The United Nations University
GEOTHERMAL TRAINING PROGRAMME
Orkustofnun, Grensásvegur 9,
IS-108 Reykjavík, Iceland

Reports 2005
Number 11

PRELIMINARY ENVIRONMENTAL IMPACT ASSESSMENT FOR THE DEVELOPMENT OF TENDAHO GEOTHERMAL AREA, ETHIOPIA

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ABSTRACT

The Tendaho geothermal field is one of two geothermal fields in the Ethiopian Rift Valley that has been explored by deep drilling. Six geothermal wells have been drilled to date, four of which are productive. There is a plan to progress the resource to development in three phases, which includes a small scale power plant, further deep drilling and a medium scale plant. In this report, analysis of the current status of the environment, environmental effects which the proposed developmental activity may entail and mitigating measures to be taken to reduce impacts to the level of insignificance, are discussed. The environmental regulations of Ethiopia are used as a guide line. The characteristics of the existing environment at Tendaho include: a flat topography, scarce wildlife, scarce vegetation, arid climate, limited surface water bodies, clean air, natural thermal features and sparse population. Impacts on the environment from deep drilling are predicted to be minimal and short term. Potential impacts of utilization of the resource on the environment are physical, chemical and socio-economic. The physical impacts on the geology and the landscape relate to construction activities and the abstraction of water from the reservoir. Given the chemical concentration of the geothermal fluids, the risk of contaminating the groundwater by waste water disposal is considered low. Air emissions during operation will cause no significant contamination of the air, since the gas content of the resource is low. The impacts on the socio-economic conditions are mainly positive, including a rise in employment opportunities and an indirect stimulation of rural development. All the impacts can be mitigated with careful management of the resource and implementation of appropriate environmental protection measures. A detailed EIA, based on evaluation of additional data and stake holder analysis, is recommended before the final phase of the proposed development.

1. INTRODUCTION

The Tendaho geothermal field is located about 630 km northeast of Addis Ababa, in the northern part of the Ethiopian rift (Figure 1). The geothermal field is one of several geothermal fields in the

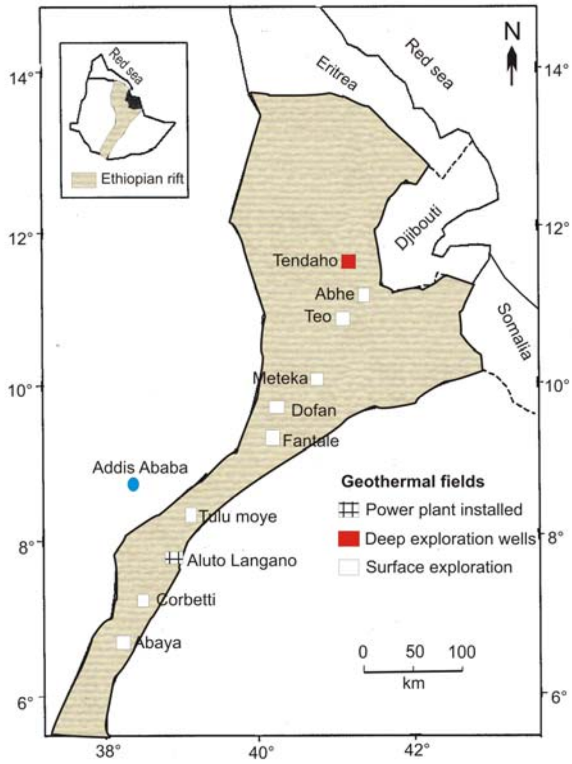

FIGURE 1: Location map of Tendaho geothermal field, Ethiopia

Ethopian rift valley which was identified as a high-temperature geothermal area, since the early reconnaisance survey that started in 1969 (UNDP, 1973).

Subsequent surveys have been carried out in the Ethiopian Rift Valley on target geothermal areas. Based on the level of the studies, the status of geothermal exploration in the Ethiopia rift can be grouped into three: (i) area where a power plant has been installed (Aluto-Langano), (ii) area tested by deep drilling (Tendaho) and (iii) areas where various levels of surface exploration have been done (Abaya, Corbetti, Tulu Moye, Gedemsa, Dofan, Fantale, Kone, Meteka, Danab, Teo and Abhe) (Figure 1).

The review of the geothermal exploration work that has been conducted in Tendaho is given in Section 2. Based on earlier surveys, three deep (maximum depth 2196 m) and three shallow (maximum depth 516 m) wells were drilled in 1993-1998. Four of the drilled wells are productive. The productive wells were estimated to be capable of sustaining about 3 MWe power using a back pressure turbine (Aquater, 1996). Using the productive wells, a developmental stategy beginning with a 1-2 MWe back-pressure unit was also suggested (Amdeberhan, 1998). Further development of the resource via additional deep exploratory and production drilling in the future envisages a power expansion of 20-30 MWe condensing units (Aquater, 1996).

Energy consumption in Ethiopia is made up of less than 1% electricity, about 5.4% hydrocarbon fuels and the balance by traditional biomass fuels (Teklemariam, 2005). Most petroleum products are consumed in the transport sector, whereas household energy is comprised primarily of biomass fuels. A large proportion of traditional biomass energy is created by burning wood which causes the loss of large areas of forest. Currently 737 MW of electricity are generated, out of which 90% is from large scale hydropower plants and the rest from diesel, mini hydro and geothermal power. The main environmental advantages of developing geothermal resources in Ethiopia over hydro resources are that:

1. It requires minimal land use and hence avoids displacement of settlement and wildlife and coverage of fertile land;
2. In arid areas such as Tendaho it is the best alternative to replace diesel plants which cause significant environmental impacts;
3. It has neither siltation nor flooding problems; and
4. Its modular design is suited for rural electrification.

A project proposal entitled “Tendaho geothermal resource development” has been prepared by the Geological Survey of Ethiopia (GSE), which may be assisted by African geothermal development imitative (“ARGeo”) project. The main aim of the regional initiative is to remove the barriers to development of geothermal energy in the East African Rift Valley. The key characteristics of the proposal upon which this environmental impact assessment was conducted are briefly stated.

With a greater global awareness of environmental issues, the efficient use of natural resources is becoming increasingly desirable. One of the ways to achieve this goal is by imposing environmental regulations. The environmental requirements and processes of Ethiopia which are the basis of this analysis are discussed. A description of the existing environment includes environmental geology, water and air quality, land use and soil conditions, climate, flora and fauna and socio economic conditions.

The environmental impact assessment (EIA) and procedural guidelines of Ethiopia are used as guidelines during this study. According to EPA, (2000) the main EIA processes are screening, scoping and decisions to reject or accept a project proposal. In the EIA guideline, development of geothermal power is designated as a project whose type, scale or other relevant characteristics has the potential to cause some significant environmental impacts but is not likely to warrant an environmental impact study. A case by case screening of the activities of the proposed project was made using a screening check list as a tool. The outcome of the screening indicated the need for an environmental assessment in limited environmental issues. During the analysis, an environmental interacting matrix, impact significance rating criteria and national and international standards were used.

The objective of this study is to analyse the current status of the environment in Tendaho geothermal field and to predict the environmental effects which the proposed development might entail and to recommend mitigating and environmental management measures to help bring about the intended development without unacceptable adverse impacts.

2. GEOTHERMAL EXPLORATION IN TENDAHO

2.1 Geology

Tendaho geothermal field is located in the Afar Depression, a plate tectonic triple junction where the spreading ridges that are forming the Red Sea and the Gulf of Aden emerge on land and meet the East African Rift. The Afar Depression is one of two places on earth where a spreading oceanic ridge can be studied on land, the other being Iceland (Abbate et al., 1995). The Tendaho geothermal field in Afar consists of a NW-SE elongated broad plain of about 4000 km^2 (Tendaho graben), mainly filled by alluvial and lacustrine deposits (Aquater, 1996). The oldest volcanic products in the area are lava pile outcroppings on the graben edges (Afar stratoid series), whereas the most recent activity, both linear and central, is concentrated within the graben (Figure 2).

Recent volcanos in the graben from northwest to southeast include: The Manda Hararo complex, Kurub volcano, Damali and Gabilima volcanoes. The nature of the volcanoes is discussed below, mainly based on Siebert and Simkin (2005).

