and economic-social information available support the exploitation of this resource and the construction of a geothermal power plant of 35 MWe. It is a necessity and a possibility, with continuous and careful monitoring as well as varied necessary mitigating measures, to take advantage of the geothermal resource that is immersed within an area of special ecological context. Following the philosophy and the guidelines for sustainable development should be the door to future geothermal operations within protected zones like national parks and natural reserves. Geothermal exploitation is a very good opportunity for ICE (Costa Rican Institute of Electricity) and for the country.

### **1. INTRODUCTION**

This report is the final part of 6 months training at the United Nations University Geothermal Training Programme (UNU-GTP) with emphasis on environmental studies, which was carried out from May to October of year 2006 in Iceland. The fellowship for this training was sponsored by the Government of Iceland and the United Nations University (UNU). Training at UNU-GTP has given several professionals of the Costa Rican Institute of Electricity (ICE), and particularly of the Geothermal Resource Services Centre (CSRG) an opportunity to become qualified in the diverse topics of geothermal exploration and development, in addition to the possibility of getting acquainted with other geothermal colleagues from around the world.

During the last decade or so, interest has increased in the environmental aspects of geothermal development. The UNU-GTP and the geothermal community, including Costa Rica, have met this by giving environmental studies an increased priority, with an emphasis on environmental impact studies covering different aspects, including even social-moral, legal and economic matters, as geothermal development must be reconciled with the interests of the local society and nature. Therefore, Costa Rica must continue to follow developments in this field and to gain better access to technology and information through qualified personnel. This makes it possible to demonstrate at a national and international level that geothermal energy is not only important as a clean energy source, but that

geothermal exploration and operation can take advantage of environmental concepts and the philosophy of sustainable development.

The objectives of the present report are:

- To show that the geothermal project Las Pailas in spite of being located in a special zone where very diverse interests converge, can be carried out in an environmentally successful way, in agreement with existing scientific, environmental, social and economic information;
- To confirm that geothermal energy is a clean energy source and a better option than energy obtained from burning fossil fuels with regards to economic, social and environmental factors;
- To demonstrate that ICE, an institution responsible for energy production of Costa Rica, can coexist with other economic and social interests, in special eco-natural areas like the Las Pailas zone; and
- To show that despite the confirmed environmental viability of the area, shown by national environmental authorities (SETENA), it is possible in future to develop geothermal projects within protected zones (like the national parks), complying with existing laws as well as the principles and philosophy of *sustainable development*.

## 2. GEOTHERMAL EXPLORATION IN THE LAS PAILAS GEOTHERMAL AREA

The *Circum Pacific Ring of Fire* is characterized as a zone of continuous and abundant seismic and volcanic activity. The most important tectonic feature of the Central American region is the interaction between tectonic plates, in this case, the Cocos plate subducted under the Caribbean plate along the Middle American Trench convergent margin (Figure 1), with rates of nearly  $10 \text{ cm}^{-1}$  across the Costa Rican segment of the trench (DeMets et al., 1990). As a result of this activity, several subduction processes have been proposed that range from smooth subduction off the Nicoya peninsula to collision, with consequently important earthquakes, volcanic activity, tectonic uplift (Gardner, et al., 1992) and geothermal activity in many locations of the region.

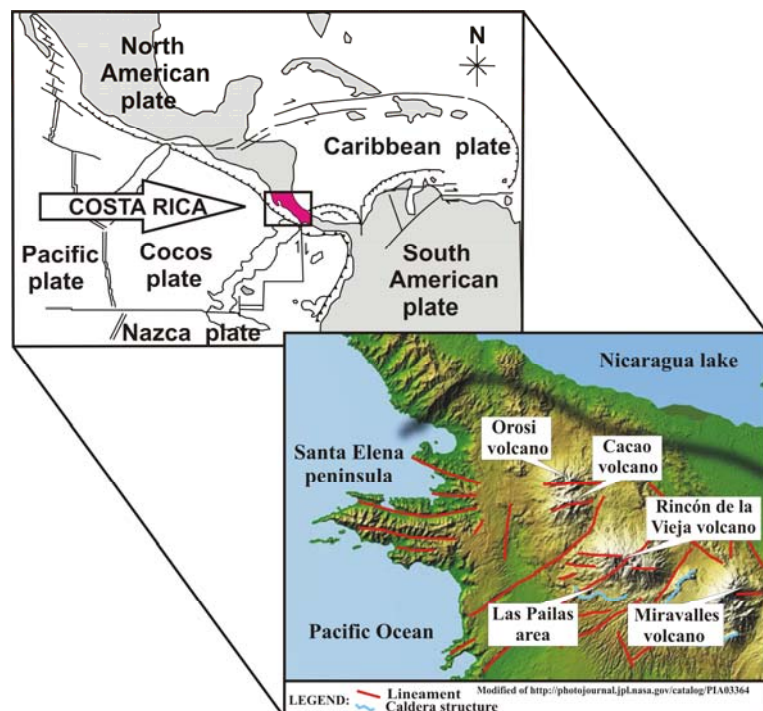


FIGURE 1: Tectonic location of Costa Rica, with special reference to the northwest part of the country

### 2.1 Geological setting

The location of the Las Pailas geothermal area is clearly related to the activity of the Quaternary volcanic system, in particular with the Rincón de la Vieja volcano. It is a composite stratovolcano in the northwestern part of Costa Rica, belongs to the Guanacaste Range (Figure 2), and forms a NW trending ridge consisting of several eruptive centres (Kempster et al., 1996; Kempster, 1997). It erupts mainly materials of basaltic-andesitic composition (including lavas, tuffs, pyroclastic flows,

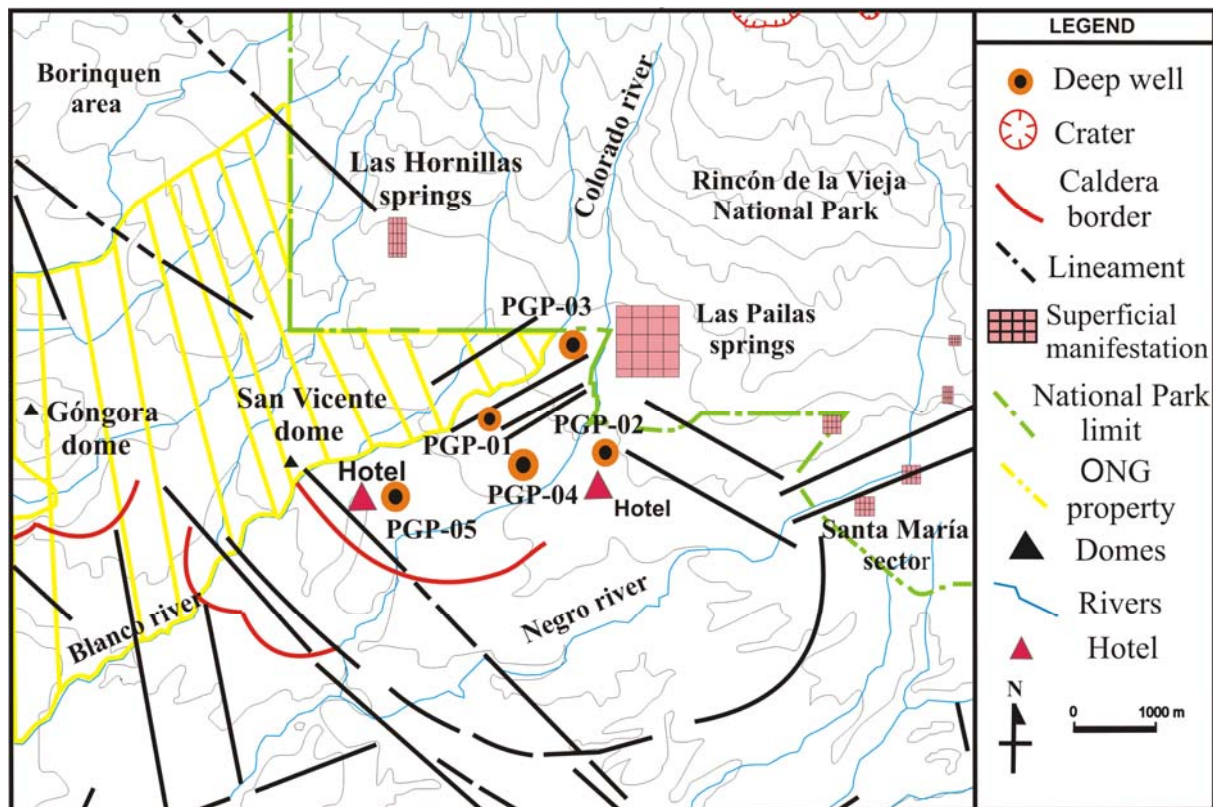


FIGURE 2: Main structural features of Las Pailas area including calderas, geothermal wells, national park and ONG's land limits

ignimbrites and lahars) but along the southern border, there are five domes called Fortuna, San Roque, Góngora, Cañas Dulces – La Torre and San Vicente (Las Pailas area) with dacitic-rhyolitic to andesitic composition more similar to basement pyroclastic flows, with ages varying between 4.3 and 1 million years (Mainieri, 1976; Kempter, 1997; Molina, 2000; Arias, 2002).

A number of recent studies have contributed to the improved understanding of the stratigraphical, structural and petrologic aspects of the volcanic rocks of the Guanacaste Range (Chiesa, 1991; Chiesa et al., 1994; Kempter, 1997), including K-Ar dating of the principal volcanic events from Upper Miocene-Late Pliocene to recent ages (Gillot et al., 1994; Kempter, 1997). The last active period occurred in 1995, generating ash deposits, throwing blocks and tephra, with the development of lahars and mud flows on the Caribbean side of the Rincón de la Vieja complex (GeothermEx, 2005). Some important chemical data for rocks are given in Kempter (1997).

In the Las Pailas area, two semi-circular structures have been proposed. The first one is a festooned border caldera, which extends from Las Pailas sector to the northwest (Borinquen area) and is referred to as Alcantaro (Kempter, 1997) or Cañas Dulces caldera (Molina, 2000; Chavarría et al., 2006). The other structure is called Guachipelín caldera (Chavarría et al., 2006) but is sometimes also referred to as San Vicente caldera (Molina, 2000). This caldera is not as evident as the first one and it is clear only in the Las Pailas area (Chavarría et al., 2006).

This zone is also characterized by several structures / fault systems with different strikes, but the most important systems follow NE-SW and NW-SE regional structural trends. Some important geothermal manifestations are aligned in this last direction. Another two minor systems with N-S and E-W orientations (Chavarría et al., 2006) are evident in lineaments seen in some rivers and other geomorphologic features.

## 2.2 Superficial geothermal manifestations

There are important geothermal manifestations on both the Pacific and Caribbean sides of the Rincón de la Vieja volcano (Figure 3). But in this work, the emphasis will be on the manifestations on the Pacific side because the Las Pailas geothermal area is located there. There are four important superficial geothermal manifestations on the Pacific volcano side called Las Hornillas, Borinquen, Las Pailas and San Jorge-Santa María, aligned in a NW-SE direction, roughly parallel to the axis of the Rincón de la Vieja volcanic axis (Molina, 2000), a good confirmation of a structural control for the deep water circulation system in the zone.

