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# ENVIRONMENTAL MONITORING OF GEOTHERMAL PROJECTS IN NICARAGUA

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#### ABSTRACT

The environmental monitoring of geothermal projects in Nicaragua is mainly based on field supervision and inspections to verify compliance with conditions stated in environmental permits, in addition to the review of monitoring reports provided by the developers. A review of the environmental impacts of geothermal utilization, the environmental framework and the monitoring process in countries with extensive geothermal development and experience in utilizing geothermal energy was made for comparison purposes with environmental monitoring conducted in Nicaragua. The monitoring process in Iceland, New Zealand and USA follows similar guidelines; local authorities monitor compliance of conditions according to consents, licences and permits. The environmental parameters identified in this report can be included in a monitoring programme to be used as a general guide by regulatory institutions in Nicaragua to enhance the follow up conferred upon geothermal projects.

# 1. INTRODUCTION

Nicaragua is the Central American country with the greatest geothermal potential. The first studies for evaluating the geothermal potential of the country began in the late sixties through recruitment of foreign consulting firms. However, the commercial utilization of geothermal resources began in 1983 in the Momotombo Geothermal field.

In 2001, the Nicaragua Geothermal Master Plan Study was completed, estimating the geothermal potential of the country as 1,519 MWe. Since the publication of the Master Plan, four geothermal concessions have been awarded to private foreign companies: San Jacinto - Tizate which is in production, El Hoyo - Monte Galan, Managua - Chiltepe, and Casita - San Cristobal, which are still in the exploration stage.

Geothermal energy is considered a renewable source, but its development also has environmental effects, most of which are associated with the utilization of high-temperature geothermal systems. According to Ármannsson and Kristmannsdóttir (1992), the most important environmental changes brought about by geothermal utilization are: surface disturbances, physical effects due to fluid

withdrawal, noise, thermal effects and emissions of chemicals, both gas emissions and liquid discharge, and social and economic effects on the communities concerned.

In Nicaragua most of the geothermal areas are located within protected areas in the Los Maribios Volcanic Mountain Range; therefore, geothermal development is of special concern. According to the Environmental Impact Assessment Act (Decree 76-2006), geothermal projects are always subject to EIA.

Environmental monitoring is a very important factor in the surveillance of geothermal projects. Monitoring needs to begin before development starts so that a good baseline can be obtained. During exploration, construction and operation/utilization stages of geothermal projects, monitoring provides feedback on the actual environmental impacts or changes in natural conditions and the results can be used to improve the implementation of mitigating measures. Official monitoring enables relevant authorities to assess the management of geothermal systems under development.

The aim of the present report is to review the environmental framework and monitoring process in different countries with extensive geothermal development and experience in utilization of geothermal energy for comparison with monitoring conducted in Nicaragua, as well as identifying the most important parameters that an environmental monitoring programme must include. The author expects that the overview provided in this report can assist the regulatory institutions in Nicaragua to enhance the monitoring and follow up of geothermal projects.

### 2. BACKGROUND

#### 2.1 Regional geology

The chain of 18 distinct volcanic centres found in Nicaragua is a part of the Central America Volcanic Arc (CAVA) which extends along the Pacific coastline of the Central American Isthmus, from Guatemala through Belize, El Salvador, Honduras, Nicaragua, and Costa Rica to Panama. This

Quaternary volcanic arc is formed by an active subduction of the Cocos oceanic plate under the Caribbean continental plate along the Mesoamerican trench. As seen in Figure 1, the Nicaraguan Depression is in the southern part of the Chortis block, a unit of mainly continental crust belonging to the Caribbean Plate (CNE, 2001).

The subduction of the Cocos plate beneath the Caribbean plate has resulted in the formation of an active volcanic arc with a NW-SE orientation known as the Cordillera de Los Maribios within the Nicaraguan depression, parallel to the Pacific coast and the Mesoamerican trench.

The Nicaraguan depression is one of the tectonic structures that can be found in the marginal Pacific zone of



FIGURE 1: Tectonic scheme of the Central American region (CNE, 2001)

Central America, extending across Nicaragua from the Fonseca Gulf to the coast of Costa Rica. The depression is partially occupied by Lake Managua and includes the volcanic chain that extends NW-SE from the volcano Cosiguina to the Maderas volcano.

Weinberg (1992) identified three different phases of deformation that accompanied the geological evolution of the Pacific region of Nicaragua: 1) Miocene phase, 2) Pliocene-Lower Pleistocene phase and 3) Upper Pleistocene-Holocene phase. During the Miocene to Pliocene-Lower Pleistocene phase, the tectonic regime was dominated by a NE-SW orientated compression, normal to the Mesoamerican trench. During the Pliocene-Lower Pleistocene, the angle of subduction of the Cocos Plate is thought to have increased, reducing the speed of convergence of the Cocos and Caribbean Plates. From the Upper Pleistocene–Holocene, a new regime began where tectonic stress was characterised by lateral strike-slip faulting and normal faults, and pull-apart structures were more evident; this became known as the Managua Graben. This resulted in a migration of volcanism westward towards the Pacific.

McBirney and Williams (1965) describe the geology of the volcanic chain in Nicaragua. The stratigraphy is divided into sequences of neritic sediments, mostly volcanoclastic, that were deposited between the late Cretaceous and Upper Miocene.

#### 2.2 Geothermal areas

In Nicaragua, the first studies on the utilization of geothermal energy resources began in the late sixties. In 1980, the Latin American Energy Organization (OLADE) began a reconnaissance survey of the geothermal resources along the Pacific volcanic chain, which was considered the base for later surveys in the geothermal areas.

A national resource assessment was carried out in 1999-2001 during which the status of the geothermal exploration in each of the geothermal fields was reviewed and the potential generating capacity of the fields for power production assessed. In 2001, the Nicaragua Geothermal Master Plan was published and, as a result, the estimated geothermal potential of the country is 1,519 MWe. According to the results of these studies, 12 geothermal areas were established (Figure 2), each of which has enough potential to be considered for a feasible project. The geothermal areas and their developmental status are summarized in Table 1.

No.	Geothermal area	Installed capacity	Gene- ration	Concession	Development stage	Potential (MW)
1	Momotombo	78 MW	26 MW	ORMAT Momotombo	Operation	154.0
				Technologies S.A.	-	
2	San Jacinto-Tizate	10 MW	9.3 MW	Polaris Energy de	Operation	167.0
				Nicaragua, S.A., PENSA		
3	El Hoyo-Monte Galán	Ionte Galán Geotérmica Nicaraguense,		Feasibility	159.0	
				GEONICA		
4	Managua-Chiltepe			Not concessioned Feasibility		111.0
5	Telica-El Ñajo Volcano			Not concessioned	Prefeasibility	78.0
6	Casita-San Cristóbal			Cerro Colorado Power, CCP	Prefeasibility	225.0
7	Caldera de Apoyo			Not concessioned	Prefeasibility	153.0
8	Mombacho Volcano			Not concessioned	Prefeasibility	111.5
9	Caldera de Masaya			Not concessioned	Prefeasibility	99.5
10	Tipitapa			Not concessioned	Prefeasibility	9.0
11	Cosigüina Volcano			Not concessioned	Reconnaissance	106.0
12	Isla de Ometepe			Not concessioned	Reconnaissance	146.0
	Total (MW)	88	35.3			1519

TABLE 1:	Geothermal	areas and	develo	pmental	status
	0			P1110110001	0.000000



FIGURE 2: Geothermal areas of Nicaragua (MEM, 2008)

# **3. LITERATURE REVIEW**

### 3.1 General

Geothermal energy is energy derived from heat from the Earth's interior. Geothermal resources are distributed throughout the world and can be found in regions with a normal or slightly above normal geothermal gradient, especially close to plate boundaries. It is highly concentrated in volcanic regions, but may also be found as warm groundwater in sedimentary formations worldwide. A schematic description of a geothermal system can be "convecting water in the upper crust of the Earth, which, in a confined space, transfers heat from a heat source to a heat sink, usually the free surface" (Hochstein, 1990).

A geothermal system is made up of three main elements: a heat source, a reservoir and a fluid, which is the carrier that transfers the heat. The heat source can be either a very high-temperature (>  $600^{\circ}$ C) magmatic intrusion that has reached relatively shallow depths (5-10 km) or, as in certain low-temperature systems, the Earth's normal temperature that increases with depth.

The reservoir is a volume of hot permeable rocks from which the circulating fluids extract heat. The reservoir is generally overlain by a cover of impermeable rocks and connected to a surface recharge area through which the meteoric waters can replace or partly replace the fluids that escape from the reservoir through springs or are extracted by boreholes. The geothermal fluid is water, in the majority

of cases meteoric water, in the liquid or vapour phase, depending on its temperature and pressure. This water often carries with it chemicals and gases such as  $CO_2$ ,  $H_2S$ , etc. (Dickson and Fanelli, 2004).

Geothermal systems and reservoirs can be defined and classified on the basis of different aspects, such as reservoir temperature or enthalpy, physical state, geological settings, and hydrological and heat transfer characteristics as shown in Table 2.

The temperature of the resource determines the geothermal development that can occur, as a direct use or electrical power generation as shown in Figure 3.

Geothermal energy projects involve three major stages: exploration and reservoir evaluation, production field development, and power plant construction and operation.