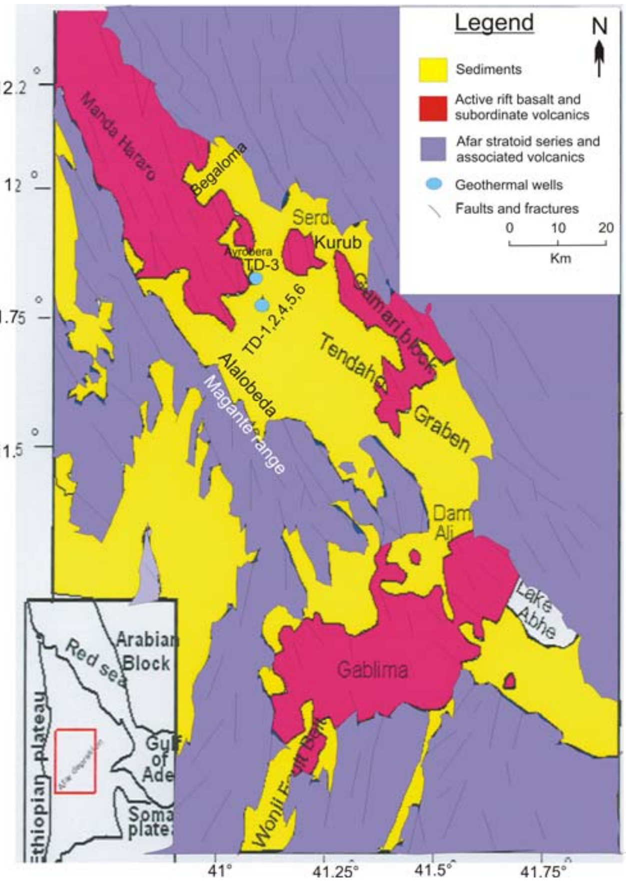

FIGURE 2: Geological map of the Tendaho region

The Manda Hararo complex is the southernmost axial range of western Afar with a summit elevation of about 600 m (Figure 2). The massive complex is 105 km long and 20-30 km wide, and represents an uplifted segment of a mid-oceanic ridge spreading centre. The dominant part of the complex lies to the south. Hot springs and fumaroles occur around Begaloma Crater Lake. Extensive hydrothermal manifestations occur at Ayrobera on the southeastern tip of the complex.

Kurub shield volcano lies in the Saha Plain, southeast of the Manda Hararo complex. Its summit elevation is 625 m a.s.l. Wind-blown sand fills the summit crater of the volcano. Initial subaqueous activity occurred along north-northwest trending fissures.

Dama Ali is a broad shield volcano that rises above the northwest shore of Lake Abhe, southwest of Tendaho. Its summit elevation is 1068 m a.s.l. The 25 km wide volcano has an arcuate chain of rhyolitic lava domes occupying the northern, western, and southern flanks. Youthful basaltic lava flows surround these domes and blanket the flanks of the volcano. Dama Ali is considered the most likely source of an eruption that was reported to have occurred in 1631. Major fumarolic activity occurs in the summit crater, and abundant hot springs are found on the volcano.

Gabilima is a strato volcano with a summit elevation of 1459 m a.s.l. and is located at the intersection of the central Afar rift zone with the northern end of the NE-SW trending main Ethiopian rift. Rhyolitic lava domes are located on the flanks of the volcano, and a 5×17 km basaltic lava field covers the plain north of the volcano.

The most recent stage of volcanism is associated with remnant magmatic bodies that are partially destined to cool at varying depths under the rift floor. Waters of meteoric origin migrate to these depths, heat up and re-emerge on the surface to form the various hydrothermal manifestations.

2.2 Hydrogeology and geochemistry

The major river draining the Tendaho Graben is Awash River. The river starts in the highlands of central Ethiopia, at an altitude of about 3000 m a.s.l. and after flowing to southeast for about 250 km, enters the Rift Valley and then follows the valley for the rest of its course to Lake Abe on the border with the Djibouti Republic. The Awash River basin is divided into 3 sub catchments: upper (upstream from Koka Dam station), middle (between Koka and Awash station), and lower (between Awash and Tendaho station) (Hailemariam, 1999). The river passes about 10 km south of the drilled geothermal wells and is characterised by extensive variations of flow throughout the year, the maximum being in September to October.

Groundwater acquifers of the region include coarse sedimentary and fractured volcanic units. Subsurface stratigraphy in the drilled wells showed that the Tendaho Graben is filled with: upper thick sedimentary sequence consisting of fine to medium grained sandstone, siltstone and clay, intercalated by basaltic lava sheets; and lower basaltic lava flows of the Afar Stratoid series. The upper layer has permeable zones at intervals, while poor permeability is indicated in the drilled Afar stratoid series.

The waters at depth in the Tendaho geothermal system are of sodium chloride type. The deep recharge to the system originates in the western escarpment and plateau at elevations above 2000 m a.s.l. The main hot springs at Alalobeda have similar isotopic compositions to those of waters from the Dubti wells, suggesting a hydrological connection (Aquater, 1991).

The shallow reservoir is characterised by a TDS value of about 2500 and 2000 ppm at wellhead and reservoir conditions respectively (Aquater, 1996). The gas content of the separated steam is low amounting to 0.1% in weight. The fluids of the deep reservoir exhibit a chemical composition similar to that of the shallow reservoir, except for a relatively higher content of non-condensable gases, amounting to about 1% in weight of the separated steam (Aquater, 1996).

2.3 Geophysics

Geophysical surveys have been conducted at Tendaho since 1980, including electrical resistivity, gravity, magnetics and micro seismic surveys (Aquater, 1996). Low-resistivity values (less than 0.5 Ohm-m) were attributed to the presence of a clayey matrix in the sediments and / or high salinity in the sediments or in the fluid contained therein. The areas with good potential seem to be conductive although resistivity values are not very low. A Schlumberger soundings and head-on resistivity profiling survey conducted at Doubti after drilling outlined a low resistivity zone coincident with hot grounds, mud volcanoes and fumaroles, aligned in a NW-SE direction (Oluma et al., 1996). On the basis of the integrated interpretations using gravity and other data, the existence of a dense, non-magnetic electrically resistive body, separated from the denser underlying basalts, was indicated.

Micro seismic monitoring surveys in Tendaho indicated the existence of NW-SE trending strike-slip faults with tensional components in a NE-SW direction, and dip-slip rupture mechanisms associated with advancing graben/horst formation. Shocks are mainly located in the central part of the Tendaho rift and their epicentral distribution highlights a remarkable coincidence with the NW-SE trending tectonically active structures. Focal depths are confined to the range of 3-8 km (Gresta et al., 1997).

2.4 Reservoir engineering and techno-economical studies

Three deep (TD-1, TD-2 and TD-3) and three shallow (TD-4, TD-5 and TD-6) geothermal wells have been drilled, four of which are productive. Tests conducted after drilling indicated the existence of a shallow reservoir (at about 500 m depth) and a deep reservoir below 1500 m depth, whose economically exploitable quantity has not yet been defined. A maximum temperature of 250 and 270°C has been measured in the shallow reservoir and the deep reservoir, respectively. The main characterstics of the shallow wells are given in Table 1.

TABLE 1: Some characteristics of the shallow reservoir at Tendaho

Well no.	Open depth (m)	Status	Total mass flowrate (kg/s)	Water flowrate (kg/s)	Steam flowrate (kg/s)	Wellhead pressure (bar-g)	Source of information
TD 4	466	Productive	50.4	36.4	14	14.4	Aquater, 1996
TD 5	516	Productive	19.2	11.9	7.3	18.3	Seifu, 2004
TD 6	505	Productive	36.5	26.8	9.6	6.6	Seifu, 2004

A techno-economical study was conducted after the completion of the first shallow productive well (TD-4). The study suggested the best alternative was for geothermal power plant development at Tendaho. On the basis of the available power, base demand, risk and existing electric connection system, a low- investment and low-efficiency alternative (steam cycle with about 3 MW back pressure unit) was recommended for the first project phase (Aquater, 1996). Development beginning with 1-2 MW in a back pressure unit was also suggested (Amdeberhan, 1998). A proposed development strategy of the resource by deep exploratory and production drilling in the future envisages power expansion by 20-30 MWe condensing units (Aquater, 1996).

3. ENVIROMENTAL IMPACT ASSESSMENT (EIA) IN ETHIOPIA

The environment is defined as the physical, biological, social, economic, cultural, historical and political factors that surround human beings. It includes both the natural and built environments. It also includes human health and welfare**.** Environmental assessment is the methodology of identifying and evaluating in advance, any impact, positive or negative, which results from the implementation of a proposed action (EPA, 2000).

In the past the environment was not given particular attention in the developing endeavours of the country, since project evaluation and decision-making mechanisms were unwarrantedly made to focus on short-term technical feasibility and economic benefits. For this reason, past development practices fell short of anticipating, eliminating or mitigating potential environmental problems early in the planning process. In order to ensure sustainable development, it is essential to integrate environmental concerns into development activities, programs, policies, etc. Environmental Impact Assessment (EIA), as one of the environmental management tools, facilitates the inclusion of principles of sustainable development aspiration in advance (EPA, 2003).

The key objectives of the Ethiopian EIA process include: integration of environmental considerations in development planning processes, in order to make use of natural resources in a responsible manner and protection and enhancement of the quality of all life forms.

3.1 The EIA process in Ethiopia

The environmental regulations of Ethiopia are similar to those of many other countries. The concept of sustainable development and environmental rights are entrenched in the rights of the peoples of Ethiopia through Article 43 (the right to development) and Article 44 (environmental rights) of the constitution.

The regulatory process for conducting an Environmental Impact Assessment in Ethiopia is shown in Figure 3. There are a number of potential role players in an EIA, including: competent agency, developer, consultant and interested and affected parties.

Environmental protection authority (EPA) is the competent agency at the federal level in Ethiopia, established by law to ensure that the developer complies with requirements of the EIA process and evaluate and take decisions on the documents that arise from it. There is a plan to raise the competency of regional EPA offices in the long term, to enable them to regulate the EIA of projects of local significance.