The geothermal exploration in Las Pailas sector revealed several manifestations. Most of them are inside Rincon de la Vieja national park. With some geochemical studies, thermal and cold springs have been characterized, as well as fumaroles with gas and steam emanations (Chavarría et al., 2006). According to the dominant anion classification and thermal determinations different water groups were defined: sulphated (hot and cold), bicarbonate (hot and cold) and sulphated-bicarbonate mixtures, but there are no chloride springs that can relate to the lateral discharge of the reservoir.

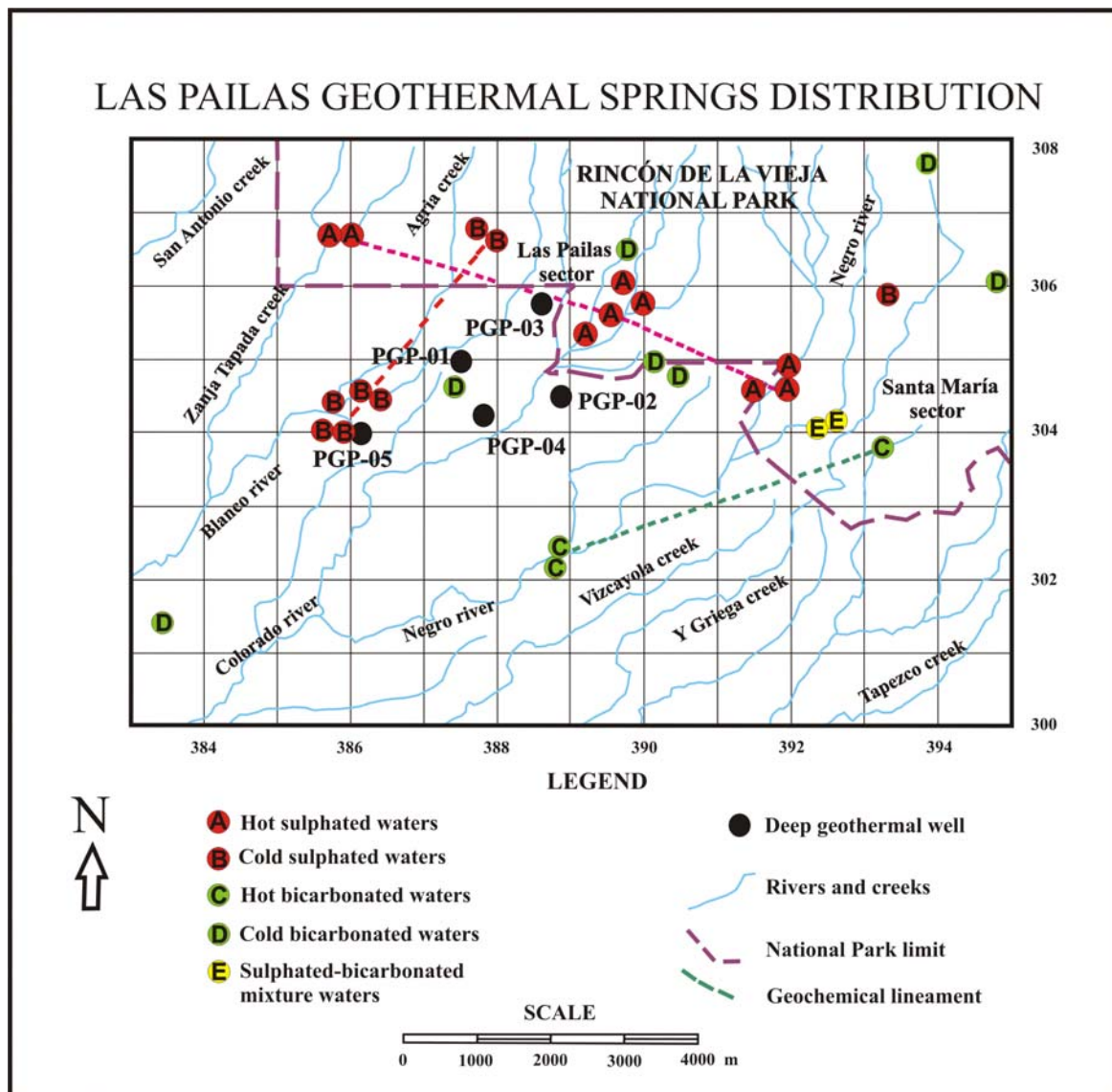


FIGURE 3: Hot and cold spring distribution in the Las Pailas area, correlated with geochemical and geostructural studies (modified from Chavarría et al., 2006)

The hot sulphated waters (A) appear to be related to regional structures with different orientations. They include the Las Hornillas, Las Pailas and Santa María manifestations, which are aligned NW-SE and include fumaroles (88-93°C), hot springs (34-96°C) and mud pools (96°C). The cold sulphated waters (B) form a lineament perpendicular (NNE-SSW) to the volcanic axis, with temperatures between 15 and 25°C and are located in the vicinity of the Agría creek and an isolated point in Santa María sector, between Negro river and Zopilote creek (Figure 3). The hot bicarbonate waters (C) are located on a NE-SW lineament in the Negro river. They are meteoric waters with geothermal influence, and temperatures between 33 and 56°C. The cold bicarbonate waters (D) are distributed over many places. Their temperatures vary between 16 and 29°C. Finally, sulphated-bicarbonate mixture waters (E) are in the Santa María sector, with temperatures around 40°C, with variable chemical compositions with time; some sulphur deposits have formed.

### 2.3 Las Pailas geothermal area exploration history

Around the mid 70s, due to the international oil crisis and the urgency for new energy alternatives, the Costa Rica Electricity Institute (ICE) began geological, geophysical and geochemical studies in the Guanacaste province (northwest part of the country). The first six gradient wells in the Las Pailas geothermal area were drilled in the years 1975-1976 (Molina, 2000), although higher priority was given to the Miravalles volcano region at the time due to factors such as location, accessibility and other logistical reasons. A national evaluation of geothermal resources in the country was carried out by ICE in November 1987 to October 1988 for selecting prospective areas suitable for more detailed studies. As a result of this study, two new zones in addition to the Miravalles volcano were chosen as high priority areas for further studies: Tenorio and Rincón de la Vieja volcanoes (Figure 1).

More geoscientific surveys were carried out in the next years in Las Pailas (Rincón de la Vieja area), with a new gradient drilling phase from 1995 to 1996. By January 2001 and as part of the energy strategy, drilling of five deep wells began to verify favourable conditions suggested in a previous pre-feasibility study (GeothermEx, 2001). Three of these wells showed good temperature and permeability conditions and were also able to produce fluids of geothermal origin (Castro, 2002; GeothermEx, 2005). The main data on these wells are presented in Table 1. At the same time, ICE has been continuing exploration with more gradient wells and some geophysical surveys in specific places.

GeothermEx (2005), presented a feasibility study to ICE authorities and it is possible that a new deep directional drilling phase will begin in January 2007, with 9 new production wells and 2 to 4 new injection wells. The proposal includes the construction of a 35 MWe power plant which is to start the production of electricity by around 2010-2011.

TABLE 1: Main data of the deep geothermal wells in the Las Pailas geothermal area

Well no.	Location		Altitude (m a.s.l.)	Final depth (m)	Production casing depth (m)	Depth of liner (m)	Maximum temperature (°C)
	North	East					
PGP-01	304 915	387 500	659	1418	783	1414	250
PGP-02	304 488	388 870	676	1764	755	-	246
PGP-03	305 788	388 607	758	1773	786	1773	247
PGP-04	304 231	387 814	630	1419	915	1400	233
PGP-05	303 966	386 088	553	1827	1395	1765	176

## 2.4 Environment and nature considerations

Las Pailas geothermal area is located in a very special context. It has beautiful places to visit and enjoy. In the northern part is the Rincón de la Vieja National Park; in the eastern part there is a natural reserve, and two mountain hotels are inside the geothermal area. Near the area there has been discovered a great quantity of *petroglifos* (prehistoric stone draws), an important part of the cultural heritage.

The climatic conditions are special. The pacific side is an area of rainy forests with a transition to rainy dry forest and some patches of secondary forest and native grassland growing over old lava flows and tuffs, in accordance with altitude and human impact effects. The mean annual temperature is 24-26°C and around 14°C in volcano tops, with 2500-3000 mm of annual mean precipitation (May to November), and 4-5 dry months (dry season, December-April); the Caribbean side is humid to very humid, with around 3000-4000 mm of annual mean precipitation (full year).

Due to the differences in altitude and precipitation, the influence of volcanic eruptions and the type of slope, the Rincón de la Vieja area displays diverse habitats. In the park there have been observed more than 300 species of birds, many mammals and some reptiles (snakes and turtles). More recently, studies were made on a hot and acid pool mud in the Pailas area by the National Institute of Biodiversity (INBio) and the Centre of Molecular and Cellular Biology of the University of Costa Rica (Sittenfeld et al., 2002; Sittenfeld et al., 2004; Sánchez et al., 2004), detecting the presence of apparently endemic micro-organisms.

The Rincón de la Vieja volcano has been a part of the Costa Rica national park system since October 1973, by means of Law N° 5398 (MINAE-ICT, 2006). It is divided into two sectors: Las Pailas and Santa María (Figure 3). It includes around 14,083 hectare, and extends from 650 to 1965 meters in elevation on both the Caribbean and Pacific flanks of the volcano. Around 35,000 – 40,000 tourists visit the Rincón de la Vieja National Park every year, traversing across the private lands and the geothermal locations. Also, there is a natural reserve in the eastern part of the project site called “Guanacaste Dry Forest”. This territory is administrated by Bio Guanacaste, an ONG (organization not governmental). Before, this territory was a UNOCAL land. At this moment, geothermal exploration by ICE is not possible within the “Guanacaste Dry Forest”.

Many tourists visit the two mountain hotels in the area: Guachipelín and Rincón de la Vieja Lodge; both buildings are inside the geothermal area, very close to the national park (Figure 2). Some hot springs and other geothermal manifestations are utilized as tourist attractions. Continuous negotiations have been made with the hotel’s owners and some of their lands are now ICE properties.

Outside the national park territory, the forest has been fragmented and destroyed for many years, and part of the land has developed into grassland, shaped by human use. This is an important point to consider, because some environmental groups have accused the ICE geothermal project of being environmentally harmful in order to receive some publicity and attention. Additional environmental considerations must be taken to avoid such situations.

An important consideration can be made at this point. The country’s environmental laws do not permit exploration and/or exploitation of geothermal resources in the national park lands. For this reason, ICE cannot explore in the Rincon de la Vieja area, despite the fact that studies have shown the main geothermal resource is possibly inside the national park territories. However, some direct negotiations between ICE, the National System for Conservation Areas (SINACs) and the Energy and Environment Ministry (MINAE) (INBio, 2006) permitted some geochemistry, geophysical and geological tests within the Rincón de la Vieja National Park for some months and at specific places, with additional SINAC supervision. In this way, additional information was obtained by ICE in order to improve the geothermal model.