Classifications	Characteristics				
Temperature (Axelsson and Gunnlaugsson, 2000)					
High temperature	Reservoir temperature is above 200°C at 1 km depth, high-enthalpy fluids. Located within volcanic zones, heat sources are cooling intrusions or magmas. Suitable for electricity production, co-generation and binary.				
Low temperature	Reservoir temperature is below 150°C at 1 km depth, low-enthalpy fluids. Located outside volcanic zones, heat source is crustal heat being conducted and convected upwards. Suitable for direct use and binary production.				
Physical state (Axelsson	and Gunnlaugsson, 2000)				
Vapour dominated	The temperature is at or above the boiling point at the prevailing pressur and the steam phase controls the pressure in the reservoir. Some water may however, be present.				
Liquid dominated Water temperature is at or below the boiling point at the prevailin in the reservoir. Some steam may, however, be present.					
Two phase	The two phases co-exist and the temperature and pressure follow the boiling point curve.				
Nature and geological se	ettings (Axelsson and Gunnlaugsson, 2000)				
Volcanic systems	systems Associated with volcanic activity. The heat sources are hot intrusions of magmas. Most often situated inside volcanic complexes such as calderas and/or spreading centres. Permeable fractures and fault zones mostly control the flow of water				
Convective systems	Heat source is hot crust at depth in tectonically active areas, with above average heat flow. Geothermal water has circulated to considerable depth $(> 1 \text{ km})$ , through mostly vertical fractures, to mine the heat from the rocks.				
Sedimentary systems Found in many of the major sedimentary basins in the world. Origin the occurrence of permeable sedimentary layers at great depths (> 1 k above average geothermal gradients (> 30°C/km). Conductive in rather than convective.					
Geo-pressured systems Are analogous to geo-pressured oil and gas reservoirs where fluid stratigraphic traps may have pressures close to lithostatic value systems are generally fairly deep; hence, they are categorised as ge					
Hot dry rock systems Consist of volumes of rock that have been heated to useful temperative volcanism or abnormally high heat flow, but are virtually imperative. They cannot be exploited in the conventional way					

 TABLE 2: Classification of geothermal systems



FIGURE 3: Potential uses of geothermal energy derived from Líndal (1973)

Exploration and reservoir evaluation activities include geological, geophysical, and drilling surveys for exploratory drilling and reservoir testing. Production field development involves drilling steam or hot water production wells and re-injection wells and processing the reservoir output for use in the power plant. Drilling will continue throughout the life of the project, as production and injection wells need to be periodically replaced to support power generation requirements.

Power plant construction activities include construction of the power plant facility and the associated infrastructure, including cooling towers, pipelines, and facilities for treatment and reinjection of waste water and gas. Other activities include the establishment of settling ponds to support drilling and well testing, and the construction of access roads, storage yards, and maintenance facilities. Operational activities include routine operation and maintenance of the geothermal power plant, well field monitoring and maintenance, periodic drilling of production and injection wells, geothermal fluid processing and pipeline maintenance.

#### 3.2 Environmental Impact Assessment

Since the first Environmental Impact Assessment (EIA) system was established in the USA in 1969, EIA systems have been set up worldwide and become a powerful environmental safeguard in the project planning process. Many countries have adopted their own EIA procedures and it is now the tool most widely used in environmental management.

The purpose of an EIA is to help public officials make informed decisions that are based on an understanding of environmental consequences and to take proper actions. The intent should not be to generate paperwork, but to enable a professional response. This requires that an EIA be analytical rather than encyclopaedic. Not only should significant environmental issues deserving of study be identified, insignificant issues should be de-emphasized, narrowing the scope of the environmental impact assessment process accordingly (Shipley Associates, 1993).

An EIA will address the impacts of both the construction and operational phases of the proposed development. Indeed, the impacts associated with these different phases of the project might be significantly different. An EIA should include short-, medium- and long-term impacts, local and global impacts, as well as direct, indirect, secondary, cumulative, permanent and temporary, positive and negative effects of the project (Heath, 2002).

# 3.3 Environmental impacts of geothermal utilization

Despite geothermal energy being considered a renewable source, its utilization can cause some environmental impacts, most of which are associated with the exploitation of high-temperature geothermal systems (Hunt, 2000).

The most important environmental changes brought about by geothermal utilization are: surface disturbances, physical effects due to fluid withdrawal, noise, thermal effects and emissions of chemicals, both gas emissions and liquid discharge, and social and economic effects on the communities concerned (Ármannsson and Kristmannsdóttir, 1992).

The environmental effects of geothermal development according to Hunt (2000) are described in the next sections.

# **3.3.1 Drilling operations**

The utilization of both low-temperature and high-temperature systems involves drilling wells to depths of 500-3500 m; this requires large drill rigs and may take several weeks or months.

*Impact of access and field development:* The construction of road access to drilling sites can involve destruction of forests and vegetation which, particularly in tropical areas with high rainfall, can result in erosion. Such erosion can result in large amounts of silt being carried by the streams and rivers draining the development area.

*Effects of drilling operations:* Drilling creates noise, fumes and dust which can disturb animals and humans living nearby. Typical noise levels (in approximate order of intensity) are:

- Air drilling 120 dBa (85 dBa with suitable muffling);
- Discharging wells after drilling (to remove drilling debris) up to 120 dBa;
- Well testing 70-110 dBa (if silencers used);
- Heavy machinery (moving earth during construction) up to 90 dBa;
- Well bleeding 85 dBa (65 dBa if a rock muffler is used);
- Mud drilling 80 dBa;
- Diesel engines (to operate compressors and provide electricity) 45-55 dBa if suitable muffling is used.

The characteristics of the site (e.g. its topography) and meteorological conditions will also have an influence. Noise is attenuated by the distance travelled in the air; there is approximately a 6 dB attenuation every time the distance is doubled, but lower frequencies are attenuated to a lesser extent than higher frequencies. Thus, low rumbling noises from drill rigs and silencers will be carried much farther than high frequency steam discharge noises.

Continuous drilling involves the use of powerful lamps to light up the work site at night and this can disturb local residents, domestic and wild animals.

#### 3.3.2 Mass withdrawal

Large-scale utilization of liquid-dominated high-temperature geothermal systems involves the withdrawal of large volumes of geothermal fluid. When the fluid withdrawn is reinjected, the reinjection wells are generally located away from the production wells to reduce the chances of the cooler reinjected water returning to the production wells and lowering the temperature of the production fluids. Even if all the waste liquid is reinjected, there may be a large mass loss (up to 30% of that withdrawn) associated with discharge of water vapour into the atmosphere from the power station. A major consequence of the mass loss from parts of the field is the formation of a 2-phase (steam + water) zone in the upper part of the reservoir, and as production continues this zone increases in size and the pressure (both in and below this zone) decreases. Pressure decline in the reservoir, as a result of mass withdrawal and net mass loss, is an important cause of environmental changes at or near the surface.

*Effects on thermal features:* In their natural and non-utilized state, many high-temperature geothermal systems are manifested at the surface by thermal features such as geysers, fumaroles, hot springs, mud pools, sinter terraces and thermal ground with special plant species. Historical evidence shows that natural thermal features have been affected, often severely, during the development and initial production stages of some high-temperature geothermal systems. The decline or increase in thermal features is associated with the decline in reservoir pressure. In the case of hot springs, as the pressure declines, so also does the amount of geothermal fluid reaching the surface and hence the thermal features decline in size and vigour. In the case of fumaroles and thermal ground, pressure decrease will increase boiling and steam formation, which usually intensifies fumarole activity.

*Depletion of groundwater:* Most high-temperature geothermal systems are overlain by a cold groundwater zone. If production from the system results in a large pressure drop in the reservoir, this groundwater may be drawn down into the upper part of the reservoir in places where there are suitable high-permeability paths (such as faults); such a situation is called a cold downflow (Bixley, 1990). If the lateral permeability of the rocks in the groundwater zone is low then a downflow may result in a drop in the groundwater level.

*Ground deformation:* Withdrawal of fluid from an underground reservoir may result in the reduction of formation pore pressure which may lead to compaction in rock formations having high compressibility and result in subsidence at the surface. Clay formations are more prone to compaction than lava formations. Horizontal movements also occur. Such ground movements can have serious consequences on the stability of pipelines, drains and well casings in a geothermal field. If the field is close to a populated area, subsidence could lead to instability in dwellings and other buildings in other areas. The local surface watershed systems may also be affected.

Subsidence in liquid-dominated fields has been greater than in vapour-dominated fields, because the former are often located in young, relatively-poorly compacted volcanic rocks and the latter are generally in older rocks having lower porosity. Another very important reason is that in liquid dominated systems the mass extraction is much greater than in vapour-dominated systems, and only the steam fraction is utilized to produce power.

*Ground temperature changes:* The formation and expansion of a two-phase zone in the early stages of utilization of a liquid-dominated geothermal system can also alter the heat flow. Steam is much more mobile than water; it can move through small fractures that are impervious to water and can move much more quickly through larger fractures. The generation and movement of steam may result in increased heat flow and increased ground temperatures so that vegetation becomes stressed or killed.

# 3.3.3 Waste liquid disposal

Most geothermal developments bring fluids to the surface in order to mine heat contained within the fluids. In high-temperature liquid-dominated geothermal fields, the volume of resultant waste water may be large, as it is also in low-temperature systems because of the large volume needed for low-temperature utilization. For vapour-dominated systems it is smaller. The waste fluid is disposed of by putting it into waterways, evaporation ponds or reinjecting it deep into the ground. Surface disposal causes more environmental problems than reinjection.

Environmental problems are not only caused by the volumes involved, but also by the relatively high temperatures and toxicity of the waste fluid. The chemistry of the fluid discharge is largely dependent on the geochemistry of the reservoir and the operating conditions used for power generation and will be different for different fields (Webster, 1995). Most high-temperature geothermal bore waters include high concentrations of at least one of the following toxic chemicals: lithium (Li), boron (B), arsenic (As), hydrogen sulphide (H<sub>2</sub>S), mercury (Hg), and sometimes ammonia (NH<sub>3</sub>). Fluids from low-temperature reservoirs generally have a much lower concentration of contaminants.