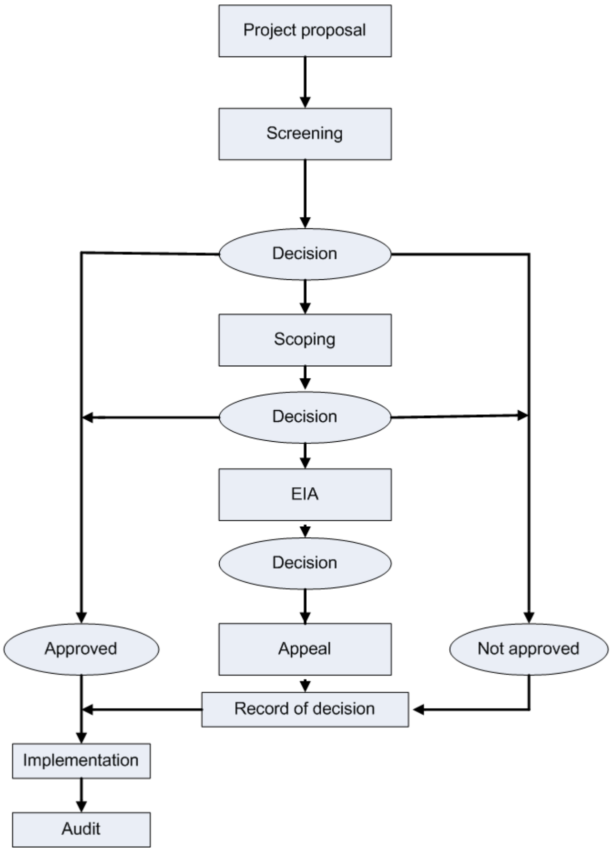

FIGURE 3: Simplified EIA process flow chart for Ethiopia

The main components of the EIA process in Ethiopia include: application, screening (to decide whether a project requires assessment), scoping (to identify and narrow down potential major environmental impacts upon which a detail impact assessment will be conducted), environmental assessment of identified issues and finally the decision process to accept or reject a project. If a project is not on a mandatory or exclusion list, it must be considered on a case-by-case basis as to whether the project is likely to have significant effect on the environment. The permitting process in Ethiopia for geothermal development is under the mining and energy sector.

The competent agency makes a review of proposed projects, based on the EIA guidelines, appropriate environmental quality standards and relevant legislation. The authority's review should be completed within four weeks of submission of the final Environmental Impact Statement (EIS). When the review has been completed, the competent agency should decide whether to accept the application as it stands, reject the application or request that the document be amended.

4. DESCRIPTION OF THE EXISITING ENVIRONMENT

4.1 Environmental geology

The area of potential interest is predominately a flat terrain at an elevation of 370-380 m a.s.l. covering a surface of thousands of square kilometres, locally interrupted by scattered isolated volcanic hills, rising a few hundred m above the flat plain. Tendaho geothermal field is located in a geologically active zone with a history of naturally occurring earthquakes. Seismic studies that were conducted in the early 1990's in the central northern part of the Tendaho rift indicate that shocks were mainly located in the central part and their focal depths were confined at 3-8 km (Gresta, et al 1997). The depth of their occurrence was deeper than the potential geothermal reservoir of the area.

Hydrothermal activity, both active and extinct, can be observed in the Tendaho graben. The active manifestations occur in various parts of the graben. High-temperature fumaroles (>90°C) and associated extensively altered land occurs at Ayrobera, aligned along a NW-SE trending structure. Hot springs at Begaloma form salty Crater Lake. Several mud pots and fumaroles emerge from sediments near Doubti geothermal wells. Erupting hot springs (near or at boiling point), silica sinter depositions and fumaroles occur at Alalobeda, about 6 km southwest of the initial development area (Figure 4). An extinct hydrothermal system indicated by silica deposition occurs southeast of Logia within an area where northwest to north-northwest trending sub-vertical fractures crosscut the rift sediment.

FIGURE 4: Erupting hot spring at Alalobeda geothermal field

4.2 Water and air quality

The only surface water body close to the intended development area is the Awash river (Figure 5). The Awash water has a sodium-carbonate type of composition with a total dissolved solids (TDS) content of about 600 ppm. It is suitable for irrigation. The groundwater potential of the area is generally high, however in large part, the water is of poor quality (high salinity, high iron and high temperature) (MoWR and UNICEF, 2003). The TDS values tend to rise in the groundwater rather than in Awash river. The natural thermal systems are also affecting the quality of the groundwater.

The state of the atmosphere at Tendaho and its surroundings is good. The area has not been exposed to any major anthropogenic interference that has a significant impact on the environment. However micro pollutions may have originated from exhaust smoke from heavy duty trucks crossing the area, fossil fuel generators for electricity production and flaring of gas and firewood in residential houses.

4.3 Land use and soil condition

The potential prospect, where exploration work may be conducted, covers an area of about 300 km^2. The land to be utilised for initial development is located in the northeast part of Doubti cotton plantation and covers a few square kilometres in area (Figure 5). The proposed initial development area was not used for farming, partly due to its high salinity, induced by widespread surface thermal activity. The main land use activity around and far away from the project area is grazing and irrigated farming. The irrigated farms are mainly: mechanised farms of Doubti, Assayita and Ditbahari. Frequent over-flooding and an increase of salinization of the soil due to irrigation mismanagement have been decreasing the suitability of the land for farming.

The prospect area is inhabited predominantly by nomadic and semi nomadic people. Permanent settlement areas are very limited and include small towns such as Logia, Semera, Doubti and Assayita. These towns are several kilometres away from the centre of the initial development area, Asayita

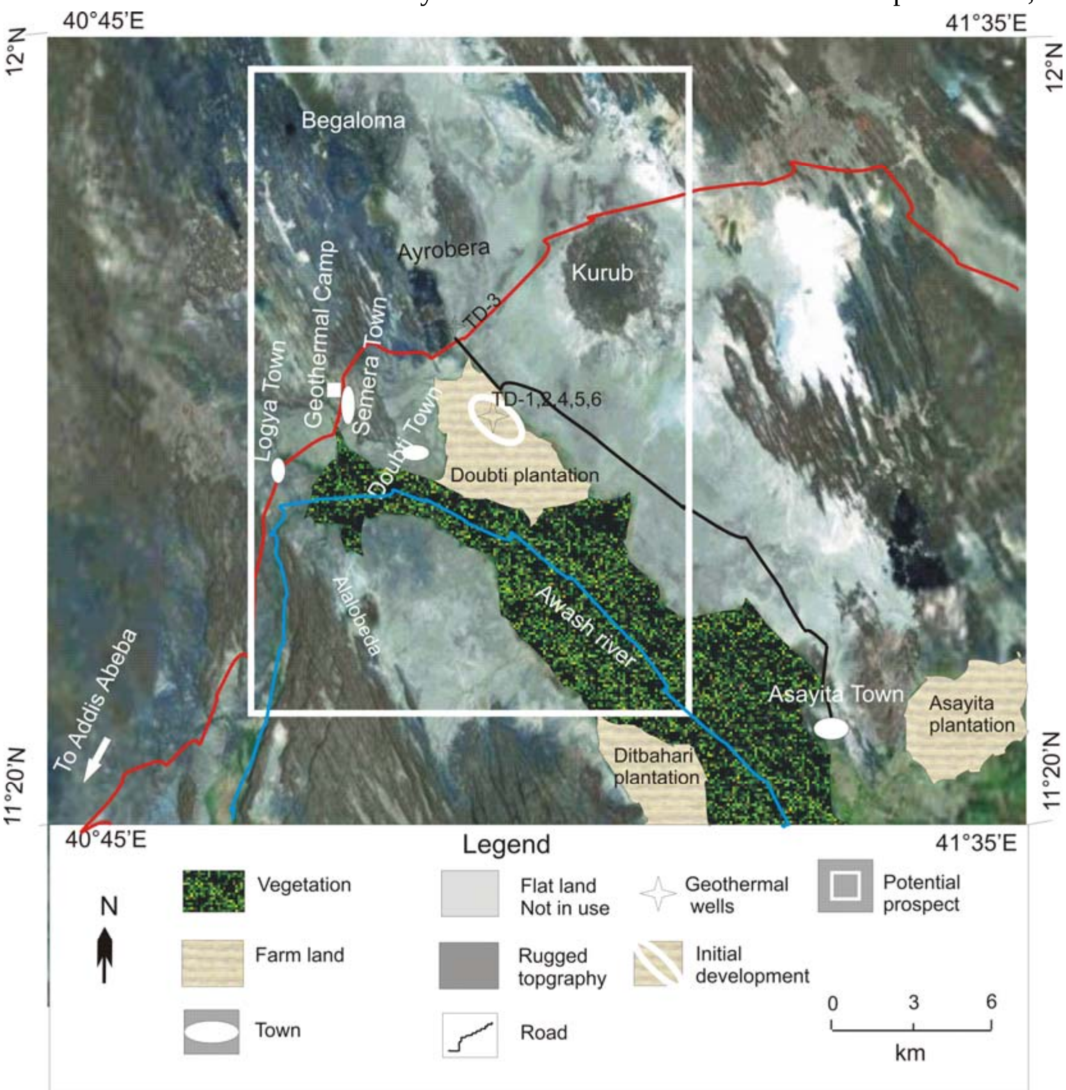

FIGURE 5: Land use and vegetation cover map of the Tendaho region

about 40 km, Logya and Doubti about 10 and 20 km, respectively (Figure 5).