### 3. ENVIRONMENTAL IMPACTS OF GEOTHERMAL ENERGY UTILIZATION

#### 3.1 Overview

Mankind has used and will continue to use all forms of available energy, with the purpose of taking advantage of them where possible in a direct way or by means of some process. But it is clear that any type of energy production requires some kind of building and engineering activity and will, therefore, cause environmental impacts (Kristmannsdóttir and Ármannsson, 2003). Generally, good technological advances have been made, especially during the last century but, at the same time, the environmental effects have also increased. This has been partly due to a poor understanding of the environment and its processes, often causing unpredictable and irreversible environmental changes (Hunt, 2001). Some details of those aspects are approached in the next sections.

Geothermal energy is vital in many countries around the world. It is generally accepted as being an environmentally benign energy source, particularly when compared to fossil fuel energy sources, but it is not completely free of adverse impacts (Hunt, 2001; Bahati, 2005). In most cases, this is proportional to the scale of such development (Noorollahi, 2005).

Geothermal power generation is often considered a “clean” alternative. The most important environmental changes brought about by geothermal utilization are associated with the exploitation of high-temperature geothermal systems (see Table 2), changes such as: surface disturbance, physical

TABLE 2: Possibilities of environmental effects of geothermal development (mod. from Hunt, 2001)

	Low-temperature system	High-temperature system	
		Vapour-dominated	Liquid-dominated
<b>Drilling operations:</b>			
Destruction of forests and erosion	X	XX	XX
Noise	XX	XX	XX
Bright lights	X	X	X
Contamination of groundwater by drilling fluid	X	XX	XX
Flora and fauna	X	XX	XX
Geological formations	X	X	X
<b>Mass withdrawal:</b>			
Degradation of thermal features	X	XX	XXX
Ground subsidence	X	XX	XXX
Depletion of groundwater	O	X	XX
Hydrothermal eruptions	O	X	XX
Ground temperature changes	O	X	XX
<b>Waste liquid disposal:</b>			
<i>Effects on living organisms</i>			
Surface disposal	X	X	XXX
Reinjection	O		O
<i>Effects on waterways</i>			
Surface disposal	X	X	XX
Reinjection	O	O	O
Contamination of groundwater	X	X	X
Induced seismicity	O	XX	XX
<b>Waste gas disposal:</b>			
Effects on living organisms	O	X	XX
Microclimatic effects	O	X	X

O: No effect; X: Little effect; XX: Moderate effect; XXX: High effect;

effects due to fluid withdrawal, noise, thermal effects and the emission of chemicals (Ármansson and Kristmannsdóttir, 1992; Hunt, 2001; Kubo, 2003). More recently, socio-cultural and economic factors are included as important aspects to consider in geothermal projects (De Jesus, 1995; Hunt, 2001).

### 3.2 Gaseous emissions

During the operation of a geothermal power plant, some geothermal gases and fine solid particles are freed to the atmosphere. Some air pollution may be caused by the discharge of these gases; but two of them in particular, monopolize the attention, i.e. carbon dioxide (CO<sub>2</sub>) and hydrogen sulphide (H<sub>2</sub>S), partly due to their effects on living organisms (including man) and for their relationship to greenhouse gases and their role (along with methane) in the warming effect on the earth, although mercury, radon, ammonia, argon, nitrogen, arsenic and boron can also be present and cause problems (Kristmannsdóttir and Ármansson, 2003; Kubo, 2003; Noorollahi, 2005). Some important details of the biological impacts of those gases are presented by Webster and Timperley (1995).

CO<sub>2</sub> is the major component of the gas present in geothermal fluids, but research in volcanic terrains suggests that the development of geothermal fields makes no differences to the total CO<sub>2</sub> emanated from those terrains (Kristmannsdóttir and Ármansson, 2003). There is some evidence that in high-temperature fields, the amount of CO<sub>2</sub> discharge decreases with time as a result of degassing of the deep reservoir fluid (Hunt, 2001). This is debatable; some state that CO<sub>2</sub> emissions increase with exploitation.

Hydrogen sulphide probably causes the greatest concern due to its unpleasant smell and toxicity at moderate concentrations (Ármansson and Kristmannsdóttir, 1992). In exploited geothermal fields, its concentration increases relatively more than the concentration of CO<sub>2</sub>, probably because of the higher reactivity of H<sub>2</sub>S. It is claimed that most of this gas will end up being oxidized to SO<sub>2</sub> to a degree, but there is little evidence of such an effect in the vicinity of geothermal plants and it has not been demonstrated that H<sub>2</sub>S is indeed oxidized to SO<sub>2</sub> to any degree. On the contrary, it has been demonstrated that a considerable proportion of the H<sub>2</sub>S is washed out of the steam and precipitated as elemental sulphur (Kristmannsdóttir and Ármansson, 2003).

### 3.3 Water

Unless all waste waters are re-injected, geothermal fluid discharge may have an impact on local and regional surface waters (creeks, rivers or lakes), polluting those waters with toxic ingredients such as lithium, boron, arsenic, ammonia and mercury (Noorollahi, 2005) and increasing the temperatures; thus, it is clear that surface disposal causes more environmental problems than reinjection (Hunt, 2001). However, reinjection not done properly can cool down the geothermal field and/or contaminate groundwater.

The release of large volumes of waste water into a waterway may increase erosion, and if uncooled and untreated, may precipitate minerals such as silica (Hunt, 2001). Changes in pH or temperature can result in the chemical poisoning of plants and animals, causing some of the toxic substances to move up the "food chain" (Hunt, 2001) or as chemicals in solution that can be incorporated into aquatic plants and fish (Webster and Timperley, 1995; Hunt, 2001).

### 3.4 Landscape impacts and land use

Geothermal plants require relatively little land in comparison to nuclear or coal plants and they do not require the damming of rivers or tunnels, open pits or oil spills. They are clean because they neither burn fossil fuels nor produce nuclear waste, and can be sited in farmland and forests and share land



with cattle and local wildlife (Noorollahi, 2005). But, geothermal energy must be utilised relatively close to its resource in order to reduce heat and pressure losses and disruption to the landscape. The exploitation can change the landscape and land use because of the required land for drill pads, access roads, steam lines and transmission lines in addition to the power plant (Brown, 1995; Hunt, 2001). On the other hand, the visual effect on the landscape depends on the type of countryside, the scale and the phase of the development. The impact of permanent features like pipelines can, for example, be reduced by painting or planting trees (revegetation) (Brown, 1995), and more recently examples of siting the pipelines below the surface have been seen. Generally, the geothermal plants have a low profile, however their visual impact may still be significant, and it may be particularly high during drilling due to the presence of tall drill rigs (Hunt, 2001), but this impact feature is temporary.

In many places, the development of geothermal projects has become controversial, mainly because many of the geothermal prospects are within protected zones (national parks or natural reserves). On the one hand, the country needs new power plants to resolve their energy necessities, and on the other, it is very important to protect resources like soil, natural forests, wildlife and water.

### 3.5 Noise

Noise (“unwanted sound”) is one of the most ubiquitous disturbances to the environment from geothermal development, particularly during construction and operation phases, especially if it is considered that geothermal development often occurs in sparsely populated areas with low noise levels, and any additional sound is very noticeable (Brown, 1995). Table 3 summarizes some noise levels in geothermal plants.

TABLE 3: Some typical noise levels (from Brown, 1995)

<b>dBA</b>	<b>Familiar sound</b>	<b>Average subjective description</b>
130	Jet takeoff at 60 m	Intolerable
125	<i>Well discharge</i>	
120	<i>Free venting well at 8 m</i>	Very noisy
110	<i>Drilling with air at 8 m</i>	
100	Unmuffled diesel truck at 15 m	
95	Loud motorcycle at 15 m	
90	<i>Construction site</i>	Noisy
90	<i>Well vented to rock muffler</i>	
85	Office with typewriter	
80	<i>Mud drilling</i>	
75	Street corner in large city	
70	Loud radio	
70	<i>Outside generator building at 8 m</i>	Quiet
60	Accounting office	
40	Residential area at night	
25	Broadcasting studio	Very quiet

Noise occurs at the exploration drilling, construction and production phases of development, where the air drilling is the most noisy (110 dBA) (Table 3), but with suitable muffling, it can be reduced to around 90 dBA (Brown, 1995; Kubo, 2003); it is important to clarify that the drilling is not a permanent feature. Most of the noise from power plants results from the cooling tower, transformer and the turbine-generator building; once the plant starts operation, noise mufflers can be effective enough to keep environmental noise below even 65 dBA (Ármansson and Kristmannsdóttir, 1992; Brown, 1995).

The residents in such areas will probably regard any noise as an intrusion. Also, animal behaviour is affected by noise and there are reports of changes in size, weight and reproductive activity, mainly of birds but also of some mammals (Noorollahi, 2005).

### 3.6 Ground subsidence and earthquakes

Withdrawal of fluid from any type of underground reservoir will normally result in a reduction of pressure in the formation pore space, and then subsidence can occur (Brown, 1995). In the case of geothermal fields, in the early stages of development the fluids are withdrawn from a reservoir many times, at a rate greater than the natural inflow into the reservoir. This net outflow causes rock formations at the site to compact, particularly in the case of clays and sediments, leading to ground subsidence at the surface. In general, subsidence is greater in liquid-dominated fields (Noorollahi, 2005), but has also been observed in groundwater and petroleum reservoirs (Hunt, 2001).

Horizontal movements and ground subsidence can seriously affect the stability of pipelines, drains and well casings. Sometimes it can cause the formation of ponds and cracks in the ground, and instability in buildings if the project is near a town. The largest recorded subsidence in geothermal areas is at Wairakei (New Zealand), where the ground subsided around 15-18 m in 30 years of fluid extraction (Hunt, 2001), but there are also reports of subsidence in places like Iceland, USA and Italy (Ármannsson and Kristmannsdóttir, 1992; Kristmannsdóttir and Ármannsson, 2003).

Geothermal fields are often located in areas of active seismicity, where there is a natural occurrence of earthquakes that are not specifically related to geothermal exploitation. Some earthquakes of very low magnitude (detected only by instrumentation) have long been recognised to occur in geothermal systems whether they are exploited or not (flow of water through subsurface channels), and sometimes it has been possible to relate this to deep injection of fluids (Brown, 1995).

Fluid reinjection can help reduce pressure drop and hence subsidence, but its effectiveness depends on where the fluid is re-injected and on the permeability of the field. It is carried out at some distance from the production wells to avoid cooling of the reservoir (Noorollahi, 2005); therefore, this process would be an inductive agent of seismicity (induced seismicity), according to Ármannsson and Kristmannsdóttir (1992).

### 3.7 Changes in natural activity

Natural surface features (hot springs, mud pools, geysers and fumaroles) are associated with most geothermal systems and because of their uniqueness, can have a high conservation value. They are often tourist attractions or are used by local residents. These visible signs of geothermal activity are a part of a country's heritage and in any geothermal development they must be taken into account as part of the environmental assessment, and monitored continuously (Brown, 1995; Kristmannsdóttir and Ármannsson, 1999).