Most of the chemicals are present as solutes and remain in solution from the point of discharge, but some are taken up in river or lake bottom sediments where they may accumulate to high concentrations. The concentrations in such sediments can become greater than the soluble concentration of the species in the water, so that re-mobilisation of the species in the sediment, such as during an earthquake or flood, could result in a potentially toxic flush of the chemical into the environment. Chemicals which remain in solution may be taken up by aquatic vegetation and fish (Webster and Timperley, 1995) and some can also move further up the food chain into birds and animals residing near the river.

*Effects on living organisms:* If hot waste water is released directly into an existing natural waterway, the increase in temperature may kill fish and plants near the outlet. Release of untreated waste into a waterway can result in chemical poisoning of fish, and also birds and animals which reside near the water because some of the toxic substances move up the food chain.

*Effects on waterways:* The release of large volumes of waste water into a waterway may increase erosion, and if uncooled and untreated there may be precipitation of minerals such as silica near the surface disposal outlet.

*Contamination of groundwater:* The release of waste water into cooling ponds or waterways may result in shallow groundwater supplies becoming contaminated and unfit for human use.

*Induced seismicity:* Most high-temperature geothermal systems lie in tectonically active regions where there are high levels of stress in the upper parts of the crust; this stress is manifested by active faulting and numerous earthquakes. In high-temperature geothermal fields, exploitation can result in an increase (above the normal background) in the number of small magnitude earthquakes (microearthquakes) within the field. High wellhead reinjection pressures increase the pore pressure at depth, particularly in existing fractures, and this allows movements to suddenly release the stress and result in an earthquake. This phenomenon occurs in both liquid- and vapour-dominated fields, but has not been observed in low-temperature fields.

# 3.3.4 Waste gas disposal

Gas discharges from low-temperature systems usually do not cause significant environmental impacts. In high-temperature geothermal fields, power generation using a standard steam cycle plant may result in the release of non-condensable gases (NCG) and fine solid particles to the atmosphere (Webster, 1995). In vapour-dominated fields in which all waste fluids are reinjected, non-condensable gases in steam will be the most important discharges from an environmental perspective.

The emissions are mainly from the gas exhausters of the power station, often discharged through a cooling tower. Gas and particulates discharged during drilling, bleeding, cleanouts and testing, and from line valves and waste bore water degassing, are usually insignificant. Gas concentrations and compositions cover a wide range, but the predominant gases are carbon dioxide ( $CO_2$ ) and hydrogen sulphide ( $H_2S$ ).

*Carbon dioxide:*  $CO_2$  occurs in all geothermal fluids but is most prevalent in fields in which the reservoir contains sedimentary rocks, particularly those with limestones. There is some evidence that in high-temperature fields the amount of  $CO_2$  discharged per unit mass withdrawn decreases with time as a result of degassing of the deep reservoir fluid and a decline in heat transfer from the formation. Carbon dioxide is generally the most abundant NCG and its emissions need to be restricted because it is a greenhouse gas.  $CO_2$  is colourless and odourless, and is heavier than air and can thus accumulate in topographic depressions where there is still air. It is not highly toxic but at high concentrations it can be fatal due to alteration of pH in the blood. Exposure limits range from 5,000 to 30,000 ppm for 10 min.

*Hydrogen sulphide:*  $H_2S$  emissions can vary significantly from field to field, depending on the amount of  $H_2S$  in the geothermal fluid, and the type of plant used to produce from the reservoir.  $H_2S$  is characterised by a "rotten egg odour" detectable by humans at very low concentrations of about 0.3 ppm. At such concentrations it is primarily a nuisance, but as the concentration increases, it may irritate and injure the eye (10 ppm), the membranes of the upper respiratory tracts (50-100 ppm), and lead to loss of smell (150 ppm). At a concentration of about 700 ppm it is fatal. Because  $H_2S$  is heavier than air it can accumulate in topographic depressions where there is still air, such as well cellars and the basements of buildings near the gas exhausters. The disappearance of the characteristic smell at concentrations greater than 150 ppm is especially dangerous because it leads to people failing to recognise potentially fatal concentrations. Exposure limits range from 10 to 50 ppm (10 min.).

*Other gases:* Geothermal gas may contain ammonia (NH<sub>3</sub>), trace amounts of mercury (Hg) and boron (B) vapour, and hydrocarbons such as methane (CH<sub>4</sub>). Ammonia can cause irritation of the eyes, nasal passages and respiratory tract at concentrations of 5 to 32 ppm. Inhalation or ingestion of mercury can cause neurological disorders. Boron is an irritant to the skin and mucus membranes: it is also phytotoxic at relatively low concentrations and extremely toxic to some plants, so its occurrence has to be watched carefully in connection with agricultural activity, especially fruit growing, wineries etc. These substances are generally emitted in such low quantities that they do not pose a human health hazard. Chemicals may be deposited on soils and, if leached from there, may contribute to groundwater contamination.

*Effects on living organisms:* The impacts of  $H_2S$  discharge will depend on local topography, wind patterns and land use. The gas can be highly toxic, causing eye irritation and respiratory damage in humans and animals, and has an unpleasant odour. Boron,  $NH_3$ , and to a lesser extent Hg, are leached from the atmosphere by rain, leading to soil and/or vegetation contamination (Webster, 1995). Boron, in particular, can have a serious impact on vegetation. Contaminants leached from the atmosphere can also affect surface waters and aquatic life.

*Microclimatic effects:* Discharges of steam may have a significant effect on the climate in the vicinity of a power station, depending on the topography, rainfall, and wind patterns. Under certain conditions there may be increased fog, cloud formation or rainfall. Microclimatic effects are mainly confined to large power schemes in high-temperature fields; utilization of low-temperature geothermal systems does not cause significant microclimatic effects.

# 3.3.5 Solid waste disposal

Geothermal development produces significant amounts of solid waste and suitable disposal methods need to be found (Brown, 1995). Sometimes waste may contain heavy metals, which are classed as hazardous and must be disposed of safely.

Sulphur, silica, and carbonate precipitates are typically collected from cooling towers, air scrubber systems, turbines, and steam separators. This sludge may be classified as hazardous depending on the concentration and potential for leaching of silica compounds, chlorides, arsenic, mercury, vanadium, nickel, and other heavy metals.

Other solid waste includes drilling muds, cement and construction debris, not normally considered hazardous. Maintenance debris can sometimes be considered hazardous due to the presence of asbestos in insulation material.

According to Brown (1995), it may be advantageous to dispose of drilling muds, sludge and scale in the form of a slurry into deep reinjection wells cased to protect the meteoric aquifers. If that is not possible, then total containment, with no significant emissions to the air, surface water or groundwater, as in landfill disposal systems, should be employed. Solid waste disposal sites need to be periodically monitored and such sites could be a long-term liability.

# **3.3.6** Landscape impacts

*Visual intrusion:* A geothermal plant must be located close to the resource, so there is often little flexibility in the siting of the plant. Geothermal plants generally have a low profile, but their visual impact may still be significant, as geothermal fields are often situated in areas of outstanding natural beauty. Visual impact may be particularly high during drilling due to the presence of tall drill rigs.

*Land use:* Land is required for well pads, fluid pipelines, a power house, cooling towers and an electrical switchyard. In many cases, the land between the well pads and pipes may continue to be used for other purposes, although at some sites the nature of the development may make this impractical.

# **3.3.7** Catastrophic events

As is the case for any large engineering development, catastrophic events may occur during the construction and operation of a large-scale geothermal power scheme.

*Landslides:* In areas of high relief and steep terrain, landslides are a potential hazard. Landslides may be triggered either naturally (by heavy rain or earthquake) or as a result of construction work, during which the "toe" of the slide may have been removed.

*Hydrothermal eruptions:* Although rare, hydrothermal eruptions constitute a potential environmental hazard in high-temperature liquid-dominated geothermal fields (Bromley and Mongillo, 1994). Eruptions occur when the steam pressure in near-surface aquifers exceeds the overlying lithostatic pressure and the overburden is then ejected, generally forming a crater 5-500 m in diameter and up to 500 m in depth (although most are less than 10 m deep).

# 3.3.8 Socio economic impacts

Due to its nature, geothermal energy is frequently utilized in remote, sometimes relatively undisturbed places. A temporary increase in employment and the importation of an outside workforce calling for various services may put a strain on the traditional way of life in the area and leave a scar when the

construction work is finished. The building of roads will "open up" the area and most probably make it attractive to tourists, thus creating a new industry (Ármannsson and Kristmannsdóttir, 1992).

#### **3.4** Environmental monitoring

Environmental monitoring provides feedback on the actual environmental impacts of a project. Monitoring results help judge the success of mitigating measures in protecting the environment. They are also used to ensure compliance with environmental standards, and to facilitate any project design or operational changes that are needed.

According to Hunt (2000), the reasons for environmental monitoring in geothermal projects are:

- To obtain data on which rational and informed resource management decisions can be made by developers and regulatory authorities;
- To verify that management decisions are having the desired outcome;
- To enable the public to have confidence in the environmental management process;
- To assist in building up a knowledge of geothermal systems and how to develop them in an environmentally responsible way.

Monitoring needs to begin before development starts so that a good baseline can be obtained. It is not possible to go back in time, so many different eventualities need to be considered and a fully integrated monitoring programme needs to be developed and initiated long before large scale productions starts.

Monitoring should be conducted at a frequency sufficient to enable natural variations to be distinguished from production-induced changes. The data collected need to be interpreted and regularly compared with pre-determined "trigger points". "Zero change" is just as important as change, and is not a valid reason for stopping monitoring, although the frequency of measurement may be reduced after a long period of no change. Data needs to be reliable and the equipment should be calibrated regularly and operated by competent persons (Hunt, 2000).