The quality of the soils is generally not good for agriculture. Soil analysis carried out on surface soil samples, collected at a depth of 0-20 cm inside the project area (Doubti Plantation) appeared to have low contents of organic matter and nutrients (Table 2). The soil is essentially alkaline with good cation exchange capacity owing to the high clay content. It consists of sand 50.7%, silt 19.1%, and clay 30.2% (Aquater, 1996). In general, the soils are of low natural fertility. The boron, chloride and arsenic values of the soil are high.

Table 2: Analytical results of Doubti soils (Aquater, 1996)

pH	Organic matter (%)	Total nitrogen (%)	Phosphorus (mg/kg)	Cation exchange capacity (meq/100g)	Chloride (mg/kg)	Boron (mg/kg)	Arsenic (mg/kg)
9	0.24	0.04	1.8	38.6	270	1.6	3

4.4 Climate, flora and fauna

Diverse rainfall and temperature patterns are largely the result of Ethiopia's location in Africa's tropical zone and the country's varied topography. Altitude-induced climatic conditions form the basis for three environmental zones: cool, temperate, and hot, which have been known to Ethiopians as the Dega, the Weina dega, and the Kolla, respectively (U.S. Library of Congress, 2005).

The hot zone consists of areas where the elevation is lower than 1,500 m. The Tendaho geothermal field is designated as a hot zone. Daytime conditions are torrid, and daily temperatures vary more widely here than in the other two regions. Although the hot zone's average annual daytime temperature is about 27°C, mid year readings in the Tendaho area often soar to more than 40°C. The moisture content of the air through most of the year is very low.

Rainfall in Tendaho area is always meagre. The total rainfall from March 2004 to July 2005 was 143.9 mm (NMSA, 2005). The evapotranspiration is much higher than the precipitation rates (Figure 6). The project area biome is characterized as desert scrubland (Wikipedia, 2001).

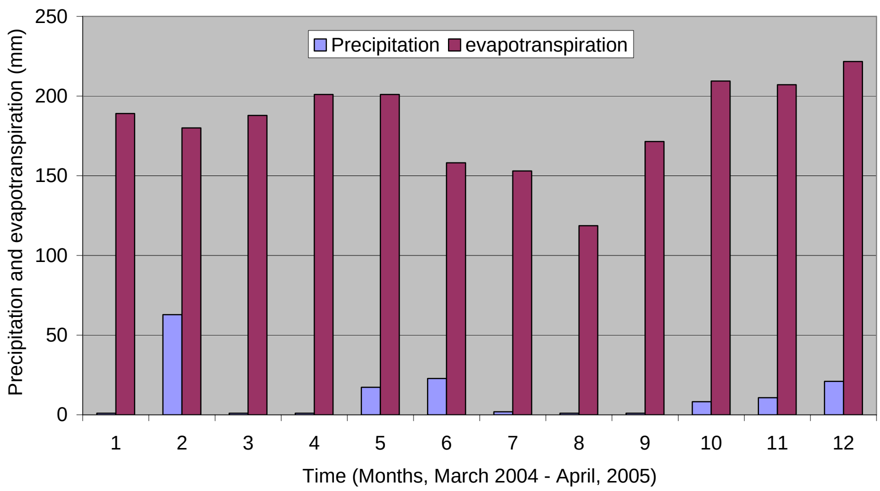

FIGURE 6: Monthly precipitation and evotranspiration at Doubti

Vegetation is mostly confined to drought-resistant plants such as acacia. Most of the existing vegetation has been destroyed by the local people to produce charcoal and for firewood. Broader leafed vegetation is restricted along the Awash river course and areas irrigated by the river. The narrow belt along the course of Awash River covers about 10% of the prospect area (Figure 5). Wildlife is rare in the project area.

4.5 Socio-economic conditions

The Afar region is divided into 5 zones and 29 woredas. The region has a total population of 1,243,000. The project area is located in Doubti woreda of zone 1 which has a population of 76,676. (MoWR and UNICEF, 2003). Zone 1 of the Afar region is predominately populated by nomadic and semi-nomadic pastoralists; settled agriculture is generally not known. Certain areas were developed into large irrigated state farm plantations for the production of cotton and other cash crops (Doubti, Dit Bahari and Assayita farms). These big farms attracted a considerable number of migrant workers, mostly from overpopulated areas in the southern part of the country.

The main transit artery of landlocked Ethiopia for import and export, formerly through Assab and presently through the Djibouti port, leads through the region (Figure 5). This road led to a typical "truck-stop economy" with towns such as Logia, commerce servicing mainly the needs and desires of truck drivers. Semera town is a recently established town close to Doubti geothermal camp, currently the capital city of Afar state and may develop soon into a major commercial centre. A paved all season road connected to the main highway passes through the area of geothermal wells to the town of Assaita. The Doubti woreda centre, Doubti town, is accessible by an all-season gravel road from the main asphalt highway.

In Doubti woreda, for domestic and livestock consumption, the main sources of water include: Water supply schemes from groundwater, Awash river, traditional wells, ponds and water tankering. As regards social services, there exists one high school, 17 low level schools, one hospital and 8 health centres (MoWR and UNICEF, 2003).

The energy consumption of the region is mainly based on biomass fuel using wood from acacia trees, crop residue and camel and goat droppings. The local community sells firewood and charcoal to generate income, by deforesting the already scarce vegetation. Electricity is supplied by small diesel units, with a total capacity of about 2 MW.

5. CHARACTERISTICS OF THE PROPOSED PROJECT

The Ministry of Mines of Ethiopia is currently in the process of designing a plan towards developing Tendaho (Teklemariam, 2005). A preliminary project proposal entitled "Tendaho geothermal resources development" was prepared in 2005, which is expected to be considered for assistance in the African Rift Geothermal Development Initiative (ARGeo project). The proposed project has three phases and the main activities are related to surface exploration, small scale power production, deep drilling and medium scale power production (GSE, 2005).

5.1 Project phases and stake holders

The three phases of the proposed project are described below:

Phase I: *Surface investigations*: Aimed at confirming past exploration results and at proposing exploration drilling targets, and compiling a feasibility study for installation of a small scale pilot plant, using previously drilled productive wells.

Phase II: *Exploration drilling*: Drilling of three deep wells for discovering and, with early success being encountered, testing the deep, high-temperature reservoir. The installation of a small scale power plant that will seek to exploit the resource brought up to the surface by past drilling for local use.

Phase III: *Evaluation - development drilling and power plant installation*: Aimed at the delineation and characterization of the full extent of the reservoir in the early stages and installation and operation of a power plant in the later stages. On the basis of past recommendations the plant to be installed at this stage is considered to be about 30 MWe unit (medium scale plant). However, it should be remembered that final decisions on the future plant will be made after the characterization of the full extent of the reservoir.

The three phases of the project may take six to ten years. With success, geothermal power production will hopefully continue for several decades.

It is anticipated that phases I and II will be executed by the Geological Survey of Ethiopia (GSE) and the Ethiopian Electric Power Cooperation and Phase III may be carried out by a power developer. Various institutions might be involved as stake holders of the project including Ethiopian Environmental Protection Authority, Afar Regional Government, Ethiopian Electric Agency, Ethiopian Rural Electrification Development Promotion Centre and Tendaho Agricultural Development Enterprise.

5.2 Main components and activities

For the purposes of discussion, the project's main components are grouped into: surface investigations, small scale plant, deep exploratory and evaluation-development drilling and medium scale power production. The type of plants mentioned and discussed in this report are to assist in identifying the potential impacts of development and should not be mistaken for a proposed generation process. Discussion of the main activities under each component follows.

The *surface exploration activities* include geological studies, geophysical exploration and geochemical sampling. The work involves earth scientists traversing over the exploration area with sampling and measurement instruments. Well testing is considered in this report as a component of power plant installation.

Small scale power plant. Before installation of the plant, well testing of the productive wells will be conducted to be followed by construction and operation of the power plant, construction of steam gathering and disposal pipelines and overhead electrical transmission lines to the surrounding towns. According to a techno-economical study (Aquater, 1996) the installation of a steam-cycle back-pressure power plant of about 3 MW was recommended, using the shallow reservoir.

During production a mixture of steam and hot water from the productive wells will be transported through two-phase pipes to a separator which separates the steam from the water. The separated steam will be delivered to a turbine to generate electricity and then transported to a silencer which silences the noise and flashes the steam to the atmosphere, with separation of the liquid. The separated liquid from the separator and silencer will be disposed of into an evaporation pond (Figure 7). It has been planned to dispose of the residual water by means of a sealed canal or pipe to an evaporation pond of about 1 km^2 area,

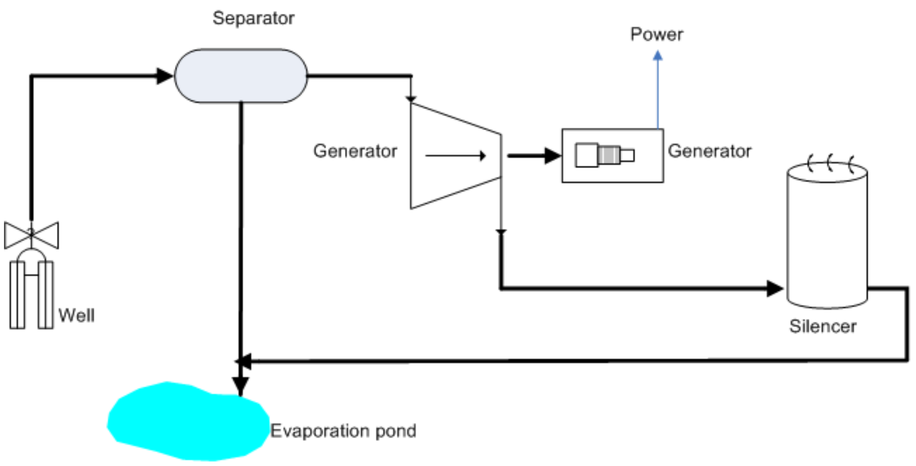

FIGURE 7: Production flow diagram of a proposed small-scale power plant

FIGURE 8: Drilling rig at Tendaho

preferably to be located a few kilometres away from the productive wells. The plant will have a power house and will feed three 33 kV surface lines which will be connected to the local system (SCS).