Historical evidence shows that natural features have been affected during the development and initial production stages of most high-temperature geothermal fields (Hunt, 2001). Withdrawal of reservoir fluid through drill holes can lead to a pressure decline in the reservoir and may cause hot springs to dry up. Reservoir depressurization may also enhance boiling at shallow depths and in this way enhance fumarolic activity. It is difficult to predict these changes before production (Noorollahi, 2005).

Before any development takes place, the superficial geothermal features should be catalogued, collecting all available information and for as long as possible to provide a data baseline for future comparison. It should also be recognised that geothermal features can change without any

interference; usually local weather, rainfall, local seismicity and subsidence can have a marked effect on the activity of geysers and fumaroles in particular (Brown, 1995). Some moderate to severe but localised effects on natural thermal features were observed in the Wairakei and Broadlands-Ohaaki geothermal fields in New Zealand (Glover and Hunt, 1996; Glover et al., 2000; Hunt, 2001).

### 3.8 Socio-economic impacts

There is an increasing tendency and need to include social and economic effects within environmental studies, in order to resolve controversies, improve plans and take mitigating measures (Kristmannsdóttir and Ármannsson, 2003). People are now more aware and wish to be considered in relation to how the project, its development and its environment may affect them (positively or negatively). Lack of information or misinformation about the nature of a proposed project, can cause resentment and criticism about the project. This can be avoided with adequate public participation. It can be used positively to provide information about the project and its impacts, prevent an escalation of frustration and anger, and thus help find solutions to conflicts that can exist and clear up misunderstandings (Glasson et al., 1994).

It is important to integrate social and economic aspects into the geothermal development, because the social-cultural acceptability of the project depends on the political, economic and social circumstances of the community. These factors can be affected by the project and the impact can be enhanced (positive effects), mitigated or prevented in the case of negative effects (De Jesus, 1995).

Also, the economic impact is directly related to the advantages of the project in the lifestyle of the community (employment, better income and social services).

## 4. FUTURE GEOTHERMAL DEVELOPMENT IN THE LAS PAILAS AREA

### 4.1 Overview

Geothermal resources have been known and used in many ways for thousands of years. Presently, they are mostly used on a large scale for the generation of electricity. Geothermal energy is based on naturally occurring fluids that contain energy and, therefore, is a clean renewable energy source. There is growing knowledge on the impacts of geothermal utilization and possible mitigating measures. This has been shown in several countries where geothermal energy occupies an important place for the generation of electricity, for example in Iceland, Italy, New Zealand, United States, Mexico and many others countries.

The current electricity generation system in the Costa Rican Republic is based on a programme oriented mainly towards the utilisation of domestic renewable natural resources, and this has been implemented since the second half of the 20<sup>th</sup> century. The Costa Rican Institute of Electricity (ICE) is the institution dedicated to the generation, transmission and distribution of electricity in most parts of the country. Geothermal energy constituted the second most important energy resource in the year 2003, with a generation equivalent to 15.1% of the total electrical energy produced in the country (Figure 4), permitting a marked reduction of the import

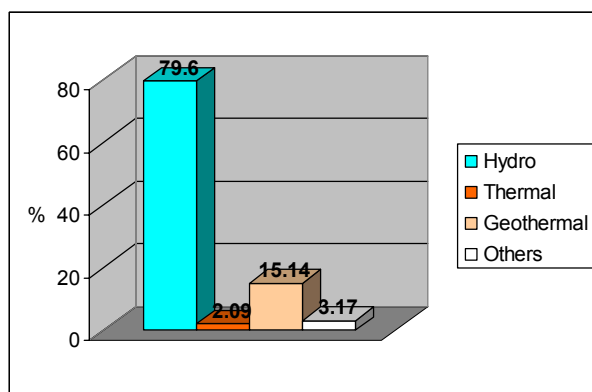


FIGURE 4: Total installed electrical capacity by source in Costa Rica for the year 2003 (modified from Mainieri, 2005)

of petroleum products necessary for the operation of thermal plants (Mainieri, 2005).

In Costa Rica the price and consumption of fuel are very high, and if the country must produce electricity using fossil fuels, the socio-economic costs will also be high. From this point of view, geothermal energy is a good choice for the country to develop from an energy and environmental perspective. Las Pailas area is a high-temperature geothermal field with good possibilities for electrical production within the concept of a sustainable exploitation. It will be the second geothermal field in the country to be exploited after the Miravalles geothermal field (Figure 1).

With the drilling of five exploratory wells in the Las Pailas geothermal area, ICE began activities leading to a feasibility study, based on positive results demonstrated during the pre-feasibility study in the last years of the 1990s (GeothermEx, 2001; Mainieri, 2005). It is a geothermal field with temperatures near 260°C, of moderate salinity and with a low content of non-condensable gases (Mainieri, 2005).

At the same time, other complementary investigations were continued to strengthen previous data, by means of additional geophysical soundings and the drilling of several gradient wells, which underlined previous conclusions on the presence of a geothermal anomaly in the Pailas area (GeothermEx, 2005). At the same time, environmental studies began with the objective of creating a “base line” (background data), understanding the natural conditions of the area prior to development, and to control these by monitoring before carrying out additional drilling and exploration activities in the area.

Four wells were drilled to confirm the existence of a geothermal reservoir that could produce commercially usable steam for the production of electricity, whereas the fifth well was developed in a peripheral sector of the field for injection of waste fluids. Three of the drilled production wells gave positive results and proved the existence of the geothermal system. The fifth (injection) well did not find good permeable conditions. Consequently, the drilling of new exploration wells for reinjection in other areas is planned.

The actual location of the geothermal area is quite complex for various reasons. The project affects the lands of the Rincón de la Vieja National Park, an area that is administered by the National System of Conservation of Areas (SINAC) of the Ministry of Environment and Energy (MINAE), through the Area of Conservation of Guanacaste (ACG). It corresponds to a narrow area located between the Blanco and Colorado rivers. The eastern border of the project has a natural limit (Blanco river), between the actual geothermal area and a natural reserve called “Guanacaste Dry Forest”, administered by Bio Guanacaste (ONG). Then, there are also two private mountain hotels within the Las Pailas geothermal area (Figure 5).

Although the project area has these singularities, it is clear that a geothermal project can be developed simultaneously (no excluding activity) as has been done successfully in Italy, United States, Japan, Indonesia, Mexico and other countries. In this case, the environmental viability has been demonstrated according to studies carried out with that aim for ICE professionals. These studies were approved according to the laws and effective environmental regulations in the country by the Technical Secretary Environmental National (SETENA) in 2005.

Independent of the approval of the environmental impact assessment (EIA), and as a part of necessary environmental control, environmental sampling was started in the geothermal area in the last months of the year 2000, to determine the background environmental parameters and to control possible impacts related to the activities of the geothermal project. All these data are in the data base of the Management and Environmental Monitoring of Geothermal Resources Centre (CSRG) at ICE. After the EIA was approved (ICE, 2005), the environmental project has continued by gathering information on noise data, water chemical analysis and H<sub>2</sub>S and CO<sub>2</sub> gases in specific points within the project area.

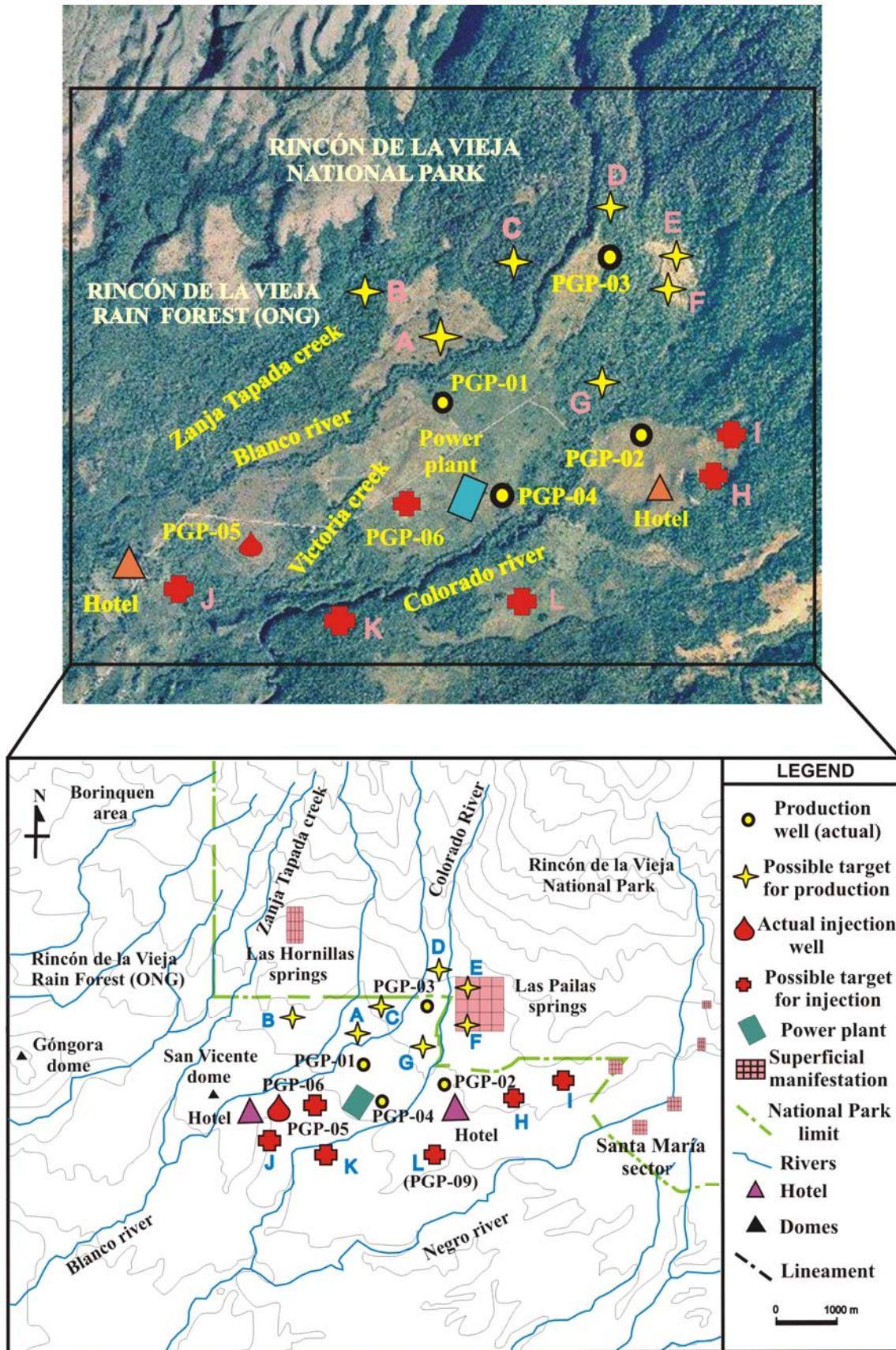


FIGURE 5: Possible future distribution of drill sites (directional production and injection wells) in the Las Pailas geothermal area

All the extensive work done by ICE, with geoscientific and drilling investigations, suggest the Las Pailas field is able to sustain a production of 35 MWe of electricity for a period of at least 20 years. From an environmental perspective, the geothermal exploratory work including the drilling of numerous gradient wells and five deep wells, has demonstrated the capacity of ICE to carry out this work in harmony with the environment.