Components within the broad definition of environmental monitoring include: planning the collection of environmental data to meet specific objectives and environmental information needs; designing monitoring systems and studies; selecting sampling sites; collecting and handling samples; conducting laboratory analysis; reporting and storing data; assuring the quality of the data; analysing and interpreting data and making it available for use in decision making (U.S. EPA, 1985).

# 4. GEOTHERMAL DEVELOPMENT IN NICARAGUA

#### 4.1 General

In accordance with the Constitution and other national laws in Nicaragua, the state is the owner of natural resources declared to be of national interest, as is the case with geothermal resources. For the development and utilization of these resources, the state can make contract with private entities granting concessions.

After the publication of the Geothermal Master Plan Study in 2001, and the publication of the Geothermal Resources Act (Law 443) in 2002, geothermal concessions have been awarded to different private companies. The Geothermal Resources Act was amended in 2006, 2008 and 2010. In the amendment from 2006 (Law 594), some environmental aspects that concession holders must manage,

in cases where an area under investigation for exploration or production is located totally or partially in protected areas, were included.

The concession holders must obtain the respective approval in the Environmental Impact Study and an Environmental Permit from the Ministry of Environment and Natural Resources (MARENA) before initiating exploration or utilization activities. Furthermore, three percent of the estimated cost of the EIA study and the Environmental Permit shall be paid to MARENA as funds to be utilized exclusively for the process of monitoring and overseeing the execution of these studies (Republic of Nicaragua, 2006).

It is the obligation of the concession holder to present to the Ministry of Energy and Mines the environmental permits issued by MARENA as a requirement for initiating the exploration phase of a project.

### 4.2 Current projects

#### 4.2.1 Momotombo

The Momotombo geothermal field is located at the extreme SE corner of the Marrabios cordillera, some 40 km NW of the nation's capital, Managua, on the shores of Lake Managua and on the south slope of the Momotombo volcano, in the village La Paz Centro, Leon department.

The Momotombo geothermal reservoir has been producing for more than twenty years, since 1983 when the first generation unit of 35 MWe went into operation. The second unit was installed in 1989 after increasing the steam production rate. During this period, production wells have shown marked changes in flow rates, fluid chemistry and specific enthalpies of produced fluids. These changes are mainly attributed to reservoir pressure decline because of excessive fluid production (Porras, 2009).

Between about 12% and 30% of separated water was reinjected from 1984 to 1996, but due to mechanical failures of the reinjection system, separated water was frequently discharged into Lake Xolotlán.

By 1999, when the power plant output dropped to 9 MWe, an international tender was issued for the rehabilitation of the project under a 15 year Concession. Ormat won the tender and undertook to implement a power output recovery programme that included an integrated geophysical exploration to define production drilling target areas and specific drilling targets within the Ormat Momotombo Exploration Concession, with focus upon the areas in and adjacent to the existing well field (Porras, 2009).

The Momotombo field has been operated by Ormat for more than ten years. Since then Ormat has drilled several production and reinjection wells, carried out work-overs and cleaned several of the older wells. A programme for total reinjection was also implemented and a 10 MW binary power plant was constructed and commissioned in 2002. Currently the generation in Momotombo is 26 MW.

The current area being utilized (including wells and the generation plant) is some 2 km<sup>2</sup> and in total 47 wells have been drilled; of those 7 are producer wells (MT-4, 23, 26, 27, 31, 35, 36, 43, 53) and 5 are reinjection wells (RMT-2, 15, 18, 6, 30). Temperature and pressure are monitored in 14 wells and 2 wells are used to monitor potential reservoir changes.

This project started before the EIA Act became effective in Nicaragua, thus the environmental management of the geothermal field has been limited.

# 4.2.2 San Jacinto-Tizate

The San Jacinto - Tizate geothermal field is located in the Marrabios cordillera, some 75 km northwest of Managua, 10 km northeast of Telica and 20 km northeast of León. El Tizate is located approximately 2 km north of San Jacinto.

In 1992-1995 Intergeoterm S.A. carried out exploratory investigations and deep drilling in a 90 km<sup>2</sup> geothermal concession area in the San Jacinto – Tizate zone. Wells were drilled in a 5 to 6 km<sup>2</sup> area, where there is a geothermal deposit of commercial interest at relatively shallow depths. Polaris Energy Nicaragua S.A. (Ram Power, Corporation) has the concession rights to a utilization area of 40 km<sup>2</sup> in the San Jacinto-Tizate Geothermal Field and has operated a 10 MW power plant with  $2\times5$  MW back pressure units there since June 2005. The current generation is 9.3 MW.

An EIA was carried out for the expansion of the project to generate 72 MWe and an environmental permit was issued in 2008 (Administrative Resolution No. 30-2008) by the Ministry of the Environment and Natural Resources, MARENA.

Eleven wells have been drilled in this field (SJ-1, SJ-2, SJ- 3, SJ-4, SJ-5, SJ-6-1, SJ6-2, SJ-7, SJ-9-1, SJ-9-2, SJ-10-1); of those 3 are producer wells (SJ-4, SJ-5 and SJ-9-1), 2 are reinjection wells (SJ-1 y SJ10-1) and 2 are producer wells, now out of service (SJ9-2 and SJ6-2). The separated water is about 690 tons/h at 170°C separation temperature; this is later pumped directly into the two reinjection wells.

Polaris is currently expanding the power plant by installing a 36 MW condensing unit. The start-up of the new unit is scheduled for the end of 2011 and another 36 MW unit is planned for 2012. At that time the old 2x5 MW units will be taken out of service, bringing the installed capacity of the plant to 72 MWe.

# 4.2.3 Casita - San Cristobal

The Casita volcano - San Cristóbal volcano area comprises a group of volcanic structures located at the NW end of the Los Marrabios cordillera. The project is carried out on the east, northeast and southeast slopes of the Casita volcano. The prospect is located in the Chinandega department, with a 100 km<sup>2</sup> concession area for exploration.

The Casita – San Cristobal geothermal field has, since 2001, been explored by two international companies, first by Triton and later by Cerro Colorado Power, which now holds the exploration license for this field. The exploration work has been focused on geological, geochemical and geophysical studies including structural geology, geothermometry and MT soundings.

An EIA was carried out for drilling exploration wells and an environmental permit was issued by MARENA in 2009 (Administrative Resolution No. 017-2009). Exploration drilling started in May 2011. Road, rainwater drainage and pad construction are taking place in the area. The drilling of a slim hole well (CSS01) from platform "A" by the company Rodio-Swissboring is in progress.

# 4.2.4 El Hoyo Monte Galan

Monte Galán is located in a zone approximately 50 km northwest of the nation's capital, Managua, between the El Hoyo and Momotombo volcanoes, including the Monte Galán caldera. A 100 km<sup>2</sup> area was granted as a concession for exploration to the GEONICA consortium, formed by ENEL-Italia (60%) and LaGeo from El Salvador (40%). An EIA was carried out for drilling exploration wells and an environmental permit was issued by MARENA in 2008 (Administrative Resolution No. 015-2008).

In April-July 2009 the first exploration well was drilled (HMG-1) with a commercial diameter (standard well, 8 1/2"open hole) reaching 2000 m depth and a temperature of about 190-200°C but

with low permeability. A second well (HMG-2) was drilled on October-December 2009 reaching 1723 m depth encountering good permeability but a low temperature.

Currently, the second phase of exploration drilling is in progress and three slim holes with a proposed depth of 1100 m will be drilled during the next months. The access road, pads and drilling sumps have already been built.

### 4.2.5 Managua Chiltepe

The Managua – Chiltepe area encompasses the entire volcanic zone that includes the Chiltepe peninsula and the volcanic strip stretching to the south, generally known as the "Nejapa alignment". The centre of the Chiltepe volcanic peninsula is located only 10 km northwest of Managua. A 100 km<sup>2</sup> area was granted as a concession for exploration to the GEONICA consortium. An EIA was carried out for drilling exploration wells and an environmental permit was issued by MARENA in 2008 (Administrative Resolution No. 033-2008).

In August 2009, the first exploration well was drilled (CHIL-1) in the area, reaching 1015 m depth. The maximum temperature measured in the well was 80°C, and its permeability at 300 m is high. The well did not show high-temperature mineralogy.

Currently, GEONICA has quit this concession and an environmental shutdown plan was approved for well CHIL-1. The area is now available to new developers.

### 4.3 Future plans

The main goal of the government of Nicaragua in the energy sector is to change the emphasis of the power generation matrix to renewable sources in the next years. The current installed capacity in the country is 1102 MW, of which 87.5 MW are in geothermal power plants, 104.4 MW in hydropower, 63.1 MW in wind power, 115.8 MW in biomass and 731.22 MW in thermal power plants. The maximum power demand in the country is about 571 MW.

In 2010, 65% of the energy was produced from non-renewable sources (thermal power plants), 4.8% from wind power, 6.8% from biomass, 8.4% from geothermal stations and 15.1% from hydropower. The proportion of geothermal generation is expected to increase from 8.4% in 2010 to 30% by the year 2017, assuming commercial utilization of geothermal resources in the areas already granted as concessions for exploration.

By developing the use of geothermal resources to generate electricity, Nicaragua could gradually achieve a significant change in the energy matrix while simultaneously reducing the environmental impacts from power generation, as geothermal energy entails relatively low carbon dioxide emissions and a base load factor of up to 95%, which is independent of climatic factors.