Deep drilling. The main activities of the proposed deep drilling will include: excavation of material for construction of drill pads and roads, construction of roads, transportation of drill rig and all necessary material, and drilling. The rig is heavy, requiring large equipment with many accessories (Figure 8). Accommodation of it requires a flat and compacted land, estimated to take about 4000 m^2 area per well. During the exploration phase, three wells may be drilled to a depth of about 2000 m. Depending on the outcome of earlier results, additional evaluation and production wells may be drilled. Water from existing productive wells might be used for drill to cool the drilling bit and to flash out the drilled cuttings. Deep wells far from the existing wells may require a supply of water from the Awash river, amounting to about 3,500 m^3 per 24 hours of drilling. Drilling each well normally takes a few months. The wells will be cased from top to bottom with the installation of control valves.

Medium scale plant. The future utilization of the geothermal resource in Tendaho depends on the nature of the geothermal resource to be discovered. After the final phases of deep drilling, the type of power plant warranted by the resource will be selected. The plant type will be decided based on the type of the resource to be discovered and its economic viability.

Initial evaluations have a perception of final expansion of the field to 30 MW and indicate that a double-flash condensing type of plant is a possibility. This type of plant is considered in this report to assist in identifying potential impacts. A double-flash condensing unit is a modification of single-flash units but utilizes the geothermal fluid better because of its double flashing design (Figure 9). Both re-injection, disposal into evaporation ponds and emission to the air are considered to be ways of disposal for waste fluid and gas. The activities during this stage of the development include land clearing, construction of power house, pipe lines and a power transmission line.

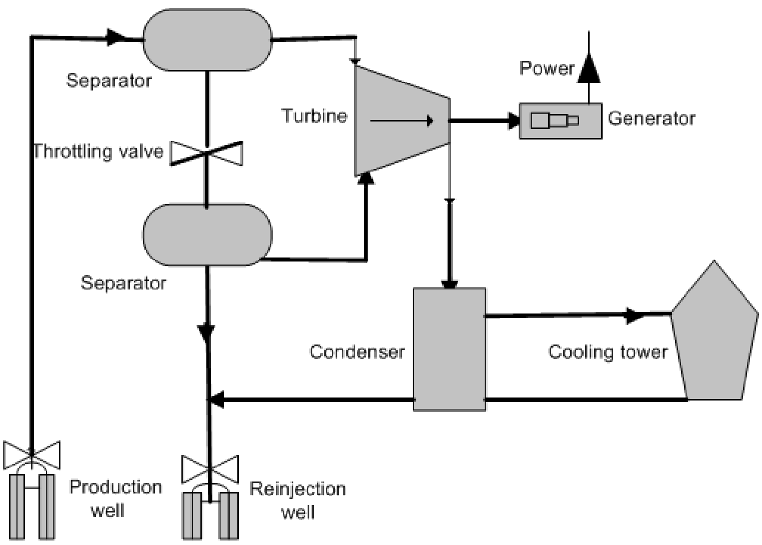

FIGURE 9: Production flow diagram of a proposed double-flash condensing unit

6. INITIAL ENVIRONMENTAL IMPACT ASSESSMENT

Mining, including geothermal development for energy production, results in the disturbance of the surface, underlying strata including aquifers and the atmosphere and therefore is subject to Environmental Impact Assessment. The issues considered during this assessment include: geology, land use and landscape, water quality, air quality, occupational safety and socio-economic conditions. To identify which of the key elements of the project have potential impacts, an assessment was made using a check list and an environmental interaction matrix (Appendix I) and those activities of the project which are considered to have potential interactions with the environment are discussed.

The proposed surface geological, geochemical and geophysical surveys will have no significant interaction with the environment. There may be slight interaction during construction of access tracks for geochemical and geophysical measurements. But the Tendaho field is predominantly a flat land and accessible and the need for such activities will be minimal and short term. Therefore, surface investigations were screened from assessment.

The environmental effects due to activities related to a small-scale power plant, deep drilling and a medium-scale plant are discussed below.

6.1 Small-scale power plant

Well testing will be conducted during the initial phase of development. During the testing, a mixture of two-phase fluid will be discharged and separated at the surface by an atmospheric separator (Figure 10). The power plant instillation involves construction of steam gathering and disposal pipelines and local electric transmission lines. Operation includes disposal of waste fluid and gas. These activities are considered to have potential interaction with the physical environment (geology and landscape), chemical environment (water quality and air quality), and socio economic condition. Issues related to occupational safety are also addressed.

FIGURE 10: Well testing at Tendaho

6.1.1 Geology, land use and landscape

The potential effects of the activities on the geology and landscape are disturbances to surface soil, an increase of steaming grounds and intrusion into the landscape.

Given that the Tendaho geothermal field is located in a desert area with little rainfall to cause erosion, the disturbances to surface soil will have a minimum impact. The operation area for a power plant depends on its type and size but generally the land needed for a geothermal power plant is approximately 20,000 m^2 (Webster, 1995). This land uptake is too low to cause land use problems in a countryside area such as Tendaho. During the initial phases of the development an increase in the amount of steam at the surface may occur due to a reduction in the water level. Such activities may have thermal and chemical effects on the soil. The visual quality of the area may not be affected by structures of the power plant, since the area is remote with little habitation.

6.1.2 Water quality

Most geothermal energy developments involve bringing fluids to the surface. In high-temperature liquid-dominated geothermal fields such as Tendaho, the volume of resultant waste water involved may be large. With an assumed production rate shown in Table 1, the total amount of waste water from the three wells will be about 4500 kg/hr. This water, if not re-injected, will be disposed of in an evaporation pond. Taking into account the evapotranspiration rate (Figure 6), a significant proportion of the waste fluid will evaporate. However, some portion of the fluid may infiltrate to shallow ground water.

The chemistry of the water from the shallow productive wells at the weir box and the surrounding water bodies (Awash river and groundwater wells at Doubti) is shown in Table 3. The concentration of the indicated chemical constituents from the shallow productive wells was, in most cases, below or close to the threshold value of drinking water, exceptions being the chloride and fluoride (TD-4) values. Chloride is the major anion in Tendaho geothermal water and has an effect on the taste and odour of drinking water when the limit is exceeded but is not hazardous to health. Fluoride concentrations above the allowable limits may affect teeth and cause bone diseases. There is no significant difference between the indicated concentrations in the geothermal wells and that of the Awash river and groundwater, aside from the chloride content.

TABLE 3: Analytical data of geothermal water and other waters in Tendaho and drinking water threshold values (mg/l)

Location	pH	Mg	Na	Cl	SO_4	NO_3	F	Source
TD-6	9.5	1	635	1000	156	1.68	1.7	Ali and Gizaw, 2000
TD-5	9.4	0.2	620	905	142	1.77	1.3	Ali and Gizaw, 2003
TD-4	8.4	0.04	708	977	129	0.5	7.2	Aquater, 1996
Awash river	7.8	10	430	60	58	2.2	1.5	Teclu and Gizaw, 2004
Doubti g/w wells	8	12-35	337-635	251-483	207-584	1.33-11	1.67-2	Teclu and Gizaw, 2004
Threshold value	5.5-9.5	100	400	600	600	10	1.5	EPA, 2000

The chemical composition of geothermal fluids is extremely variable. The chemistry of the fluid discharged is largely dependent on the geochemistry of the reservoir, and the operating conditions used for power generation vary from one geothermal field to the other. Most geothermal waters contain at least one of the following contaminants: lithium (Li), boron (B), arsenic (As), hydrogen sulphide (H_2S), mercury (Hg) and sometimes ammonia (NH_3) (Brown, 1995). These constituents have been reported in the thermal water of well TD-4, except for mercury (Aquater, 1996). The concentration of the trace constituents is compared with that of other geothermal fields and threshold value (Table 4). The values are low compared to the values in the selected geothermal fields.