## 4.2 Possible geothermal development

Having approved the respective environmental studies (EIA), GeothermEx (2005) presented to the ICE authorities the results of the geothermal feasibility study, supported by mathematical modelling, confirming the capacity of the field and recommending the installation of a first unit of 35 MWe in the Las Pailas area. ICE plans to have a geothermal plant on-line by the year 2010 (Mainieri, 2005), and is now looking for external financing to complete the drilling for an additional volume of steam, and the construction of the power plant.

### 4.2.1 Drilling of additional geothermal wells

In order to maintain a generation of 35 MWe with the utility of the power plant running for at least 20 years, it will be necessary to drill several additional wells to the five existing wells. The aim will be to fulfil production demands for the plant and to handle the production fluids of the plant through reinjection. GeothermEx (2005) has estimated that approximately 9 production wells and maybe 2-4 injection wells are needed for the project of generating 35 MWe. Replacement of the production wells would be expected during the third, sixth and tenth years of the project, respectively.

Acquisition of land necessary to project development has been completed and the project will continue with the drilling of the new wells in the year 2007. The final number of wells will be a subject of the results and capacity obtained during this drilling phase. Once the project is in operation, it will be necessary to drill additional wells to compensate for production decline and to optimize the development and handling of the geothermal field.

The new location of wells for production and injection (Figure 5) should be aimed at targets that can be reached by means of directional drilling, either from existing platforms or new ones or, in some cases, by means of vertical wells. Their location can be defined in different terms, according to necessity. It is important to note that the location of drilling targets is approximate. The intention with the proposed sites in Figure 5 is to show the recommended distance between wells and the accommodating spatial limitations. The results from new wells must then be taken into account, and influence the location of further new wells. Thus, it is possible to modify the conceptual model of the geothermal system, as more information is gathered.

According to Figure 5, the possible sites for the production wells are:

- Existing wells PGP-01 and PGP-03:
- Site A: It can be reached by means of a directional well with an approximately northwesterly direction from a new platform that can be constructed between the platforms of wells PGP-01 and PGP-03.
- Site B: It can be reached by means of a vertical or directional well from a new platform between the platforms of wells PGP-01 and PGP-03.
- Sites C, D, E and F: They can be reached by means of drilling directional wells in the approximate directions west, north, northeast and south-southeast from platform PGP-03.
- Site G: It can be reached by drilling a directional well from the platform of PGP-01 or from a new platform to be constructed between wells PGP-01 and PGP-03; alternatively, it could be reached by means of a vertical well from a new platform.

- Additionally, PGP-04 is a potential production well and even PGP-02, if deepened.

Figure 5 also displays the possible locations of injection wells:

- Site H: This site can be reached by means of a vertical well (for injection) drilled from a new platform that would be constructed in this sector.
- Site I: It can be reached by means of a directional well from a new platform.
- Sites J and K: They can be reached by means of directional wells from the platform of well PGP-05.

There are several possible future scenarios for well drilling strategy, based on the requirements or the results obtained from the first wells. It is possible to go through a recommended sequence as is described in the following. At the end of each step in the described sequence, the results of drilling and testing each well must be evaluated and used to refine and, if necessary, to modify subsequent steps (Figure 5):

- a) Drilling for target H will demonstrate the injection capacity in the east sector of the field, and at the same time provide access to a well making it possible to inject water from the initial long tests into production wells.
- b) If site H proves successful, the next step could be drilling for target I; alternatively, after evaluating the results, drilling can be considered for targets J and K, or for additional targets to provide the necessary injection capacity.
- c) To drill for target B (by means of a vertical or slightly deviated well).
- d) From the same platform (B), to drill for target A. If this target is verified to be of high production, drilling of future additional wells can be considered in this same sector, from the same platform or from the platform of well PGP-01.
- e) To drill up to 4 directional production wells from the platform of well PGP-03, oriented towards targets C, D, E and F, in that approximate order. The total number of wells to be drilled from this platform and the precise location of targets will depend on the results that are obtained from the previous wells.
- f) If additional steam capacity is necessary for production, drilling for target G, from any one of the platforms, based on which location is judged best, can be considered; otherwise, this target can be reserved for a future replacement well.
- g) Finally, it is possible to consider the deepening of well PGP-02, and to evaluate if well PGP-04 can be used commercially to avoid the necessity of drilling an extra well.

On the other hand, Chavarría et al. (2006), based on the same information and relating to the three injection wells proposed, suggested the following:

- Not to drill for targets J and K: because they are located in a sector where the possibility of success is small according to the thermal gradient, resistivities and geological structures.
- Not to drill where PGP-06 is located, as it is in a sector of strong uncertainty due to its proximity to well PGP-05 and to the geophysical conditions of the nearby border.
- To drill for target L (PGP-09): It is considered that this well has a better possibility for success. Nevertheless, is recommended to relocate it approximately 300 m to the north of the present position, with the purpose of moving away from the caldera border and into a zone of greater geophysical interest.

#### **4.2.2 The power plant and other superficial constructions**

The approximate area of the project is around 10 km<sup>2</sup> (Figures 6 and 7). Within this area, all the related works of the project will be constructed. They mainly include the following:

- Provisional facilities;
- Routes of access and terraces of drilling;
- Deep wells (see Section 4.2.1);
- Pipelines;
- Separating stations;
- Generation plant;
- Sub-station and transport network.

The development of the Las Pailas will take advantage of the human resources, laboratories, drilling equipment, camping and other specialized infrastructure available in the Miravalles geothermal field. This avoids the construction of new facilities.

The location of the power plant has been chosen based on economic and site-specific reasons. The selected site is suitable with regard to geologic and geotechnical conditions; it has water availability and its elevation will result in the production and waste (hot and cold) fluids travelling by gravity to the power plant and injection wells, respectively. This way, there is no great loss of either pressure or temperature, which is an important aspect in developing geothermal energy. Finally, the selected site corresponds with a zone of grass (almost free of trees), an important reason for locating this power plant there (Figures 6 and 7). An important fact is that most of the roads already exist, but they will need to be improved; in some cases, it will be necessary to construct new roads to access different facilities or possible new drill sites, complying with environmental regulations.

One possible alternative based on the actual Las Pailas reservoir conditions, is for ICE to decide to build a “single-flash” power plant. Such a plant has a steam turbine, where geothermal fluids include liquids in a gaseous phase, making necessary a separation process (in this case at 7 bar and with two separating stations), with the steam used just once to generate electricity.

The waste waters (hot and cold) will be injected into the deep injection wells (Figure 5), drilled and selected for that aim; and this will avoid any type of contamination of superficial and ground waters.



FIGURE 6: Future geothermal plant site and the platform for well PGP-04, in relation to the national park entrance road



FIGURE 7: View of Las Pailas area, showing the location of 4 deep wells, the national park and the territories of the ONG, Rincón de la Vieja Hotel and the site selected for the geothermal plant



## 5. MONITORING AND ENVIRONMENTAL IMPACT ASSESSMENT IN THE LAS PAILAS GEOTHERMAL AREA

### 5.1 Monitoring considerations – an overview

Monitoring is defined as “periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals” (EPA, 2006). Another definition is “to keep track systematically with the intention of collecting information” (Answer Com, 2006). Both terms are correct, but the most important consideration is that monitoring is a very useful tool to obtain data and, based on that, to make the best decision.

A fair amount of information on environmental factors in geothermal areas should be available as a previous step to exploitation (Ármansson and Kristmannsdóttir, 1992), but it is clear that monitoring data and its interpretations need to be actively used and not merely filed away (Hunt, 2001) or kept only as a legal requirement. Base line conditions provide the context for evaluating the environmental impact of a project (Bahati, 2005).

Hunt (2001) displays some important reasons for monitoring:

- (a) Obtain data on which informed resource management decisions can be made;
- (b) Verify that management decisions are having the desired outcomes;
- (c) Enable the public to have confidence in the environmental management process; and
- (d) Assist in building up knowledge on geothermal systems and how to develop them in an environmentally responsible way.

He also considers that there are some basic principles in monitoring such as:

- (a) Needs to begin before development starts so that a good baseline can be obtained;
- (b) It should be conducted frequently so that natural variations can be distinguished from exploited-induced changes;
- (c) The data collected needs to be interpreted and regularly compared with pre-determined trigger points; and finally
- (d) Data needs to be reliable; equipment should be calibrated regularly and operated by a competent person.

Additionally, in order to assess the influence of variations in climatic conditions on thermal features and groundwater temperatures and levels, it is necessary to also measure rainfall, air temperature and air pressure.

Costa Rica had many laws on with environmental aspects, but with the approval of the Organic Law of the Environment in 1995 (Zeledón, 1998), important and more scientific and realistic criteria were established to permit the viability of a project (or not). This law has the fundamental objective of improving the environmental quality and life of the inhabitants of the country, integrating nature and man and establishing the necessary environmental procedures to follow in order to establish any type of project. In addition, it establishes the National Environment Technical Secretary (SETENA) as being in charge to transact and to approve, or not to transact, and to pursue projects in environmental matters, according to laws and procedures.

In February 2000, ICE presented to the SETENA, a Preliminary Form of Environmental Evaluation (FEAP) with the purpose of initiating feasibility studies in the Las Pailas area. This first stage consisted of the drilling of 10 deep exploratory wells in the zones called Las Pailas and Borinquen (5 wells in each area). Receiving the environmental permissions from the respective authorities, the drilling stage of the geothermal development began in the year 2001, but the environmental activities

of the Las Pailas project began in August 2000, some months before the first deep geothermal well was drilled (ICE, 2005). Those studies were oriented at obtaining base data (background), with the objective to gain knowledge of the environment's quality (physical and chemical). The first monitoring data were obtained on superficial water quality, air quality (H<sub>2</sub>S and CO<sub>2</sub> concentrations) and noise, and then critical sites were chosen as points for sampling and reference according to local environmental conditions. Additionally, the collection of climatic data began (temperature, rainfall, etc).

From 2002, a higher level environmental phase began in the project area, including biological variables (flora and fauna), social variables, the baseline data were strengthened, especially with regard to physical and chemical aspects such as atmospheric quality, hydrology and soils. Later, archaeological and landscape studies were added, and then a complete environmental profile of the area of the Las Pailas geothermal project was obtained. Environmental monitoring has, to date, continued as an essential part of the development of the Las Pailas project.

In December 2004, SETENA communicated to ICE that the environment evaluation process must continue and it would be necessary to carry out an Environmental Impact Assessment (EIA) according to established laws and procedures. The study generated prevention and compensation measures in all its aspects. The study was approved last year and new plans, including the drilling of new deep wells and the building of a power plant in the Las Pailas area are to be realised in the year 2007, with the aim of initiating operations in 2010-2011 (ICE, 2005).

In the following sections some important dispositions are described that have been approved in the Las Pailas EIA, and, therefore, they are effective and legally obligatory for ICE in the next years. Also, it is important to comment on some legal and economic situations that relate to future development and necessities in the energy and environmental matters of the country.

