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PRELIMINARY ENVIRONMENTAL ASSESSMENT FOR DRILLING IN THE KRÍSUVÍK-TRÖLLADYNGJA AREA, SW-ICELAND

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ABSTRACT

The Krísuvík-Trölladyngja high-temperature area is located on the Reykjanes Peninsula, SW-Iceland. This area has been investigated for geothermal resources by various researchers in the past due to the interest in using geothermal steam. This report presents a preliminary environmental impact assessment for drilling in the Krísuvík-Trölladyngja geothermal fields. A preliminary review is carried out of the environmental components and the proposed project in order to decide whether to carry out an environmental impact assessment (EIA) and what key impacts, issues and alternatives to consider. In this study, an attempt has been made to identify the likely impact of drilling and potential mitigating measures. A checklist was used for impact identification, while for impact prediction a matrix was utilized. The results of this study suggest that detailed studies be carried out on water supply for drilling, on how to get rid of effluent water, on the monitoring of gas emissions to the atmosphere and on steam flow and gas concentrations in steam.

1. INTRODUCTION

The Krísuvík-Trölladyngja high-temperature area is located on the Reykjanes Peninsula, SW-Iceland (Figure 1) and was first explored before 1950 (Arnórsson et al., 1975). It covers a large area and can be divided into several fields such as Krísuvík, Trölladyngja, and Sandfell. In this study only the Krísuvík (also written Krýsuvík) and Trölladyngja fields are considered. This area has been investigated for geothermal resources by various researchers in the past due to the interest in using geothermal steam. Ármannsson et al. (1994) described the state of exploration of these two fields and recommended what needed to be done in order to confirm the presence of an exploitable resource.

Scientific investigations carried out by Orkustofnun scientists and UNU Fellows in this area include geology (Jónsson,1978; Kifua, 1986; Vargas, 1992), geophysics, geochemistry and reservoir assessment (Arnórsson et al.,1975; Arnórsson, 1987; Orkustofnun and Vatnaskil Consulting Engineers, 1986). The area has high precipitation (1500-2000 mm) and all water percolates into the bedrock through faults, open fissures and fractures as well as through porous lava flows. Drilling started between 1940 and 1950