TABLE 4: Trace constituents in selected geothermal fields (mg/l)

Geothermal field	As	B	H_2S	NH_3	Li	Source
Tendaho (TD-4) (separated water)	0.4	4.6	< 0.1	1.49	1.06	Aquater, 1996
Wairaki (NZl) (deep water)	4.7	30	1.7	0.2	14	Brown, 1995
Salton Sea (USA) (deep water)	12	390	16	386	215	Brown, 1995
Cerro Prieto (Mexico) (deep water)	4.7	19	0.6	127		Brown, 1995
Nesjavellir (Iceland) (separated water)	0.05	2.1				Wetangula, 2004
Threshold value	0.3	0.5	*0.05	*1.5		EPA, 2000 and *Brown, 1995

The biological impacts of geothermal development include impacts on animal and human health through the effects of chemical contamination. To control these impacts, criteria are set to provide an upper limit for contaminant concentration in the environment. Different criteria have been developed for different purposes: for air, drinking water, aquatic life protection, crop irrigation and stock watering. Even though the geothermal waste water to be disposed of at Tendaho will not be utilized for drinking, the drinking water threshold value is referred to in order to predict its impact on the groundwater, if infiltrated. The trace constituent arsenic is a major concern, due to its toxicity. Chronic arsenic poisoning causes skin damage, circulatory system problems and increased risk of cancer. The maximum value recommended for domestic use is 0.3 mg/l (EPA, 2000). The arsenic concentration in well TD-4 is very close to the threshold value. Therefore no significant contamination of the groundwater by arsenic will be expected at Tendaho.

Long-term exposure to boron (B) leads to mild gastro-intestinal irritations in humans as B is rapidly and almost completely absorbed by the intestinal tract. High concentrations of B in drinking water can cause weight loss in stock, but does not appear to affect aquatic life (Brown, 1995). The boron concentration in Tendaho is higher than the threshold value.

It is unlikely that a harmful dose of hydrogen sulphide could be consumed through drinking water and the criteria set is mainly to avoid odour and tastes problems. The concentration at Tendaho is close to the threshold value.

Ammonia (NH_3) in drinking water does not directly affect human health. It can, however, compromise disinfection efficiently during drinking water treatment, and cause taste and odour problems. Ammonia is not a major consideration in either stock or irrigation water.

Some trees are sensitive to lithium (Li) with severe toxicity symptoms occurring at concentrations of 0.1-0.25 mg/l. Li does not appear to have an adverse effect on human health or aquatic life.

Given the chemical concentration of the geothermal fluids at Tendaho only minor contamination of the groundwater could be envisaged. However, some mitigating measures should be taken to reduce the likelihood of contamination as close to zero as possible.

6.1.3 Air quality

One of the most significant benefits of geothermal energy is its near-zero air emissions. Variations in geothermal power plant technology and cooling systems can influence emission levels. Geothermal energy facilities, for example, across the United States of America (USA) comply with all federal standards for air quality. Compared to fossil fuel power plants in terms of carbon dioxide (CO_2) and sulphur dioxide (SO_2), geothermal power plant emissions are very low (Kagel et al, 2005). Typical CO_2 and SO_2 emissions from an average power plant are compared with fossil-fuel power plants in USA (Figures 11 and 12). Data from the Tendaho geothermal field is added to the figures for comparison.

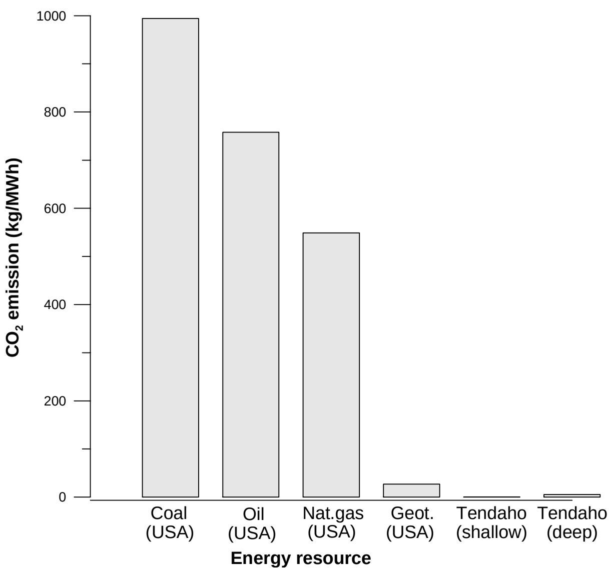

FIGURE 11: CO_2 emission comparison between fossil fuel and geothermal energy

The proposed power generation at Tendaho using a standard steam-cycle plant, will also result in the release of non-condensable gases

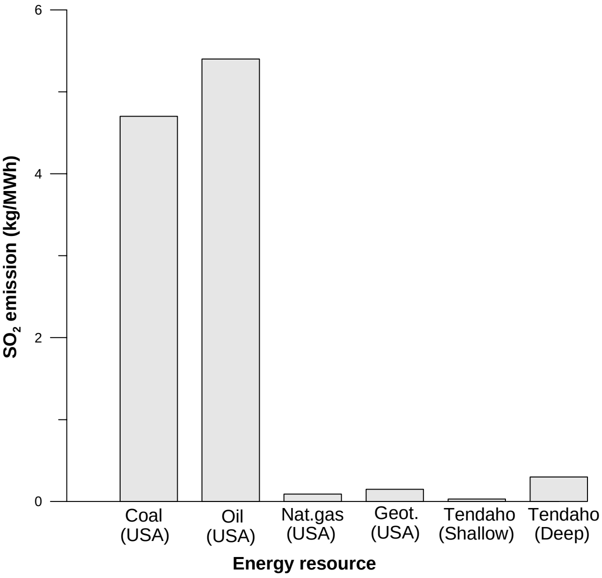

FIGURE 12: SO_2 emission comparison between fossil fuel and geothermal energy

(NCG). The main NCG in the steam are CO_2 (90%) and H_2S (5%). The H_2S emission will be oxidized by the air as SO_2. The NCG value in the steam is 0.1% by weight of the separated steam (Aquater, 1996). Assuming a production rate shown in Table 1, the total steam flowrate from the three shallow wells will be about 1850 kg/hr. The total NCG emission from this production amounts to 1.8 kg/hr, which corresponds to 1.62 kg/hr of CO_2 and 0.09 kg/hr of SO_2. If the indicated steam production is assumed to produce 3MW electricity in a back-pressure plant, the CO_2 and SO_2 emissions from the plant using the shallow reservoir will be 0.54 and 0.03 kg/MWh respectively. The NCG value of the deep reservoir at Tendaho is about 1% in weight of steam (Aquater, 1996); accordingly, the CO_2 and SO_2 emissions using the deep reservoir are estimated to be 5.4 kg/MWh and 0.3 kg/MWh. These values are plotted in Figures 11 and 12, indicating a very low polluting potential.

6.1.4 Occupational safety

Occupational safety is necessary to protect the human population in the workplace. The host community, due to a scarcity of water in the area and lack of awareness, may utilise the water to be disposed of in evaporation ponds for human consumption. But here the waste water is neither chemically nor thermally safe for human use, as discussed in Section 6.1.2.

Besides the normal accidental injury type of hazard associated with engineering and machinery operation, the principal safety hazards are burn and noise. Although relatively rare, hydrothermal eruptions constitute a potential hazard in active geothermal fields and need to be included in the Environmental Impact Assessment.

Burns are a function of the many areas of high temperature found in geothermal developments. Contact with boiling water drains and heated pipes are the common causes of burning. A potential hazard due to noise is also not uncommon.

Hydrothermal eruptions occur when the steam pressure in the near surface aquifers becomes greater than the overlying lithostatic pressure and the overburden is ejected to form a crater. At present three separate cases have been identified that may cause hydrothermal eruptions (Brown, 1995). The first mechanism assumes an expanding zone in the reservoir due to exploitation which increases the steam flow to the surface. Near the surface, acquicludes can restrict the flow of steam and pressure can increase. During long dry periods, the thickness of the near-surface aquifer is reduced and further increased heating and steam flow occurs. If there is a period of heavy rain or water disposal at the surface, then the permeability of the ground is reduced and pressure can be further increased to trigger an eruption. The second mechanism involves hydraulic fracturing allowing the release of non-condensable gases to decrease the boiling point close to the surface. The third mechanism is a reduction in the lithostatic pressure by the removal of the overburden, either naturally by slumping or landslides or by excavation by man.

Hydrothermal eruption occurred at Tendaho in 2000 while testing the shallow reservoir (Amdeberhan, 2005). The cause of the eruption was suggested to be percolated water from a nearby evaporation pond that had been heated and developed high shallow subsurface pressure. Reduction in permeability of the shallow subsurface formation due to the percolation also might have created a favourable condition for eruption.

6.1.5 Socio-economic conditions

One of the main aims of small-scale (< 5MWe) off-grid geothermal development is to provide power for rural and isolated communities which are dependent on imported fuels for power generation. The socio-economic impact of the proposed development is mainly positive. Providing better electricity to the rural people will contribute to rural development. Tendaho is a remote area with an arid climate, far from the utility grid; villages and small towns could replace their diesel generators with the geothermal plant. The rural poor often buy relatively costly and polluting energy services: diesel for power, kerosene for light, charcoal for cooking. The availability of cheaper geothermal electricity is also a stimulant to the rural economy, increasing agro-industrial development and the creation of new job opportunities.

6.2 Deep drilling

The second phase of the proposed project involves the drilling of three deep wells and, if conditions prove to be favourable, additional evaluation and development drilling may be conducted. Deep drilling is designed to identify, define and test the geothermal reservoir. The main elements of the environment to be affected by deep drilling at Tendaho are the geology and the landscape. The proposed development will involve the construction of access roads to the drill sites for moving equipment and accessories, and clearing the land for drill pads. During road construction and drill site preparation, surface disturbances and changes to the natural conditions could occur. However, the Tendaho geothermal field has a flat terrain and is easily accessible. Therefore, such activities are of limited scale. The effects of drilling on the biome of the area cannot be seen, since the area is predominantly barren.