## 5.2 Land requirements

In geothermal projects most surface impacts occur during construction and drilling. Each drill site usually occupies an area between 200 and 2500 m<sup>2</sup>. Geothermal power plants require some space, but relatively little in comparison to other energy types (nuclear or coal plants) and they do not require the damming of rivers, tunnels, open pits or oil spills (Noorollahi, 2005).

According to ICE (2005), the approximate area needed for the Las Pailas project is around 10 km<sup>2</sup>; Within this area ICE will construct all buildings and other works related to the project (Figure 7), including: (a) provisional facilities, (b) roads and other access to the power plant site and the new drilling platforms, (c) new deep wells, (e) pipelines, (f) the separator stations, (g) a sub-station and energy transport lines, and (h) the power plant including offices. The size of the area affected by the construction of a power plant of 35 MWe is estimated to be about 2.5 km<sup>2</sup>, covering a rural zone without forest cover.

For the development of the Las Pailas geothermal project, ICE will take advantage of human resources, laboratories, drilling equipment, camping and other specialized infrastructure already available in the Miravalles geothermal field (around 10 km away, straight line). In addition, it is important to mention that many of the necessary roads and most of the deep well platforms already exist, because ICE is planning for new deep wells to be drilled by means of directional drilling using mainly the existing platforms. With this strategy, ICE only needs to construct a few new well platforms (Figures 5 and 7).

Finally, an important aspect to consider concerns options for routing electrical transmission lines between the power plant (future substation Pailas) and Liberia town (around 12 km to the south), as part of the ICE interconnected national system (SNI). The analysis and criteria that prevailed for the

selection of the definitive route included: a cartographic study of possible ways; trying to prevent impacts in forests (primary or secondary) and forest plantations; avoiding impacts on Rincón de la Vieja National Park; reduce, as possible, interference with tourist activities in the area; adapt the design to the landscape compositions; diminish the access construction; and avoid breaking the continuity of forests because of negative biological effects (ICE, 2005).

### 5.3 Air

The quality of the air is a very important parameter for the standard of life. Therefore, its constant monitoring has become a tool used to obtain real data on its quality all over the world.

Electricity generation from geothermal resources involves much lower greenhouse gas emission rates than that from fossil fuel. Replacing one kilowatt-hour (kWh) of power from fossil fuel with one kilowatt-hour of geothermal power reduces the estimated global warming impact by around 95% according to the International Atomic Energy Agency (IAEA). In addition, the extraction, refinement and transport of fossil fuels can entail substantial greenhouse gas emissions (Hunt, 2001). If geothermal energy replaces other forms of energy, especially from fossil fuel, the benefits for many countries are evident, not only because of reduced dependence on imported fuels but also in eliminating pollution caused by particles and greenhouse gases (Lund and Freeston, 2000).

During operation normal geothermal plants produce non-condensable gases which are released to the atmosphere. Two of these gases have high importance as they affect people's health and contribute to global warming: hydrogen sulphide ( $H_2S$ ) and carbon dioxide ( $CO_2$ ). The Organic Law of the Environment defines this type of waste as an atmospheric contamination (Zeledón, 1998). Hydrogen sulphide ( $H_2S$ ) is a poisonous gas, common in volcanic areas and as a decompositional product of organic matter. In very high concentrations, it can cause the death of humans, but at low concentrations it may have some effect on vegetation. Carbon dioxide ( $CO_2$ ) is another very common gas. In its natural form it is found in the atmosphere, and in some excess in volcanic zones. In high concentrations it can lead to mental disorder, headache and, finally, loss of consciousness. It can even cause death due to pH variation in human blood. In comparison with other sources of electrical energy production, the amount of  $CO_2$  emitted in geothermal plants is relatively low and additionally do not produce gases of  $NO_x$  type (Kubo, 2003; GeothermEx, 2005).

There are strict international norms for the permitted maximum emissions of both types of gas. In Las Pailas area, five critical sites were chosen within the project area: one hotel, inside Rincón de la Vieja National Park, deep well sites and Curubandé (nearest town, around 7 km away). The equipment used is a portable monitoring station that registers data on both  $H_2S$  and  $CO_2$ . The measurements are done weekly, with additional measurements during production tests of deep wells. The gas concentrations remained quite similar during the weekly monitoring.

The  $H_2S$  detection equipment has 0.0003 ppm as the detection limit, and an error range of 0.001 ppm. The measured values of  $H_2S$  were generally 0 (zero), however values of 0.005 ppm were sometimes registered. It is important to emphasize the presence of fumaroles and the volcano near the project area, since these are natural sources of  $H_2S$  emission, which in stable climatic conditions can locally give high signals for  $H_2S$ . In Costa Rica, the maximum permitted value for  $H_2S$  is 0.03 ppm (ICE, 2005). In the case of  $CO_2$ , the values varied in the range 300-600 ppm as normal values in the atmosphere, taking into account the error range of normal equipment. The equipment used for monitoring  $CO_2$  registers data in the range from 0 to 10000 ppm and has an error range of 100 ppm for maximum concentrations. In Costa Rica the maximum permitted limit is 5000 ppm.

According to available data from the Miravalles geothermal field on different gases and an estimate on the gas content in the Las Pailas geothermal wells (Table 4), and considering the atmospheric

conditions in the area, commercial operation of the Las Pailas power plant should not cause a significant impact in the quality of the air in the area (ICE, 2005; GeothermEx, 2005).

TABLE 4: Non-condensable gas production in the Miravalles geothermal field and the assessed values for Las Pailas geothermal field (ICE, 2005)

Plant	Production (MWe)	CO <sub>2</sub> *	H <sub>2</sub> S*	N <sub>2</sub> *	CH <sub>4</sub> *	H <sub>2</sub> *
Miravalles 1	55.0	2.59	0.020	0.03	0.00	0.00
Miravalles 2	55.0	3.07	0.020	0.06	0.00	0.00
Miravalles 3	26.1	2.74	0.020	0.01	0.00	0.00
TOTAL	136.1	8.39	0.050	0.10	0.00	0.00
Pailas wells	16.4	0.09	0.010	0.02	0.00	0.00
Pailas plant	35.0**	0.18	0.016	0.04	0.00	0.00

\* tons/h.; \*\* Extrapolated value

#### 5.4 Noise

The definition of noise is “a sound that is loud, unpleasant, unexpected or undesired” (Answer Com, 2006). In Costa Rica noise is included in the environmental laws, where it is considered an atmospheric contamination. It also establishes responsibilities in the control of sonic contamination with corresponding sanctions (Zeledón, 1998).

Knowing the particular location of the project, the next step was to identify and establish sites of greater vulnerability and impact in relation to noise. In October 2002, an intense measurement survey of noise levels was carried out, which consisted of measuring at the chosen sites three times a day at different hours (morning, noon and at night) every minute. The selected sites were Rincón de la Vieja National Park (office), Rincón de la Vieja Lodge (inside and outside), the road close to the platform of well PGP-01, an adjacent parcel to a natural forest, Guachipelín Hotel (inside and outside) and the centre of Curubandé (nearest town to the project). The results of this survey are presented in Table 5.

TABLE 5: Average noise measurements in decibels, dB (A), during a survey in October 2004 in the Las Pailas project area (ICE, 2005)

Location	Level of sonorous pressure (SPL) during measurements		
	06:00 – 08:00 h.	12:00 – 14:00 h.	18:00 – 20:00 h.
RV National Park (office)	52.4	47.3	49.0
RV Lodge (outside)	50.4	55.0	53.5
RV Lodge (inside)	50.0	47.0	48.0
Road in front of well PGP-01	45.1	51.0	47.5
Site adjacent to forest	55.1	56.2	n.d.
Guachipelín Hotel (outside)	48.3	56.0	54.0
Guachipelín Hotel (inside)	44.6	44.0	44.0
Centre of Curubandé town	47.5	54.2	60.0

n.d.: no data available; RV: Rincón de la Vieja

Sound is measured in decibels - dB (A), a unit that represents the level of sonorous pressure of the noise, with a ponder filter, simulating the form in which it is perceived by the human ear. Also, it is important to mention that some external noise (passing vehicles, wind gusts, high-volume radios, near creeks, etc) is incorporated in the measurements (ICE, 2005), and that during this period, a deep well was being drilled in Las Pailas area.

According to the legal frame of Costa Rica in the Decree of the Ministry of Health 18209-S (1988) the following is stated, "...are uncomfortable... when... perceived inside the neighbouring rooms with a greater intensity than 65 dB (A) from 06:00 to 18:00 hours and greater than 45 dB (A) during the remaining 12 hours".

The collected data indicates that the sites of most noise are the centre of Curubandé town and the areas outside both hotels in the early hours of the night (18:00 - 20:00 h). Since the presence of machinery is inevitable, and considering the natural existing conditions in the area, in which no source of contamination by noise exists now, the study concluded that the intensity of noise is moderate and not widespread (very local). Anyway, silencer systems of all machines should be in a perfect state for their operation, which reduces the generated amount of noise to minimum levels (Kubo, 2003; ICE, 2005).

There will be some occasions during the project work and well test evaluations when the level of 85 dB (A) will be surpassed, but the impact is only generated sporadically and the effect will disappear immediately after the emission source is eliminated. Additional mitigating measures should be taken; it may be necessary to use special efficient silencers and to measure noise during the tests. If the noise levels still exceed the permitted limit, it may be necessary to add stone beds to the silencers or to inject water in the line to reduce noise.

### 5.5 Water (superficial and groundwater)

The area of direct project influence included the following micro-river basins: Blanco river, Negro river, Colorado river and Victoria and Zanja Tapada creeks (Figures 5 and 6). They display a radial and parallel drainage pattern. In general, they are all mountain rivers and creeks.

The micro basin of Victoria creek (Figure 7), due to its proximity to most of the drilled wells, and to being used as the primary source of supply of high-quality water for Curubandé town and Guachipelín hotel, seems to be a place of high vulnerability (ICE, 2005).

Hydrological studies show that the entrance volumes of the Blanco and Colorado rivers into the project area were 0.44 m<sup>3</sup>/s and 0.93 m<sup>3</sup>/s, respectively. In the case of Blanco river, its volume when exiting the project area has doubled (0.98 m<sup>3</sup>/s), while the Colorado river triples its volume average (2.6 m<sup>3</sup>/s) due to the contribution of Negro river and Victoria creek waters (Table 6). This study was made between January and September of the 2004, and includes values from both the dry season and the rainy season. The waters of these rivers and creeks are "crystalline" in appearance through most of the year, but despite that are not appropriate for human consumption due to their geochemical characteristics: they are usually acidic and sulphated due to the thermal and mineral contributions of the nearby geothermal springs (ICE, 2005).

TABLE 6: Flow measurements in the Blanco and Colorado rivers in Las Pailas area, made in January-September 2004, according to data from ICE (2005)

	Flow measurements in 2004 (m <sup>3</sup> /s)							
	15-01	11-03	14-04	19-05	16-06	14-07	10-08	24-09
Blanco river – upstream	0.757	0.25	0.14	0.28	0.23	0.40	0.26	0.42
Blanco river – downstream	1.29	1.57	0.56	0.68	0.64	0.61	0.61	1.27
Colorado river – upstream	1.84	0.64	0.40	0.76	0.78	0.78	1.10	1.27
Colorado river – downstream	4.12	1.34	0.96	1.82	2.04	2.04	2.81	3.41

In general, the waters of this fluvial system display pH values varying between 3.9 and 8.3, depending on the spring water type contribution. Its low pH value seems to be one of the main reasons for the absence of fish in the Blanco river. In other rivers, pH-values allow the existence of aquatic life in their waters, but still the studies show a low biodiversity in this fluvial system (Cháves, 2004; ICE, 2005).