# 5. ENVIRONMENTAL FRAMEWORK OF GEOTHERMAL DEVELOPMENT

# 5.1 Environmental Impact Assessment

The Environmental Impact Assessment (EIA) is a formal procedure carried out as part of the planning process prior to any development. Its purpose is to assess the future impact of a proposed development on both the natural and human environments. For large projects with potentially significant environmental impacts such as a major geothermal energy scheme, the EIA might be compulsory. For smaller projects, such as geothermal heat pump installations, the EIA might be

optional but might be produced in support of a planning application to demonstrate that the environmental impacts have been considered (Heath, 2002).

The regulations regarding the EIA process in Nicaragua and Iceland are described in the following sections to present an overview of the procedure that all the developers of geothermal projects must follow to comply with the applicable environmental framework.

### 5.1.1 Nicaraguan regulations

The Act on Environment and Natural Resources (Law 217) was published in 1996. It introduced the concept of environmental impact assessment in Nicaragua: "Environmental impact assessment is understood as an environmental management and policy instrument consisting of technical procedures, studies and systems for estimating the effects that specific works, activities or projects may have on the environment" (Republic of Nicaragua, 1996). The Act also stipulates that: projects, works, industries or any other activities that may deteriorate the environment and natural resources given their characteristics, must apply for environmental permits issued by the Ministry of the Environment and Natural Resources (MARENA) prior to their implementation.

In Nicaragua, the first Environmental Impact Assessment Act (Decree 45-94) was established in 1994. In 2006 the Act was amended and replaced by Decree 76-2006. The new Act defines the institutional system for the environmental assessment, the structure and administration, de-concentration and decentralization and establishes categories of projects, works and/or activities. Strategic environmental assessment has also been established for national sector development plans and programmes, executive branch development plans, regional plans and programmes, national plans and programmes for soil use planning and physical planning and urban development. The environmental assessment categories of projects, according to the EIA Act (Decree 76-2006), are described below.

*Category I:* Projects that may cause large environmental impact (8 groups, subject to EIA). These are special projects with a bi-national or regional scope. The projects in this category are approached by MARENA through the Environmental Quality Direction (DGCA).

*Category II:* Projects with large environmental impact potential (51 subject to EIA). The projects in this category are also approached by MARENA through the DGCA. Geothermal projects included in this category are: geologic and geothermal exploration projects, including drilling to more than 50 m depth and geothermal power generation at any level.

*Category III:* Projects with moderate environmental impact. These projects are subject to an environmental assessment, which is presented to MARENA Territorial Delegations (DT). Geothermal and geologic prospecting projects are included in this category.

Descriptions of projects with small environmental impact potential that are not included in the above categories must be submitted to the respective municipality in a duly completed environmental application form for the relevant permit. A copy shall be sent to MARENA.

MARENA is the proper authority to manage the system, in coordination with the relevant institutions. The developers of projects must submit a formal request, an environmental form and a scoping document for the proposed project to MARENA, according to the procedure for each category, in order to start the EIA process (Figure 4).

For the preparation of Terms of Reference (TORs) for the EIA of projects, MARENA has to work in coordination with sectorial environmental units and other institutions. The results of the environmental impact studies must be discussed with competent sector organisations and municipal

governments before an environmental permit or authorisation is issued, shown in Figure 4. The opinion of the general population must also be considered in the EIA process.

All geothermal areas in Nicaragua are located within protected areas in the Los Maribios volcanic mountain range. These sites were declared protected areas prior to the creation and publishing of the Geothermal Resources Act (Law 443); therefore, special concerns apply to the development of geothermal projects.

Protected areas are subject to a special regulation (Decree 01-2007) in which categories of the natural reserves and the tools to manage the activities that can be developed within the areas are defined. Among these tools are the Annual Operation Plan (POA) and Management Plans.

In the Management Plan, the category of the area is reported, the buffer zones and the nucleus of the reserve defined, the flora and fauna and abiotic elements reported on, and activities that can be developed in the areas defined. In the absence of such plans, POAs, which are prepared annually and state necessary elements to manage the reserve, may be used. The approved Management Plan and POAs must be considered by the developers while preparing the EIA for geothermal projects.



FIGURE 4: The environmental impact assessment process in Nicaragua

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The Direction of Protected Areas in MARENA plays an important role in the EIA process, being involved in the issuing of environmental permits for geothermal projects. Environmental permits and authorisations include obligations, follow up and compliance. MARENA is the proper authority to apply sanctions as a result of failure to comply with required administrative conditions.

# 5.1.2 Icelandic regulations

The Environmental Impact Assessment Act in Iceland was composed in accordance with EU-Directives 1985, amendment 1997. The first law was established in 1994 and amended in 2000 and 2005. According to the EIA Act, all projects which may have significant effects on the environment should be subject to EIA. The Minister for the Environment executes the EIA Act and the National Planning Agency (NPA) advises the minister and supervises the implementation of EIAs, provides guidelines, determines which projects are subject to EIA and gives an opinion on the EIA for a project. The system is based on three important steps:

# Screening

The first step in the process is to find out if a project is subject to an EIA. All projects included in Annex I of the EIA Act are unconditionally subject to an EIA. Examples of such projects are geothermal plants with a heat output  $\geq 50$  MWt and power installations with an electricity output  $\geq 10$  MWe.

Projects which may have significant effects on land, within territorial waters and air or in the pollution zone of the territory of Iceland are listed in Annex II of the EIA Act. These projects are assessed case by case, based on the criteria in Annex III. The selection criteria depend on the characteristics/nature of the project, the location and the characteristics of the potential effects on the environment. Four weeks after the receipt of data on the project, the National Planning Agency shall give notification as to whether a project shall be subject to EIA. Geothermal projects which may be subject to an EIA are:

- Exploration and production wells in high-temperature areas;
- Geothermal drilling in low-temperature areas where mineral water sources or hot springs are on the surface or in the vicinity;
- Industrial installations for production of electricity, steam and hot water > 200 kW;
- Geothermal heat production > 2500 kW gross power;
- Installations: pipes for carrying steam and hot water, underground cables  $\geq 10$  km, overhead transmission lines in protected areas and submarines cables.

# Scoping

If a proposed project is subjected to an Environmental Impact Assessment, the developer shall submit a scoping document proposal to the National Planning Agency as early as possible in the preparatory stage of the project. In this proposal, the developer shall describe the project, the project site and alternatives which could be considered, and provide information on the planning of the project site and how the project will comply with development plans. The plan shall also include a proposal as to which aspects of the project and of the environment should be emphasised, describe what data is already available, which data will be produced where and how, a plan for making information available, and for public consultation. The developer shall make the scoping document proposal known to the consultation bodies and to the general public and may consult with the National Planning Agency. The scoping document is the most important document regarding the Environmental Impact Assessment as at this stage it is decided and agreed upon which research and data are needed for the assessment (Gunnlaugsson, 2007).

As seen in Figure 5, the National Planning Agency shall make a decision on the developer's proposal within four weeks of its receipt, having received the opinion of the licensors and other parties, as appropriate. For geothermal power plants the principal consultation bodies are the local government,

# Aráuz Torres

	NPA reviews SD	Developer prepares preliminary EIS		NPA reviews EIS			Appeal Process	
Time	4 weeks	Unlimited time	2 weeks	6 weeks	Unlimited time	4 weeks	4 weeks 12 weeks	
	Scoping document (SD) submitted to NPA	Preliminary EIS submitted to NPA	Preliminary EIS publicized and opinion of SBC sought	Submission of opinion from SBC	Deadline for submission of public comments	EIS submitted to the NPA	Development permit	
		NPA's decision on the SD announced				NPA's opinion on EIS announced	Decision of the Icelandic Planning and Building Tribunal announced	

EIS: Preliminary EIS plus comments from the public, opinion of the SCB and the developer responses

NPA: National Planning Agency

Preliminary EIS: A report on the assessment of the environmental impact of the proposed project and resulting activities

SCB: Statutory Consultary Bodies

SD: Scoping document is a document prepared by the stakeholder where the aspects of the project, the environment and a plan for public participation and consultation concerning EIS will be emphasised

FIGURE 5: Time schedule for the environmental impact assessment process in Iceland (modified from Gunnlaugsson, 2007)

the Environment Agency of Iceland, the National Energy Authority, the Archaeological Heritage Agency and the Division of the Environment of the local community or region. The NPA can approve the scoping document proposal with or without comments. Should the Agency make comments, they shall become part of the scoping document. If the NPA does not approve the scoping document proposal, the Agency must provide grounds for its decision, indicate what it deems to be deficient and instruct the developer as to how the scoping document should be further elaborated. The approved scoping document proposal is then made known to the licensors and consultation bodies (Gunnlaugsson, 2007).

#### Environmental Impact Statement

An initial Environmental Impact Statement (EIS) has to be prepared by the developer. The report shall specify the effects, direct and indirect, which the proposed project and related activities may have on the environment and the interaction of individual environmental factors. The report shall also explain on what premises the assessment is based. It shall describe the aspects of the proposed project which are regarded as most likely to have an impact on the environment, including its scale, design and location and what environmental monitoring is planned. The main alternatives considered, and their environmental effects, shall always be explained and compared. A non-technical summary shall be prepared describing the report's main findings.

When the developer is ready with the initial Environmental Impact Statement it is submitted to the National Planning Agency. Within two weeks of the NPA receiving the initial environmental impact statement, the agency shall assess whether the report meets the criteria and is consistent with the scoping document.

The Agency may refuse to accept the initial environmental impact statement for review in cases where it does not meet the above criteria. In such cases the National Planning Agency shall provide guidance to the developer regarding further elaboration of the initial Environmental Impact Statement. When the NPA has approved that the statement meets the criteria and is consistent with the scoping document it shall publicise the proposed project and the initial EIS.