Noise is one of the most ubiquitous disturbances to the environment from deep drilling. However, as the project area is remote and scarcely habited, the noise to be created is unnoticeable. The occupational safety aspect of drilling noise could be easily mitigated by wearing ear mufflers.

The land requirement for drill pads is little and has no effect on the land use. In arid areas like Tendaho, the problem of a suitable water supply can be acute. However the productive wells can be used as a source of water for drilling. The other potential source of water for drilling is the Awash river. A deep well requires up to 3000 m^3/day of water for a period of a few months. This amount of water extraction from the river will not affect the flow. The energy required for drilling will be generated from the drilling rig itself. Therefore, the drilling activity will have no noticeable effect on the energy base of the development area.

Generally environmental impacts due to drilling will not be an issue in Tendaho, due to the particular nature of the existing environment and the short period over which drilling will be carried out.

6.3 Medium-scale power plant

Project activities during this phase will not significantly differ from the earlier phase in their effect on the environment. However, a relatively minor increase in the magnitude of impacts will be expected. Medium-scale operation will involve the construction of a power plant, connection of the geothermal wells to the power plant and operation of the plant throughout its lifetime. The main impacts are considered to be related to construction and civil works, mass withdrawal of the geothermal fluid from the reservoir, waste fluid disposal, waste gas disposal and the generation of electricity. The environmental issues to be assessed are essentially similar to the small scale power production and include the geology, land use and landscape, air quality, water quality, occupational safety and socio-economic conditions.

6.3.1 Geology, land use and landscape

The land uptake for the medium-scale plant is essentially similar to that of the small-scale plant previously discussed. The land requirement will not conflict with the existing land use.

Degradation of the landscape by civil work such as access roads to pipe lines and powerhouse construction will have minor effects.

It is difficult to predict the effect of the proposed development to surface geothermal features. However from experience in other parts of the world, the tendency for hot springs is to decline with exploitation of the deep reservoir. The major hot spring activity at Tendaho is in a remote area at the southwest margin of the field (Alalobeda) (Figure 4). Mass withdrawal, on the other hand, initially increases the activity of steaming grounds and mud pools. This is due to decreasing pressure in the reservoir causing greater steam flow, which has a high mobility through the earth. As reservoir steam zone pressure declines with continuing exploitation, the amount of steam reaching the surface declines and the natural steam features also slowly decline (Webster, 1995). These natural activities are common in the central part of the field, which are part of the scenic value of the landscape.

Deep re-injection may be required at Tendaho to dispose of the waste water during phase III of the project. Injection of fluids to deep formations may be recognized as increased causes of seismicity. Micro-earthquake activities could be triggered by re-injection at high wellhead pressures. However micro-earthquakes are of low magnitude and there has been no record of geothermal production causing damaging levels of seismicity anywhere in the world.

6.3.2 Water quality

As indicated from the results of well TD-2 (one of the productive wells), the geothermal fluids of the deep reservoir exhibit a chemical composition similar to that of the shallow one (Aquater, 1996). The amount of geothermal waste water to be disposed of will be normally much higher than for the shallow reservoir, due to a higher magnitude of production. The means for waste water disposal for the medium scale plant will be decided after a feasibility study in the future. One of the alternatives, surface disposal, if implemented will have an impact on the shallow ground water. Re-injection is the other alternative, which has an advantage in terms of reservoir management and environmental protection.

6.3.3 Occupational safety

Normal accidental injury type hazards associated with engineering and machinery operation, burn and noise hazards, similar with that discussed in Section 6.1.4 can happen. The likelihood of a hydrothermal eruption while exploiting the deep reservoir is low compared to the shallow reservoir.

Withdrawal of fluid from the underground reservoir will also normally result in a reduction of pressure in the formation pore space, which can lead to subsidence. In a remote area like Tendaho where there may be little or no settlement, subsidence can have no major consequences to the public. However it may affect the stability of pipelines, drains and well casings.

6.3.4 Air quality

The main NCG's, while exploiting the deep reservoir for medium-scale power generation will be similar to that of the small-scale plant. NCG's such as CO_2 (green house gas responsible for global warming) and H_2S (oxidized by the air to form SO_2) will be emitted into the atmosphere during power production. The NCG value for the deep reservoir was estimated at 1% in weight of the separated steam (Aquater, 1996). The amount of CO_2 and SO_2 to be emitted by producing from the deep reservoir is calculated (similarly as discussed in Section 6.1.3) to be 5.4 kg/MWh and 0.3 kg/MWh CO_2 and SO_2, respectively. This emission is compared with the emission from fossil fuel and geothermal energy sources in USA and is plotted in Figures 11 and 12. The comparison shows that the proposed geothermal development will cause relatively low air pollution.

6.3.5 Socio-economic conditions

The proposed power production will introduce a new type of energy, geothermal energy, into the energy mix of the country. This will be a healthy development replacing fossil fuels which are currently being used in the region. Replacement of imported fuels by the indigenous resource, geothermal energy, will save foreign currency. The excess power from the local demand will be connected to the national grid to serve as a backup for hydropower. Investment in the area will be attracted by the availability of sufficient electricity. Therefore, geothermal development will have a positive impact on the socio-economy both at local and national levels.

7. MITIGATING MEASURES

The potential impacts of geothermal utilization to the existing environment at Tendaho, even though at low level, are related to land clearing and construction work, water taken from the reservoir, waste water disposal, re-injection and the introduction of sufficient electricity. These impacts are considered to have a potential effect on the geology, landscape, water quality, occupational safety, and socio-economic conditions. The degree to which the geothermal utilization affects the environment is proportional to the magnitude of the proposed development. The type of the environment to be affected by both small scale and medium scale power development are similar, even though of different magnitude. Mitigating measures for both cases are discussed together.

7.1 Geology, landscape and land use

The construction work of the plants involves clearing and leveling the land. These will have no significant change on the topography given that the area of the construction site is flat land. However, generally every surface disturbance should be remedied to restore the integrity of the surroundings. Pipelines for steam gathering and disposal, may intrude into the natural landscape. This could be mitigated by painting and camouflaging the pipes to blend in with the landscape. Evaporation ponds to be constructed by excavation of the top soil will form artificial piles of earth material which may be prone to soil erosion and reduce the aesthetic value of the landscape. Mitigating measures include planting trees all around the pond margins.

Water taken from the reservoir during exploitation might affect the natural features of the area, such as hot springs, mud pools, geysers, fumaroles and steaming ground. These visible signs of geothermal activity are part of the community's heritage. Because of their unique nature, they could also be potential tourist attractions. Geothermal development that draws from the same reservoir will have a potential effect on these features. This effect on the environment could be mitigated by monitoring the response of the thermal manifestations to exploitation and implementing necessary adjustments to avoid overexploitation. Re-injection that may be exercised during the medium-scale production will help to maintain reservoir pressure and will reduce the effect of exploitation to the surrounding thermal manifestations. The micro-earthquake triggering effect of high-pressure deep re-injection could be minimized by pumping the water at lower pressures.

The land requirement for the proposed power developments will be mainly for construction of pipe lines, power plant and switchyard, which will total a few square kilometres of land. These may not conflict with the existing land use of the area. The land requirement can even be minimized by constructing the plant as close as possible to production wells.

7.2 Water quality

The chemistry of the waste water to be disposed of to an evaporation pond, in the case of the small scale plant is not so harmful but, as discussed in Section 6.1.2, the concentration of some of the chemicals is above the threshold value of drinking water. Therefore, to minimize any contamination of the ground water by thermal water infiltration in the long term, it is advisable to locate evaporation ponds on relatively impermeable soil. To minimize the likelihood of infiltration, locating the pond away from fracture systems will also be an advantage. Precipitation of scales at the bottom surface of the pond may also produce an impermeable barrier.

In the case of a medium-scale power production, it is envisaged to dispose of the waste water by deep re-injection. Re-injection would be the best way to avoid environmental issues connected with surface disposal. It would also be helpful in maintaining reservoir pressure and avoiding groundwater depletion that may be caused by cold downflow.

7.3 Air quality

The amount of gases (CO_2 and H_2S) to be released from the proposed geothermal development at Tendaho is low and does not cause hazardous concentrations in the atmosphere. Exploitation of the deep reservoir may have relatively more polluting effects than the shallow reservoir. The gases to be discharged into the atmosphere will be rapidly diluted and the concentration of hazardous gases will be reduced below tolerance limits for human beings, animals and plants. Therefore, no mitigating measures are required, at least in the short term.

7.4 Occupational safety

A review of the occupational safety measures during geothermal development was given by Brown, 1995. The management of normal accident injury type risks is handled by appropriate controls and protocols, where access to a hazardous area is only allowed to people with appropriate training and with appropriate safety equipment. Burns or utilization of the waste water for human consumption by unaware locals could be handled by fencing to isolate the area and by a training schedule to raise awareness of the harm. Appropriate safety clothing is required when working with geothermal fluid pipelines. The use of leather gloves and safety glasses will minimize potential harm during chemical sampling. The hearing hazard due to noise is controlled by engineering design, such as new silencer designs, and the use of appropriate hearing protection.