The environmental studies included the chemical characterization of the water of each river, with concentrations determined for Na, CO<sub>3</sub>, Cl, Ca, SO<sub>4</sub>, Fe and TDS (total dissolved solids). The temperature and conductivity of the waters were also measured in the field and in the laboratory. Comparative data for each river and creek included in the study, show that SO<sub>4</sub><sup>-2</sup> was the predominant ion both during rainy periods as well as dry ones, followed by Ca<sup>+2</sup>, whereas the Na<sup>+</sup> and Cl<sup>-</sup> contents were smaller (Cháves, 2004).

Additionally, a detailed study with several stations in the area of the project shows the variation of rainfall and the chemical characteristics of the water. The pH values vary between 5.2 (close to well PGP-02) and about 6.0 in Curubandé town. Between 2003 and 2005, a more intense survey was carried out inside the area of the project's environmental influence.

In Las Pailas zone there are many surface manifestations, some of them of geothermal origin. Some geochemical data and other details are given in Section 2.4 and Figure 3. Special care must be exercised regarding the springs in the area; in fact many of them are located within the edges of the Rincón de la Vieja National Park and are considered natural attractions for tourists. But perhaps most importantly, they are part of an ecological system that is very fragile. From a geo-environmental perspective, these natural surface manifestations must be monitored regularly for the purpose of detecting any sudden or gradual change in their characteristics such as pH, conductivity, temperature, flow, chemical content, etc, especially during the drilling of geothermal wells and the operation of the Las Pailas geothermal power plant.

Finally, it is important to mention that waste geothermal water (hot and cold) will be re-injected down to deeper levels through re-injection wells located in areas previously selected based on their characteristics in permeability and their distance from the production areas. This technique consists of using wells sealed in their upper part with a whole casing to avoid contact with the groundwaters of the upper layers, but injecting the fluids into permeable layers that are almost always at depths below 800-1000 m. Usually, some artificial "lagoons" or "pools" are constructed, that serve as temporary storage (provisional), in case of emergency, during production well tests and/or during maintenance stages of the power plant.

## 5.6 Landscape and visual impact

There are many landscape definitions, but definitively this should include diverse features such as some of the area's most unusual geological formations, topographical features, areas of human interactions, as well as the vegetation and animals. It is important to note that a strong interrelation exists between landscape and biodiversity (Bridgewater, 1988). The project area constitutes a landscape in constant evolution for natural and anthropological reasons. Evolution has been slow because the agent modifiers are natural causes such as geologic and geomorphologic processes. In other cases, the agent modifier is man and the change of land use from forest to grasslands.

In agreement with the field work in the zone, there are two factors of the landscape that were especially distinguished between: scenic beauty and natural singularities. The first one refers in particular to individual panoramic views; they are characterized because they do not have apparent limits for the vision, with predominate distant elements and the sky dominating the scene. The natural singularities are characterized by the presence of a single component: an isolated tree, a waterfall or a

prominent land form. In the area, 14 natural singularities were identified, most of them located along the Blanco and Colorado rivers and in the Rincón de la Vieja National Park (ICE, 2005).

The presence of artificial elements in the Las Pailas area modifies the landscape in all its aspects: its naturalness, volume, form, chromatics and texture. The landscape study defined the points of greater visibility and the most probable places of observation. The Rincón de la Vieja National Park and the route that leads to the national park were considered the most important and forced (focus) points for observation for the people. It is clear that the visual impact of the power plant complex will be experienced from the start of construction as happened in Kenya (Kubo, 2003). The affected area is local though and limited to the work sites, and will be limited to the time of the construction.

As a part of the mitigating processes of visual impact, both during the phase of construction as well as during the operation of the power plant, for the natural landscape of the zone bordering the project, it is necessary to establish some design strategies, such as the construction and installation of ecological informative fences, an architectonic design in harmony with the environment of the place, establish vegetal screens and do revegetation in critical places, around buildings, pipelines and well platforms (ICE, 2005).

### **5.7 Vegetation and animal life**

As in other parts of the world, the tropic deforestation and the transformation of forests into grasslands is a very common process and is inextricably linked with habitat loss (Laurance, 1999; Hill and Curran, 2005); Costa Rica is no exception. Las Pailas area is formed by a mosaic of ecosystems where the grassland are predominant, but a few patches of forest exist outside the park limits. Generally these are secondary forests, where the more valued wood has already been extracted (ICE, 2005).

The construction of the power plant will affect the biotic and abiotic environments and it will be necessary to mitigate some activities to compensate for, or lessen, the magnitude of those impacts. For that reason, it is very important to study the forests and the fauna associated with the area to have an idea of the current status and how it will be affected (Cháves, 2004). Biologically, this zone is considered little studied, but the abiotic conditions and vegetal and faunal associations that converge here correspond to the “dry tropical” and “rainy pre-mountain forests” life zones (ICE, 2005). This puts greater emphasis on the area directly influenced by the project, i.e. the location of the deep wells and the power plant, as it corresponds to a different and complex mosaic of forest plantations, grasslands and secondary and gallery forests (Figure 7).

The study of flora was correlated with the sampling sites of the fauna. The biological study was conducted in two parcels of 1000 m<sup>2</sup> each at previously selected sites. In these an inventory of each tree was made, determining the botanical species, its diameter, commercial height and its total height. In the grasslands and pasturelands, a special sampling zone was not established, but the species of plants and their abundance were counted. The more important forest species are (in Spanish): melina, eucalipto, teca and pochote, the last one being the only native species of this forest zone. In a descending sequence the 10 most important species found at the site are the following (in Spanish): guácimo molenillo, guácimo, jiñote, laurel, manteco, matapulgas, guachipelin, lechozo and coyol, according to ICE (2005).

A greater diversity of mammals and amphibians was seen in the gallery forests bordering the national park, but the diversity of birds was superior in the secondary forests. In general, the established plantations and the grassland were habitats of smaller diversity. A total of 29 species with reduced populations and 9 species in danger of extinction were identified. Also, evidence exists that 13 species have been extinguished during the last three decades as a consequence of forest destruction (Bridgewater, 1988). Las Pailas biodiversity (animal) data are shown in Table 7 and Figure 8, based on data from Cháves (2004).

TABLE 7: Taxonomic diversity (animals) in Las Pailas area utilizing data of ICE (2005)

	<b>Mammals</b>	<b>Birds</b>	<b>Reptiles</b>	<b>Fish</b>	<b>Amphibians</b>	<b>Insects</b>
Orders	9	16	-	-	-	4
Families	26	38	10	4	4	28
Sub-families	-	22	-	-	-	-
Genus	39	125	31	6	5	148
Species	46	182	40	7	7	215
Species in R.P.	5	20	2	-	2	-
Species in E.D.	6	1	1	-	1	-

R.P.: Reduced populations

E.D.: Extinction danger

In the area, 46 species of mammals were identified (Table 7 and Figure 8), out of which 5 are species with reduced populations and 6 are in danger of extinction. The gallery forests and secondary forests and the forest in natural regeneration (“charral” in Spanish) with more vegetal cover were the habitats with more species of mammals. Here, around 137 species of resident and 45 species of migratory birds (182 species in total) were identified, 20 of which present reduced populations and one which is in danger of extinction.

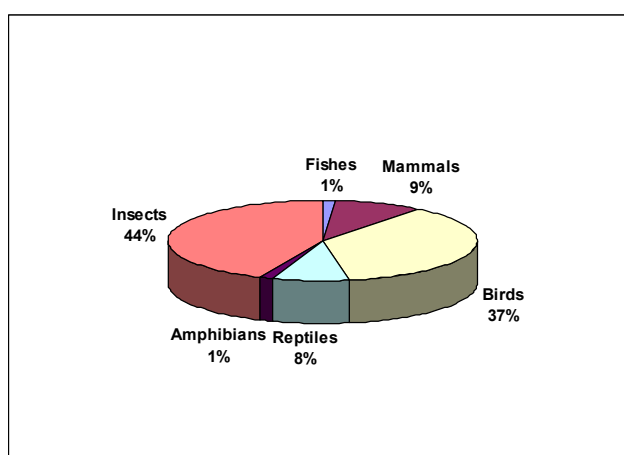


FIGURE 8: Diversity of animals in Las Pailas area considering only species level, data from Cháves (2004)

On the other hand, at the sites of incipient regeneration (young and secondary forests), the insects and reptiles seem to be diverse. There is especially a great wealth of butterflies observed in secondary forests and

pasturelands, similar to that seen in other tropical regions, where a great butterfly diversity in altered forest fragments is associated with a greater micro-environmental diversity, plant types and other necessary resources for the different butterfly stages. Cháves (2004) reported 215 species of insects, none of which are protected at the moment. On the other hand, 40 species of reptiles were identified, with two belonging to species with reduced populations and one to a species in danger of extinction.

The fish and amphibians had a smaller diversity. Of the different creeks and rivers, only in the Blanco river was no fish expected at the considered altitudes. This last aspect relates to the pH of the water, as mentioned in Section 5.5. For the whole area, a total of 7 species of fish were observed, none of which is a protected species. This diversity is very low in comparison to other rivers of Costa Rica (Cháves; 2004), see Table 7 and Figure 8.

The obtained results show that, in spite of the high degree of intervention in this area, a considerable diversity is experienced for some groups (e.g. for lepidopteron, reptiles, birds and mammals). Some examples are given in Figure 8. Probably these species have managed to survive in the zone thanks to their capacity to mobilize themselves between forest patches and to take advantage of the existing availability of resources in each one, as well as to the proximity of the national park. There is evidence that the degree of isolation between the wooded patches of a fragmented ecosystem as in Las Pailas is relative, and that it depends on the particular natural history of each species (Cháves, 2004; ICE, 2005). But it is also well documented that forest fragmentation lowers species number and alters community composition as a result of this change in forest shape (Hill and Curran, 2005).



It is very important to mention the presence of apparently endemic micro-organisms in the Las Pailas hot pool mud according to recent INBio studies (Sittenfeld et al., 2002; Sittenfeld et al., 2004; Sánchez et al., 2004), as mentioned in Section 2.4 and Figure 9.

In conclusion it can be said that according to the studies in the area, the biological impacts are very local, and in some cases of little duration (in time). The location of the Rincón de la Vieja National Park lands being relatively near the project permits the migration of animal species to the national park. Some of the ICE lands will not be used and instead used as zones of natural forest regeneration. In these cases, biodiversity will benefit directly. This has been demonstrated within ICE lands in the Miravalles geothermal field. Additional information will be given to workers involved in the project as a preventive measure to avoid possible negative impacts that they might exert on the local biodiversity. Finally, it is important to consider what to do precisely in areas with forests that are mostly secondary in growth that were already affected prior to the project. The project will mainly be developed in areas of extended grassland with isolated and impacted forest fragments (Figure 7). However, it is clear that mitigating measures must be considered and implemented in corrective ways with project advancement. The situations presented were not unanticipated.