The initial Environmental Impact Statement shall be made easily accessible at a location near the project site and at the National Planning Agency for six weeks, which shall also be the time limit for submitting written comments to the NPA. Anyone may comment on the initial EIS which has been made public. The NPA shall call for the opinion of the licensors and other parties as appropriate. The consultation bodies shall express their view as to whether the initial EIS has discussed aspects within their area of concern in a satisfactory manner and, furthermore, whether the proposed mitigation measures are satisfactory. They shall, if there is cause for so doing, specify what should be investigated further and point out possible mitigation measures (Gunnlaugsson, 2007).

The National Planning Agency shall send to the developer the opinions and comments it receives. When the developer has received the opinions and comments, the developer produces a final Environmental Impact Statement on the basis of the initial EIS. In the EIS the developer has to discuss the comments and opinions given, and express its position regarding the comments and opinions. The report is then submitted to the NPA.

Within four weeks of receiving the Environmental Impact Statement, the National Planning Agency shall deliver a reasoned statement of opinion on whether the report meets the criteria of this Act and regulations issued on the basis of the Act, and whether the environmental impact is satisfactorily described. In the statement the main premises of the assessment, including the quality of the data on which the assessment is based, and its conclusions shall be explained. In the statement the developer's response to the comments and opinions received when the initial environmental impact statement was made public shall also be discussed.

If the National Planning Agency's view is that further conditions should be laid down for the project, or that other and more extensive mitigating measures are required than those for which provision is made in the Environmental Impact Statement, the Agency has to specify such conditions and mitigating measures, and the reasons for them. If the NPA finds that the developer's EIS is inconsistent with the Preliminary Assessment Report in important aspects, it shall be presented again to the public.

When the National Planning Agency has given its opinion, this shall be made known to the Minister for the Environment, the developer, the licensors, the consultation bodies, and also those who made comments on the initial Environmental Impact Statement during the period of public presentation. The public shall have ready access to the National Planning Agency's opinion and the Environmental Impact Statement, and the Agency shall advertise in a national newspaper that the opinion and environmental impact statement are ready. The final decision on development is in the hands of local authorities through a development permit (Gunnlaugsson, 2007). A simplified diagram of the whole Environmental Impact Assessment process in Iceland is shown in Figure 6.

#### 5.2 Institution roles in the follow up and monitoring of geothermal projects in Nicaragua

In Nicaragua, geothermal resources are a common property in accordance with the Constitution and other national laws. The Ministry of Energy and Mines (MEM), the Ministry of the Environment and Natural Resources (MARENA) and the Nicaraguan Energy Institute (INE) are jointly responsible for regulating, supervising and controlling geothermal resource exploration and utilization activities.

MEM is responsible for proposing, planning, coordinating and implementing the Strategic Plan and Public Policy of the energy and geological resources sector. MEM also authorizes and grants geothermal resource research and utilization licenses in accordance with applicable laws. The terms and conditions of the license must be agreed upon by and between MEM and the respective license holder, aiming at the optimum use of geothermal resources. MARENA administers the use management and of environmental resources by means of actions, economic investments. measures. institutional and legal procedures maintain to or recover and enhance the quality of the environment, decrease vulnerability and ensure productivity of resources and sustainable development.

MEM and MARENA establish coordination with municipal governments in the areas for which the geothermal resource licenses are granted. Municipal governments issue a statement of opinion regarding the contracts or concessions in their district to utilize natural resources prior to the approval by the competent authority. MARENA must inform municipalities all involved of the conditions under which environmental permits are granted.

The Environmental Management Unit (UGA) at MEM works closely with MARENA on every aspect of the EIA process for geothermal projects. The role of the sectorial environmental management units is to ensure compliance with the norms, regulations and other environmental practices in the



FIGURE 6: Environmental impact assessment process in Iceland (Gunnlaugsson, 2007)

programmes, projects and activities of the institutions and monitor the compliance with sectorial environmental policies within the institution's and other executive agencies' power.

In order to carry out monitoring of geothermal projects, the license holder is to provide MEM with technical reports at the end of each three month period relevant to the work and purposes covered by the license. This report is to detail work accomplished, approximate costs incurred and any modification planned by the license holder to change the annual work programme and budget as a result of contract operations. The relevant progress report must also contain an annual account summarizing the four quarterly reports. MEM may, where appropriate, carry out inspections and supervisory actions. MEM can monitor and supervise license related operations and activities, and the license holder must provide MEM with facilities to ensure the fulfilment of obligations and liabilities defined in laws, regulations and the license.

The Nicaraguan Energy Institute (INE) is in charge of the general direction of electricity and is the national electricity regulator. INE applies the policies defined by the government and is in charge of regulation and taxation. INE authorizes temporary licenses for generation and transmission as well as distribution concessions and supervises the Prices Purchase Agreement (PPA) between the distributor and the developer. INE is also responsible for protecting the rights of consumers of electricity, approving and monitoring fees to the final consumer sales and related services, monitoring compliance, criteria and specifications to ensure efficient and reliable operation.

When the developer receives the exploration concession and has ascertained the base load, the developer applies to INE for a tariff. The developer can sell the excess generation on the public market; however INE can fine the developer for not producing according to the PPA. The developer has to keep technical matters in order, according to a special operation manual; if the developer fails to do so, the distributor can withhold payments to the developer.

#### 5.3 Environmental monitoring of geothermal projects

The environmental monitoring of projects serves two main purposes: to ensure that the project sponsor/proponent complies with the applicable environmental standards and various environmental components of operations included in legal agreements, and to keep track of ongoing environmental impacts associated with project operations and of the effectiveness of mitigation measures. The environmental monitoring process in different countries, with extensive development and experience in utilizing geothermal energy, is described and analysed below for comparison purposes with monitoring carried out in Nicaragua.

### 5.3.1 Monitoring process in Iceland

The public monitoring of the environment surrounding geothermal projects in Iceland is reflected in the stated aims of the Nature Conservation Act (No. 44/1999). The objective is to regulate the interaction of man with his environment so that it harms neither the biosphere nor the geosphere, nor pollutes the air, sea or water. The ultimate aim is to ensure that the Icelandic ecosystem can develop naturally and to ensure the conservation of its exceptional or historical aspects (Steinsdóttir et al., 2009). In the Resources Act it is stipulated that the Nature Conservation Act should be consulted for research and monitoring purposes.

When resource utilisation and power plant licences are issued, environmental factors should be taken into consideration. Surveying, utilisation and power plant licences may be bound by specific conditions in order to safeguard environmental requirements, according to the Resources Act and the Electricity Act. To achieve the objectives of the monitoring of the environment, the Environment Agency and the local health authority play the most important role (Steinsdóttir et al., 2009).

When it comes to research or utilisation of geothermal energy, the National Planning Agency is only responsible for administering an environmental impact assessment, where necessary. The Agency has no responsibility as a monitoring authority; as soon as the environmental assessment has been conducted the monitoring becomes the responsibility of the authority that issues a licence for a project. For example, after a municipal council has issued a development or a building licence for construction subject to an environmental impact assessment, that council is thereafter responsible for monitoring that construction.

The councils can only issue development licences if an environmental impact assessment has been carried out or if the National Planning Agency has decided that the project is not subject to such an assessment. The council then reaches a decision based upon the verdict of the National Planning Agency, and in the development licence the council can apply the recommendations set forth in the Agency's decision on the need for an environmental impact assessment. The municipalities have executive power, according to the Planning Act. It is the municipal council's responsibility to continue to monitor projects, both those subject to a development licence and those subject to a building licence; the council is to make sure that the project is carried out according to the description in the licence and relevant legislation.

The Environment Agency (Umhverfisstofnun), which operates under the direction of the Ministry for the Environment, is the regulatory authority of the Nature Conservation Act. Its role is to promote the conservation and sustainable use of Iceland's natural resources, as well as public welfare, by helping to ensure a healthy environment and safe consumer goods, according to the Nature Conservation Act. Should the Environment Agency consider it necessary to supervise a certain project specifically, it shall conclude an agreement thereon with the developer. The agreement shall concern internal checks and monitoring by the developer and supervision by other public parties (Steinsdóttir et al., 2009).

It is also the Environment Agency's and Nature Conservation Committees' responsibility to present their verdict before a development or building licence is issued. The Environment Agency supervises the proper enforcement of the Pollution Control Act by supervising and coordinating health inspection and monitoring and ensures that it is carried out in an efficient manner and does not overlap.

An environmental monitoring plan is always included in the EIA of a geothermal project, which has to be implemented once the project is in operation. The parameters included are discussed and proposed by the developers and approved by the Environment Agency. Monitoring and reporting is the responsibility of the developers and the monitoring reports have to be submitted to the local environment agencies and the municipal governments.

# 5.3.2 Monitoring process in New Zealand

New Zealand is a country that has pioneered the sustainable use of its geothermal resources, and the main key for achieving this goal is the management of environmental effects through appropriate regulation.

The principal environmental legislation in New Zealand is the Resources Management Act (RMA). The RMA was designed to bring all resources under one set of environmental regulations. The Act was implemented in 1991 along with the 1991 Crown Minerals Act. These two laws consolidated and amended scores of acts to provide for a streamlined review and the protection of natural resources. The RMA focuses on the effects of projects, rather than on the type of project, in order to ensure that all activities are treated equally (Hietter, 1995).

The environmental management of geothermal resources is administered by Regional Councils under the Resource Management Act (1991). Monitoring is organized through a District Plan Monitoring to fulfil the RMA, Section 35: "to gather information, monitor, and keep records of the state of the whole or any part of the environment of its region to effectively carry out its function". The environmental impacts of activities are primarily controlled by the RMA through the requirement to apply for resource consent as well as through any conditions for permitted activities included in the relevant regional or district plan. Prior to implementing a geothermal project, the applicant must follow a resource consent process. The five types of consent are: land use consent, subdivision consent, coastal permits, water permits and discharge permits.