To minimize the risk of hydrothermal eruption, environmental management measures, such as not overexploiting of the reservoir, siting evaporation ponds as far as possible from the productive wells and in a relatively stable area, construction of the plant at least 200 m away from the location that evidenced hydrothermal eruption, and monitoring of the surface thermal activities to help predict any future eruption, will be essential. Maintaining reservoir pressure to minimize steam formation and the concomitant increase in heat flow is recommended. Thermally active locations should be avoided for drilling and building sites.

The risk of damages to the surroundings due to subsidence that could be induced by mass withdrawal of fluids could be mitigated with appropriate reservoir management. Before exploitation, a baseline levelling survey with installations of levelling stations needs to be undertaken. A monitoring programme is required not only for environmental reasons, but also for the safe operation of the steam field.

7.5 Social and economic conditions

The use of geothermal energy for power generation in Tendaho as part of the rural electrification programme of the country, results in improved quality of life through better illumination, better air quality, improved access to information and communication as well as being a stimulus to business development. The off-peak capacity from geothermal power plants can be cheaply used for regional development projects such as pumping irrigation water. These effects are considered positive and should be enhanced. Employment opportunities that will be created are an advantage. Preferential employment should be given as benefits to host communities. Supplying drinking water to the communities close to the development area will minimize the need to fetch water from the geothermal effluents. In order to get the support of the communities there must be consultation, information, education and evidence that the lives of the rural poor are to be improved as a result of the geothermal development.

8. ASSESSMENT OF IMPACT SIGNIFICANCE

8.1 Criteria of assessment

The magnitude and significance of impact is measured using various criteria. Most commonly it is measured using scientific standards or clearly described criteria. Here the criteria by Munn (1979) is referred to, which uses the extent, intensity, duration, mitigation potential, acceptability and degree of certainty of the impact. The criterion for categorizing these impacts into low, medium and high is given in Table 5.

TABLE 5: Categories for rating of impact magnitude and significance

Criteria	High	Medium	Low
Extent of impact	National/ International	Regional	Site specific/local
Intensity of impact	Affects endangered species and / or protected areas	Affects areas of potential conservation value	Affects areas of little conservation value
Duration of impact	More than 15 years	5-15 years	0-5 years
Mitigation potential	Little or no mechanism exists	Partially mitigatable	Mitigatable to the level of insignificance
Acceptability	Unacceptable or requires redesigning	Manageable with regulatory controls	No risk to public health
Degree of certainty	Over 70%	40-70%	Less than 40%

8.2 Impact significance of the medium-scale power plant

The impacts of the proposed medium scale plant on the existing environment are rated according to the criteria set in Table 5. The results of assessment are shown both with and without mitigation of impacts (Table 6). The predicted extent and intensity of impact on the geology, landscape and water quality is rated medium and could be mitigated to low. The duration of impacts are rated high, due to the life span of geothermal plants, which is normally more than 15 years but if appropriate measures are to be taken through monitoring it will have lower duration. Impacts on the socio-economic condition are positive and have a national extent with a high percentage of certainty. All the impacts are either partially or completely mitigatable or manageable with regulatory controls.

TABLE 6: Impact significance rating of the medium-scale plant

A: CRITERIA			B: CHARACTERISTICS OF THE EXISTING ENVIROMENT	Geology	Land use	Landscape	Water quality	Air quality	Flora and fauna	Occupational safety	Socio economic condition
	Medium-scale power plant	Without mitigation	Extent of the impact	M	L	M	M	L	L	L	H
			Intensity of the impact	M	L	M	L	L	L	L	L
			Duration of the impact	H	L	H	H	H	L	H	H
			Mitigation potential	M	L	M	M	M	L	M	
			Acceptability	M	L	M	M	M	L	M	L
			Degree of certainty	M	L	M	H	M	L	M	H
		With mitigation	Extent of the impact	L	L	L	L	L	L	L	
			Intensity of the impact	L	L	L	L	L	L	L	
			Duration of the impact	M	L	M	M	M	L	M	
			Acceptability	L	L	L	L	L	L	M	
			Degree of certainty	L	L	L	M	L	L	L	

NOTE:

H: High
M: Medium
L : Low

8.3 Impact significance of the small-scale power plant

The impacts of the small-scale power plant on most of the environmental elements are rated low, even without mitigation (Table 7). Impacts on water quality and socio-economic conditions (positive) are rated medium. As regards occupational safety, impacts are rated medium in terms of mitigation potential, acceptability and degree of certainty. All the impacts are mitigatable to a low level with the exception of water quality and occupational safety which are rated at a medium level.

TABLE 7: Impact significance rating of the small-scale plant

A: CRITERIA – Small-scale power plant		B: CHARACTERISTICS OF THE EXISTING ENVIROMENT →	Geology	Land use	Landscape	Water quality	Flora and fauna	Occupational safety	Socio economic condition
Small-scale power plant	Without mitigation	Extent of the impact	L	L	L	M	L	L	M
		Intensity of the impact	L	L	L	L	L	L	L
		Duration of the impact	L	L	L	H	L	H	M
		Mitigation potential	L	L	M	M	L	M	
		Acceptability	L	L	M	M	L	M	L
		Degree of certainty	L	L	M	H	L	M	H
	With mitigation	Extent of the impact	L	L	L	L	L	L	
		Intensity of the impact	L	L	L	L	L	L	
		Duration of the impact	L	L	L	M	L	M	
		Acceptability	L	L	L	L	L	M	
		Degree of certainty	L	L	L	M	L	L	

NOTE:

H: High
M: Medium
L : Low

9. CONCLUSIONS AND RECOMMENDATIONS

The potential prospect for geothermal development is in a remote area, characterized by: a flat terrain, scarce vegetation, scarce wild life, arid climate, limited surface water, unpolluted air and hydrothermal activities. The existing land use is limited to irrigated farming and settlement area which covers less than 5% of the potential prospect.

Environmental impacts due to drilling will not be an issue in Tendaho, due to the particular nature of the existing environment and the short period over which the drilling will be carried out. Physical impacts on the geology and the landscape relates to the proposed construction activities and the abstraction of water from the reservoir. However, construction activities will have a small footprint on the environment and the effects on the landscape due to the abstraction of water could be mitigated by appropriate management of the resource. Given the chemical concentration of the geothermal fluids, the risk of contaminating the groundwater is considered low. However, some mitigation measures should be taken to reduce the likelihood of contamination as close to zero as possible. Monitoring of the chemistry of the waste water should be adopted as a pollution control precautionary measure.

Due to the low gas content, the proposed geothermal development will cause no major problems as regards air pollution. However, monitoring of air emissions and wind pattern studies should be conducted during exploitation, to know the temporal changes in gas content and to predict the dominant wind direction and the possible effects.

Impacts on the socio-economic conditions are mainly positive, including a rise in employment opportunities to the host communities and indirect stimulation of the rural development. Occupational safety is to be given due consideration during exploitation of the field.

The proposed geothermal power production will introduce a new type of energy, geothermal energy, into the energy mix of the country. This will be a healthy development, replacing fossil fuels which are now being used in the region. The use of geothermal energy for power generation, as part of the rural electrification programme of the country, would result in an improved quality of life through better illumination, better air quality, improved access to information and communication as well as being a stimulus to business development.

The environmental aspects of the proposed development are mainly dealt within the early stages of development. A more detailed EIA is recommended before phase III of the proposed development, based on evaluation of additional data and stake holder analysis.

ACKNOWLEDGMENTS

I would like to express my gratitude to the director of the UNU-GTP, Dr. Ingvar B. Fridleifsson, and the deputy director Mr. Lúdvík S. Georgsson for selecting me for this very special programme, and Ms. Gudrún Bjarnadóttir for everyday arrangements and help during the course. My thanks are due to Ms. Audur Andrésdóttir, VGK Consulting Engineers, my supervisor, for her great help and critical advice during the preparation of this report. I wish to give my thanks to all lecturers and staff members at Orkustofnun and to ISOR for their comprehensive presentations and willingness to share their knowledge and experience.

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APPENDIX I: Environmental interaction matrix used for assessment of drilling and geothermal utilization at Tendaho geothermal field.

A: CHARACTERISTICS OF THE PROPOSED PROJECT			B: CHARACTERISTICS OF THE EXISTING ENVIRONMENT → Geology	Land use	Landscape	Water quality	Air Quality	Flora and fauna	Occupational safety	Socio economic condition
Geothermal utilization	Large-scale plant	Land clearing and plant construction	•	•	•					•
		Disposal systems	•		•	•	•		•	
		Plant operation	•			•	•		•	•
		Labour requirements								
		Power transmission line		•	•					•
		Raw materials	•							
		Water demand								
		Potential emergencies	•		•				•	
	Small-scale plant	Land clearing and plant construction	•	•	•					•
		Disposal systems	•		•	•	•		•	
		Plant operation	•			•	•		•	•
		Labour requirements								
		Power transmission line		•	•					•
		Raw materials								
		Water demand								
		Potential emergencies	•		•				•	
Drilling		Road construction and site preparation	•	•	•		•			•
		Disposal systems	•	•	•	•	•			•
		Drilling operation							•	
		Labour requirements								
		Energy demand								
		Raw materials	•							
		Water demand								
		Potential emergencies							•	

NOTE:

A: Actions which are part of the proposed project.

B: Characteristics of the existing environment.

• Activities of the project which have potential interaction with the environment.