FIGURE 9: Las Pailas area is a place of exceptional beauty and high biodiversity (especially lepidopteron, mammals etc); some micro-organisms live in the geothermal waters

## 5.8 Social-economic aspects

The construction of an electrical generation project represents a socio-economic factor of national importance and with local effects that can be gradual and different depending on their size and the installed power. Also, the source of generation used defines the degree of impacts for social and biological aspects (ICE, 2005).

The area of influence of such a project can be direct (primary) or indirect (secondary), based on the location of the power plant, wells and the distance to the nearest towns. A radius of around 500 m is indicative for the area of direct influence on buildings or towns. In this case, the nearest town is many kilometres away. According to national environmental regulations, the indirect influence area corresponds to the geographic space which is indirectly affected by the project, in a diverse degree of intensity. In this particular case, the nearest locality to the power plant, Curubandé town, is located 12 km away. Hence, it is within the area of indirect influence. On the other hand, ICE, with experience from the Miravalles geothermal field on prevention and mitigations, intends, as far as possible, to manage the field in total harmony with the surroundings. It will integrate the project into the landscape and aims at contributing to the area with technological elements of interest that will increase the local tourist potential.

According to population studies in July 2004, Curubandé district had 1952 inhabitants within its area, 993 men and 959 women. The local Social Security Institution (EBAIS) reports that within this

population, the age group between 20 and 44 years is dominant which means that the population is mainly young and of working age. The studies demonstrated that eco-tourism was the main source of income for the inhabitants of Curubandé, followed by work related to agricultural activities. Most of the women work in their homes, as is to be expected in a rural, traditional Costa Rican society, usually associated with the necessities of taking care of children.

The educational level of the inhabitants of the area is such that 96.6% of the population is at a secondary or lower level, and only 1.8% has a university education. This situation indicates that in a regional context, the Curubandé inhabitants are predominantly of a secondary non-university level. This means that presently it is difficult to find people within the Curubandé district who would apply for positions that require university (academic) background. It is possible that male manual labour may have more opportunities, and many young people leave school to take such jobs. That is supported by the fact that women (17.4%) surpass men (13.6%) at the secondary educational level, according to studies by ICE (2005).

ICE (2005) conducted a survey on the opinion of the zone's inhabitants with respect to the geothermal project. About 80% of Curubandé inhabitants had heard about the project whereas 63% of them said they knew that ICE is the institution that is going to carry out the project. About 53% of them knew what the project was about, and 98% of the group asked said that they were in agreement or in total agreement with the project being developed. The collected data concluded that the local people did not seem to have a clear understanding of what the project was about, but there was still 98% support for the project. Based on the available data, it was feasible to assume that the inhabitants see the project as a possible solution to increased job opportunities, at least temporarily. This relates most probably to their greatest worry of a lack of job opportunities in the area.

Additionally, it is important to emphasize the positive effects or impacts that the project will have for Curubandé town. The development will improve the road network in the area, especially between the location of the geothermal plant and the main routes. And other resources will be necessary, such as greater and better access to electricity, telephone, potable water and, probably, an improvement in public transport and network cover of cellular telephones. Obviously, an indirect positive impact will be better possibilities for studies. For the local economy, transport of more consumer products will be necessary. Furthermore, it is expected that at some point in time, the Pailas project may need 1000 workers for construction work for a period of 36 months. Hence, a growth in consumption of products and services is expected in Curubandé.

It is recommended that a plan be made for information and education, in order to reduce or mitigate the possible negative impacts in social aspects when new workers are integrated into the community and during construction. A very special and important issue is the social behaviour of the workers. It is important that they show respectful and socially acceptable behaviour, especially during leisure hours or free time. Also, information on the project by means of meetings, posters and murals will be given, which will cover subjects such as occupational health, labour security, technical aspects of the project, environmental guidelines established by ICE and aspects related to the handling of the archaeological patrimony (ICE, 2005).

## **5.9 Other studies or aspects**

As a part of the feasibility studies, other important topics were considered to complete the Environmental Impact Assessment. These subjects included soil characterization and mapping of its units, a typical geotechnical survey of the possible power plant construction sites, a description of geological and geomorphological units and mapping of the total area, an exhaustive identification and evaluation of the national archaeological patrimony within the area, taking prevention and mitigation measures with necessary compensation to protect it if found within the ICE land; and, finally, a thorough study on the economic and financial aspects of the Las Pailas project.

### 5.10 Final remarks

The Las Pailas geothermal project is located in a special and complex place, where private, economic and eco-tourist interests (two mountain hotels) converge with ecological and scenic beauty (Rincón de la Vieja National Park and ONG's private lands) and a geothermal resource with a possible development, due to national energy interest, represented by ICE. Additional parties of interest would be the inhabitants of Curubandé town; the development of this project could make an important contribution to their socio-economic development with a possibility of more and better job opportunities, and access to goods and services that at the moment they do not or cannot have for different reasons and circumstances.

Special considerations have been granted to the environment (biotic and abiotic), for obvious and diverse reasons. Some are economic but others are ecological, meant for the preservation of local nature. But it is clear that this can become an example where humans, nature and economic apexes converge in the same area at a determined moment. That is the philosophical reason of "sustainable development", in agreement with the principles adopted from the Earth Summit in Río de Janeiro in 1992 (Parson et al., 1992; Kates et al., 2005).

Las Pailas project is a good opportunity for ICE to demonstrate that it is prepared as an institution to develop projects of this kind near protected areas or within them as has been done in other countries, like the USA (Defenders of Wildlife, 2006) or Kenya (Kubo, 2003). Not only "to fulfil" what is demanded by national environmental laws or existing international norms, but also with the possibility "to gain" an image with proven facts. From an environmental perspective, all the studies made in this area during the last five years have demonstrated the "viability" of carrying out the project. The time has now come to put theory to practice. High-temperature geothermal energy is mainly associated with volcanoes and most of the volcanic zone is declared national parks. In agreement with present legislation, these areas cannot be "touched"; therefore, the energy associated with them cannot be exploited. This is a serious problem for many developing countries, Costa Rica being one of them.

Like any country that requires development, Costa Rica increasingly needs energy. Costa Rica of the future needs energy. The energy should preferably come from environmentally friendly and clean power sources, that can be exploited economically and contribute in a significant way to the great and increasing national demand for energy. Every day, petroleum gets more expensive. Still some countries (including Costa Rica) are investing in thermal plants based on oil products or other fossil fuels to be able to meet the needed power demand in the country. This has a high cost economically (particularly for poor countries), the environmental costs are impossible to calculate, but they are enormous. The possibility of exploring and exploiting geothermal resources that are found at depth within some national parks should be evaluated, including a cost-benefit analysis in relation to other power plants such as ones based on fossil fuels.

The geothermal energy represents a viable, economic and technical possibility. This valuable resource must be utilized and perhaps some of their environmental problems can be mitigated. This may therefore, be the right moment to allow a controlled and restricted development within certain protected areas. The benefits will be economic and environmental for the country, and locally for the nearest communities, as they will have better job opportunities available. On the other hand, some economic benefits must be included for the national parks of Costa Rica. A new law is necessary in order to permit this, but, more urgently, a new concept about environmental, economic and human development is needed, a sustainable development.

## 6. CONCLUSIONS AND RECOMMENDATIONS

Some important conclusions and recommendations about the geo-environmental aspects of the Las Pailas geothermal project can be made:

- In this area converge very diverse but equally important interests: geothermal energy that can be utilized with present, but even more important, future necessities of an ever increasing demand in mind; an area of great scenic beauty where a high biodiversity is found; hotels (private capital) with well established eco-tourist development, and a rural community with few economic possibilities and little options for work.
- The Environmental Impact Assessment (EIA) for the project was completed and finally approved by the national environmental authority (SETENA) in 2006, showing the “environmental viability” of the project, a 35 MWe geothermal plant in Las Pailas.
- According to the monitoring data, H<sub>2</sub>S and CO<sub>2</sub> values are very low and below the limits permitted by law (maximum permit values are 0.03 ppm and 5000 ppm, respectively). The expected values for Las Pailas geothermal plant are 0.016 ppm and 0.18 ppm, respectively (extrapolated values based on well test values).
- The local biodiversity will not be seriously affected by the project, and maybe only in some special aspects; but in other cases, the effects will be positive for example some ICE lands will be used to create secondary forests.
- All the waste geothermal waters (hot and cold) will be re-injected into deep wells. Some artificial “pools” will be constructed as temporary storage in emergency cases or/and for production well tests. Some additional care must be taken to avoid problems with tourists and animals.
- The natural surface manifestations must be monitored constantly to detect any changes (temperature, pH, conductivity, chemical content, etc.) and to avoid ecological and legal problems in the drilling stage and under production conditions.
- Also, all rivers and creeks within the geothermal project area must be monitored. Victoria creek, because it is very near the geothermal wells and used as a primary supply source of high quality water for Curubandé town and Guachipelín hotel, looks like a “fragile” location and special care must be taken there.
- The Curubandé town will be subjected to the most direct impacts (positive and negative), both socially and economically, as it is the nearest population centre to the Las Pailas project. Programmes to promulgate information and for mitigation are necessary. ICE will be responsible for that.
- A good opportunity for showing the “true spirit of sustainable development” is possible with the development of the geothermal resource in the Pailas area of Costa Rica; a change in attitude of the involved actors is necessary to try to understand all the aspects and points of view.
- ICE will have the opportunity to show the country that it is perhaps prepared to develop projects of this kind in areas near protected zones or within them as has been done in other countries, such as USA and Kenya.
- Generally, geothermal energy in Costa Rica is associated with volcanic activity, and most of the areas of active volcanoes are national parks. This is a serious problem in Costa Rica and also in many other developing countries. The possibility for exploring and exploiting the geothermal resources inside these areas is something that has to be evaluated, but always with the best alternative and the philosophy of sustainable development in mind.

### ACKNOWLEDGEMENTS

My deepest gratefulness to God for giving me this opportunity. Thanks for all the sacrifice and six months of patient and unconditional support and love go to my wife Gloria and my two daughters Keren and Kimberly. Thanks to all my relatives and friends, especially to my mother Rosa María; and to my partners and friends of the CSRG-ICE for their help and continuous support.

My sincere gratitude to the UNU-GTP staff, Dr. Ingvar B. Fridleifsson, Mr. Lúdvík S. Georgsson, Mrs. Gudrún Bjarnadóttir and Ms. Thórhildur Ísberg for their generous help, care and advice during the training period. Special thanks to my supervisors, Audur Magnúsdóttir and Stefán Gunnar Thors, for their time, interest and support. Finally, I would like to sincerely thank all the Orkustofnun and ÍSOR staff and lecturers, especially Benedikt Steingrímsson, Thráinn Fridriksson and Halldór Ármannsson, and the library personnel, Rósa S. Jónsdóttir and Hildur Ýr Ísberg, for their help and patience. Finally, thanks to all the UNU-Fellows 2006 for their friendship and support.

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