A resource consent provides permission to carry out an activity so long as it complies with any conditions attached to the consent. Local authorities have an obligation to monitor the exercise of resource consents which have an effect on their region or district and to take appropriate action where this is necessary.

The conditions of a resource consent may also require the consent holder to monitor the environmental effects of the activity to assist in ensuring compliance with the consent conditions and to determine effects of the consented operation. This may include collecting samples and making measurements, carrying out analysis, surveys, investigations or inspections and providing information to the consent authority at specified times. The results of such monitoring should be publicly available and obtainable from the consent authority.

Geothermal resources are scattered in many regions of New Zealand, but it is thought that 80% of the high-temperature resources are located in the Waikato region, administered by the Waikato Regional Council, also known as Environment Waikato. An environmental monitoring programme, established under conditions associated with the original resource consent, has included subsidence, gas emissions (H<sub>2</sub>S, Hg), groundwater, streams, vegetation, fauna and surface thermal features in the Rotokawa, Mokai, and Wairakei geothermal fields.

Each year in the Waikato region, the consents for geothermal developments are examined to see whether monitoring and reporting conditions have been complied with. The site is visited by council staff, who also look for unauthorised activities and potential hazards. Compliance monitoring reports are then sent to the developer setting out the consent conditions which have not been complied with (if any), and any issues of concern to council staff. If a developer contravenes a regulation or resource consent, the council can issue a legally enforceable abatement notice ordering them to stop. The developer can appeal to the environment court against the abatement notice. If they do so, they can continue with the activity until the case is heard (Hunt, 2000).

According to Hunt (2000), a common problem in New Zealand is that regulatory authorities rarely have scientific or engineering staff with the appropriate qualifications and experience to assess the monitoring data. To overcome this problem, the monitoring results are initially examined by a Review Panel. Each developed field has a separate Panel. The panels are composed of 3 geothermal experts who are independent of the developer, and often comprise retired geothermal professionals and university staff. The panels meet twice yearly for the first two years of development, then annually after that, to examine the results of the monitoring programme which are prepared by the developer and given to panel members prior to panel meetings. The formal meetings last about one day, and the costs are paid by the developer. The Panel then prepares a report to the regulatory authority, which may then recommend changes to the direction in which the development proceeds and any further monitoring that might be needed. Data and interpretation provided by the developer to the panel, and the panel reports are considered to be public information and can be requested by any member of the public, except that the developer may request that certain information which might be of commercial value be kept secret.

#### 5.3.3 Monitoring process in USA

Geothermal development in the U.S is governed by a variety of broad, as well as resource-specific, laws developed and implemented at the federal (national), state and local levels. Environmental regulations include requirements to prepare an environmental analysis for a proposed project, as well

as specific laws designed to protect air, water, land, and socio-cultural environments. In some cases there are overlapping jurisdictions with overlapping regulations, guidelines, and policies (Hietter, 1995).

Development of every type in the U.S. is governed by many environmental laws at the federal, state and local level. The key laws that

pertain to the environmental aspects of geothermal development are:

- *National Environmental Policy Act (NEPA);*
- Geothermal Resources Operational Orders (GROs);
- Specific resources protection laws.

The National Environmental Policy Act (NEPA) is one of the primary U.S. laws for the protection of the environment. The California Environmental Quality Act (CEQA) is an example of state legislation based on NEPA. CEQA requires that each local agency of the city, county or state develop and implement an environmental monitoring programme for all public and private projects for which an environmental impact report (EIR) or a negative declaration is prepared (Roberts, 1991).

An example of a monitoring programme to meet the CEQA requirements is described by Roberts (1991), in the City of Folsom, California. The goals of the monitoring programme include: (1) the utilization of existing inspection officials wherever possible; (2) the merging of mitigation measures, conditions of approval, and verification procedures into a single document stream managed by the city; (3) making the project proponent responsible for preparation of the compliance schedule; (4) verification of compliance by independent, professionally qualified personnel; (5) submission of periodic compliance reports by the project proponent; (6) an annual environmental monitoring report by the city.

The city monitoring programme is under the general direction of the city's monitoring manager and under the general supervision of the city's planning director. The project proponent is responsible for compliance with the mitigation measures and for meeting the requirements of a compliance schedule. The project proponent periodically submits compliance reports. The specific reporting frequency is established in the compliance schedule, and is approved by the appropriate verification inspection The monitoring manager, city inspectors and delegated authorities conduct periodic, entity. unannounced spot checks to verify project compliance. The verification reports are compiled by the monitoring manager. Any person or agency may file a complaint alleging noncompliance with the conditions of approval. Such a complaint must be in writing and provide specific information on the alleged violation. The monitoring manager receives all such complaints, and, with the help of the appropriate city inspector, determines the validity of the complaints and reports the result to the planning director. At the end of the year, the monitoring manager prepares an annual environmental monitoring report which includes a summary of all verification reports, analysis of deficiencies and actions to correct them, a summary and analysis of any disputes, and recommendations for future mitigation measures and other corrective actions needed.

Besides the broad requirements of NEPA, there is a series of federal, state, and local regulations that addresses protection of the environment for specific parameters, such as air quality, water resources, fish and wildlife, vegetation, cultural and archaeological resources, and public health and safety. Specific environmental laws include the:

- *Clean Air Act;*
- Clean Water Act;
- Endangered Species Act;
- Archaeological Resources Protection Act;
- Occupational Health and Safety Act.

In addition to compliance monitoring for the NEPA document, each of the permitting agencies has their own programme for monitoring compliance with permit conditions. The number of agencies involved can result in a complex web of permits and compliance (Hietter, 1995).

#### 5.3.4 Monitoring process in Nicaragua

Once an Environmental Impact Assessment Study is approved by MARENA for the development of any geothermal project, the developer/proponent is responsible for the compliance of all the conditions established in the Environmental Permit. The monitoring and follow up of the permits is the responsibility of the Territorial Delegations (DT) of the Ministry of Environment and Natural Resources, but the local government and sectorial environmental units (UAS) also play an important role in the monitoring of the mitigation conditions in the field. A monitoring programme for each project is included in the EIA document/report, which is also commented on by other institutions during the revision of the EIA, before it is approved by MARENA.

In the environmental permit document, general conditions for the monitoring are settled. For example, for the technological reconversion of the San Jacinto Tizate geothermal project, the frequency of monitoring ( $H_2S$ , noise, soil and water, etc.) was established as at least two times a year during the operation stage of the power plant. Furthermore, the developer has to set up a monitoring database, in which the date, the time, the sampling sites and the analysed parameters have to be detailed.

A monitoring report has to be prepared by the developer and submitted to the institutions involved in the follow up of the project, in this case the Municipality, DGCA in central MARENA, DT MARENA and the Environmental Management Unit (UGA) at MEM. The report is revised by the parties and for additional information that might be requested depending on the case.

In the environmental permit it is also stressed that personnel from any of the above mentioned institutions can conduct field supervision and inspections with or without previous notification to the developer, in order to verify the report or carry out independent spot checks of the mitigation conditions. If a developer contravenes a regulation or the conditions stated in the environmental permit, MARENA can apply administrative sanctions, which can be retention, intervention, temporary or final suspension of activities or closure and fines.

The government institutions do not develop any type of monitoring surveys directly; the developers must provide all the information about the environmental variables in the area influenced by the projects during the baseline gathering and during the different stages of implementation of the geothermal projects.

# 5.4 Environmental parameters to be included in a monitoring programme

A monitoring programme must cover all aspects of the physical, biological and socioeconomic environment for the exploration, construction and utilization/operation project phases. Before the exploration stage of the project and construction activities commence, baseline data gathering has to take place to validate and assess the project's environmental impacts. Environmental monitoring activity should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

For geothermal projects, the most important parameters that a monitoring programme must include are described below.

#### During construction

To control the surface disturbances where roads, new wells, or other civil works may be located and in the vicinity of the project, monitoring has to be focused on the clearing of land, runoff and drainage, soil stability and landslides, erosion and effluent lagoons or evaporation ponds. In situ inspections and photography during construction activities, as a measurement estimate of the runoff volume and sedimentation are necessary.

Special care has to be taken to record the volume and type of soil material removed, and storage conditions. If the geothermal development is planned in a region with high forest coverage, the trees cut must be carefully recorded for later implementation of mitigation measures.

### During utilization/power plant operation

- Ground deformation: Horizontal and vertical (subsidence, inflation) movement during ground deformation takes place simultaneously, although subsidence is prevalent. Ground subsidence and inflation can be determined by repeated levelling using traditional optical survey techniques. Permanent survey benchmarks need to be installed on the ground or on permanent structures. The frequency of surveys will depend on the rate of subsidence and the location of the subsidence area. Horizontal deformation can be determined from repeated measurements of horizontal angles between reference points using a theodolite. Generally the reference points are permanent markers specifically installed for the purpose. Horizontal deformation can also be determined from repeated measurements of horizontal distances between reference points using electromagnetic distance measuring equipment (Hunt, 2000).
- Seismicity: Seismometers have to be installed in the geothermal field to continuously record small earthquakes.
- Reservoir mass changes: Generally developers routinely measure the amount of mass withdrawn from, and reinjected into the field. However, these measurements do not provide information about natural mass losses from thermal features or natural recharge. Changes in mass can be determined from microgravity monitoring at selected points (Hunt, 2000).
- Reservoir chemistry changes: Withdrawal of deep reservoir fluid generally induces recharge which may alter the chemistry of the fluid, especially if a significant proportion of the recharge water has a very different chemistry. Samples can easily be obtained for analysis by sampling from the weir box associated with a wellhead separator, sampling from a 2-phase pipeline from the well, or using a downhole sampler (Hunt, 2000).
- Natural thermal features: Geothermal development may cause changes in natural thermal features. Hot spring flow rates, temperature and chemistry of the fluid emerging all have to be monitored. Flow rate is generally measured using a permanently fixed V-notch in the overflow channel. If the spring does not overflow, the water level in the pool is an alternative parameter that can be measured. In both cases corrections may be needed for leakage into the surrounding soil if the edges of the pool are not sealed. Samples can be collected from the overflow channel for analysis of chloride (Cl<sup>-</sup>), boron (B), magnesium (Mg<sup>+2</sup>), silica (SiO<sub>2</sub>) and sulphate (SO<sub>4</sub><sup>-</sup>) concentrations. Temperature is generally measured using a thermocouple, but it is important to take the measurement at the same point each time, especially if the spring discharges into a pool because local atmospheric conditions can affect the temperature near the water's surface (Hunt, 2000).

Changes in distribution and the temperature of thermal ground are often manifested by differences in vegetation species and the thermal stress of individual species. Ground temperature can be measured at selected sites at 1 m depth or greater to minimise daily and seasonal temperature variations. The measurements are generally made with a thermocouple inserted in a rod, connected to a hand held display unit. A hole is first made in the ground with a steel rod or auger, and then the thermocouple rod is inserted. A survey may be made in a grid pattern or at specific intervals along profile lines through the thermal ground (Hunt, 2000).

• Groundwater changes: Variations in water level in the shallow unconfined groundwater aquifer can easily be measured in shallow monitoring holes. These holes are about 3-5 cm diameter and

are generally drilled vertically using a small truck mounted auger. The depth of the hole depends on the depth to the water table, but needs to extend 5-10 m beyond the natural water table. The hole should not be situated in a topographic low that might become flooded, close to roads, or within the grout screen area of a deep production well (Hunt, 2000).

- Groundwater temperature and chemistry: The temperature can easily be measured in groundwater monitoring holes using a digital thermometer and a probe. Samples for laboratory analysis are best obtained after water level and temperature measurements have been made. Samples of stale and stagnant water in these holes should not be collected; but after 5-10 wellbore volumes of water have been removed and naturally replaced. Removal of stagnant water and collection of the sample are generally carried out using a small portable electric pump. Important parameters that should be determined are: pH, chloride (Cl<sup>-</sup>), lithium (Li<sup>+</sup>), calcium (Ca<sup>2+</sup>), boron (B), sodium (Na<sup>+</sup>), potassium (K<sup>+</sup>), magnesium (Mg<sup>2+</sup>), sulphate (SO<sub>4</sub><sup>2-</sup>), total silica (SiO<sub>2</sub>), total bicarbonate (HCO<sub>3</sub><sup>-</sup>) and fluoride (F<sup>-</sup>). In addition, the determination of stable isotopes δ<sup>18</sup>O, δ<sup>2</sup>H, and tritium is worthwhile (Hunt, 2000).
- Weather: In order to assess the influence of variations in climatic conditions on thermal features, groundwater temperature and level, it is necessary to monitor rainfall, air temperature and air pressure. These can generally be obtained from a weather observatory installed near the power station. In the early stages of development it is generally necessary to install several small weather observatories, in and around the geothermal field, to collect information which will enable various air discharge scenarios for the power station to be modelled (Hunt, 2000). Regional air flow patterns, atmospheric temperature gradients, humidity and topography are also important for the baseline data collection.
- Precipitation chemistry: B, NH<sub>3</sub> and to a lesser extent Hg are leached from the atmosphere by rain and can affect soil, vegetation and surface waters. Heavy metals in rain, anions such as SO<sub>4</sub><sup>2-</sup>, NO<sub>3</sub><sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, cations such as NH<sub>4</sub><sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup> and other parameters such as pH and conductivity have to be monitored.
- Noise emissions: Noise levels at sensitive receptor sites can be measured by use of a hand held integrating-averaging sound level meter. The number and locations of the stations for noise monitoring have to be selected after carrying out an extensive survey to determine the potential noise sources in the project area. Generally, the main areas of concern are well pads during drilling and flow tests, and near equipment during operation of power plants: cooling towers, turbine and generator, switch yards/substations, gas extraction systems, pumps, control valves, etc.
- Non condensable gases (NCGs): The gas emissions can be calculated from the total fluid flow rate, gas fraction of fluid and the concentration of each gas in the fluid. H<sub>2</sub>S and CO<sub>2</sub> are the main non condensable gases that are released to the atmosphere.

Hydrogen sulphide emissions are calculated from measured concentrations in gas and condensate, and from the measured or calculated flow of water and/or condensate. The frequency of sampling the sources (wells, steam vents, condensers, and ejection systems) must be at least once per year. Portable or permanently fixed detectors and analysers for concentrations in ambient air and fixed sensors in power plant areas may be used to directly measure gas concentrations.

Carbon dioxide monitoring can normally be accomplished by measuring its levels. The concentration of other NCGs like NH<sub>3</sub>, CH<sub>4</sub>, Hg, B and Rn should also be monitored.

• Waste water chemistry: The chemical composition of the fluid discharge is largely dependent on the geochemistry of the reservoir, and the operating conditions used for power generation. Chemical elements of environmental significance in wastewater are trace constituents like Li, B, As, Hg,  $H_2S$  and  $NH_3$ . These should be monitored at least every five years, and in cases where wastewater is discharged into natural waterways or close to sensitive areas, these elements should be monitored twice a year.

- Surface water chemistry: Rivers, streams and springs in the vicinity of power plants should be monitored for chemical constituents, especially if there is a discharge of cooling water containing steam condensate, or of the separated geothermal water, into a surface waterway.
- Ecosystems: Wildlife and vegetation density and diversity within the area influenced and in the vicinity of the power plants need to be monitored to follow the changes due to different activities considered in geothermal development. Particular attention should be paid to native species protected by law, species used for food or commercial income. Monitoring frequency could be at 6 or 12 month intervals because biological impacts are unlikely to show up in the short term. It is important to monitor at the same time of year, and under the same physical and chemical conditions, if possible, so that results can be compared to those of the previous year or season. It is also important to record physical and chemical parameters such as temperature, pH, river/air flow and climatic conditions in a biological monitoring programme (Webster and Timperley, 1995).

According to Hunt (2000), in setting up a monitoring programme it should be recognised that the programme is likely to extend for several years or even decades, therefore all observations and measurements need to be thoroughly documented in a suitable archive. Monitoring sites need to be marked and monitoring facilities (e.g. groundwater monitor wells) need to be maintained. The monitoring frequency should be sufficient to provide representative data for the parameter being monitored and the programme is likely to need revision from time to time.

# 6. DISCUSSION

The Environmental Impact Assessment process in Iceland and Nicaragua is similar and there are no specific requirements for geothermal projects. According to the EIA Act in both countries, the same procedures to apply for permits must be followed for all kinds of projects that may have significant effects on the environment. The main difference in the systems is that in Iceland the National Planning Agency just gives its opinion on the Environmental Impact Statement, but the final decision regarding the issuance of developing permits is in the hands of local authorities; in Nicaragua the review and approval of the Environmental Impact Assessment of projects, as well as the issuance of environmental permits is the responsibility of the Ministry of Environment and Natural Resources.

The environmental monitoring process in countries like USA, Iceland and New Zealand follows similar guidelines, but the regulatory institutions involved in each country vary. In most of these countries local authorities have the obligation to monitor compliance with conditions according to consents, licences and permits. In Nicaragua the environmental monitoring of projects is mostly based on field supervision and inspections to verify compliance with conditions stated in environmental permits in addition to the review of monitoring reports provided by the developers.

In the case of Iceland, environmental monitoring programmes have to be proposed by developers as a part of the Environmental Impact Statement. The programmes have to be approved by the Environment Agency, which also has the final decision on which parameters must be determined and the frequency of monitoring. Developers get, in most cases, the monitoring service from a consulting firm, which can also provide suggestions about parameters and frequencies. The approved monitoring programme is agreed upon between the parties: developer, consultant and regulatory institution.

A common obstacle in environmental monitoring in Nicaragua and New Zealand is that regulatory authorities sometimes do not have scientific staff with the appropriate experience to assess the monitoring data provided by the developer. It can be valuable to make consultations with geothermal

professionals for the examination of monitoring results and reports. Another difficulty in Nicaragua is that institutions involved in monitoring do not have enough personnel and logistic resources to conduct field supervision and inspections.

The monitoring and follow up process must cover: surveillance and inspection to ensure that conditions are being followed during the project construction stage; monitoring to check for compliance with standards or regulations, to test the effectiveness of mitigation measures and to identify changes in environmental conditions; management to respond to unforeseen events; evaluation to review aspects of environmental practice and performance and to provide feedback for process improvement and decision making.

### 7. CONCLUSIONS

The success of an environmental monitoring programme depends on the baseline data gathering to establish background information valuable for comparing changes in environmental conditions during geothermal development, as well as for identifying natural variations not related to the activities considered in a proposed project.

The regulatory institutions play an important role in monitoring and follow up of the environmental compliance to geothermal projects, and must provide general guidelines for the developers to carry out monitoring surveys. Official monitoring reports are important tools enabling relevant authorities to assess the management of geothermal systems under development. A very important factor in monitoring is that results and reports can be made available to the public and obtainable from the consent authority.

It is necessary that monitoring programmes can be discussed and agreed upon in order for developers and regulatory institutions to be able to state the parameters and frequency according to the interests of the parties. The responsibility for protecting the environment during a geothermal development rests with the developer; this responsibility cannot be shifted to the regulatory authorities or the government.

Part of the environmental parameters identified in this report to be included in a monitoring programme can be used as a general reference/guide by regulatory institutions in Nicaragua to enhance the surveillance and follow up conferred upon geothermal projects.

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