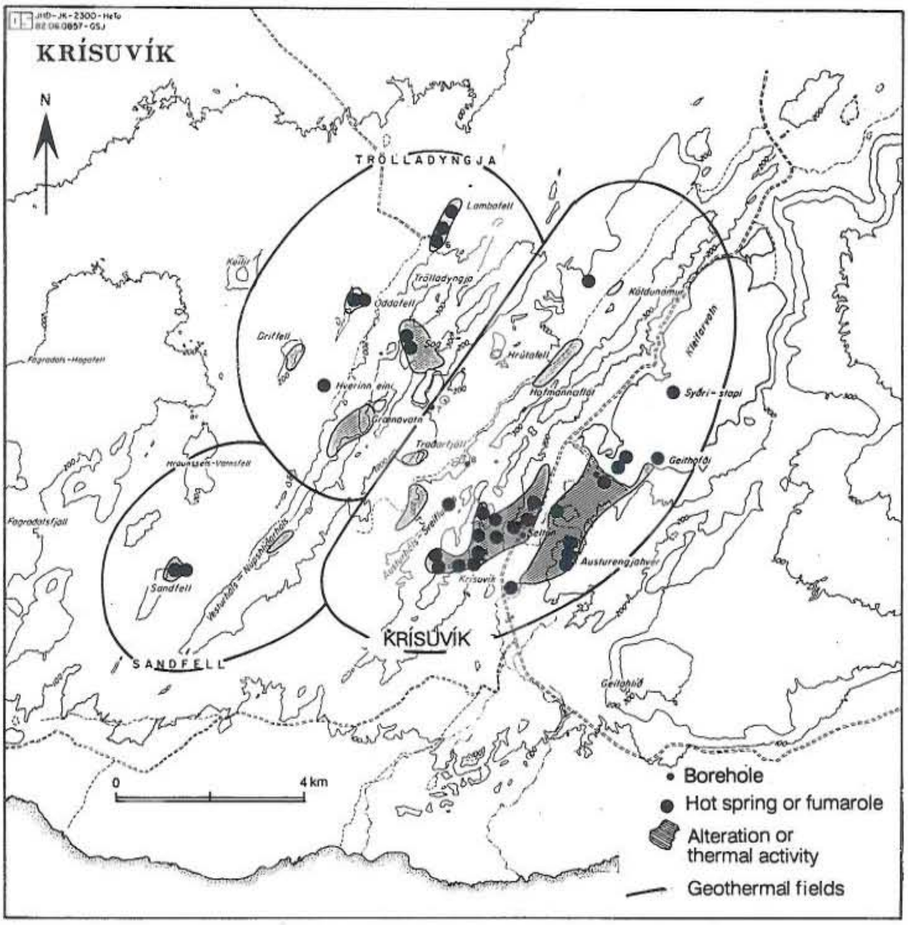

FIGURE 1: The Krísuvík-Trölladyngja geothermal area (modified from Stefánsson et al., 1982)

and 15-20 shallow wells had been drilled in the Krísuvík area before 1950 as a part of an exploration programme that was undertaken by Hafnarfjördur Electrical Services to investigate its potential for the generation of electricity.

In 1970-1973 another exploration effort funded by the Icelandic Energy Fund involved the drilling of six slim exploration wells 816-943 m deep, to obtain information on geology and temperature. Of the six drilled wells, five displayed a thermal reversal or inverse gradient (Figure 2). Well KR-09 is the most recent in Krísuvík, drilled in 1995. In comparison with the old profiles for wells KR-01 and KR-02, there seems to be no cooling in the area.

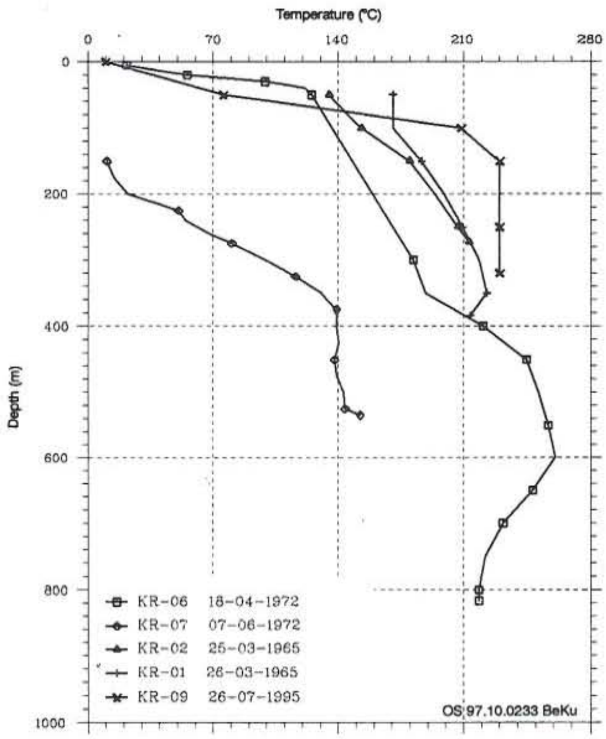

FIGURE 2: Temperature logs of deep wells in the Krísuvík area (Ármannsson and Thórhallsson, 1996)

The purpose of this project is to carry out a preliminary environmental impact assessment (EIA) for drilling in the Krísuvík-Trölladyngja geothermal fields. A preliminary review is carried out covering the environmental factors pertaining to the proposed project in order to decide whether to carry out an EIA (screening) and what key impacts, issues and alternatives to consider (scoping) (Morris and Therivel, 1995). The emphasis will be on scoping, to find the probable impact of drilling and to suggest potential mitigating measures. The methodology involved is a checklist for impact identification which will serve as a guide to the potential impact of drilling, in the two fields (Appendix I). A matrix will be utilized for impact prediction.

2. GENERAL INFORMATION ON THE KRÍSUVÍK-TRÖLLADYNGJA FIELDS

In a report by Checchi and Company and the Architect Collaborative Inc. (1975) the following is stated: "It can almost be said of Krísuvík that it is Iceland in miniature because almost all the geophysical and nature uniqueness that makes Iceland a fascinating vacation spot is to be found right in this one place." The active steam vents, steaming grounds, birds in the cliffs, Lake Kleifarvatn, Lake Graenavatn and the compromising climate make Krísuvík very attractive to tourists. It is a rather remote area with few signs of modern farming or manufacturing industries. A road which was heavily disputed because of high cost was constructed along the bank of Lake Kleifarvatn in 1940. The area is protected to a certain extent, being a part of the official Reykjanes country park. Several recreation possibilities have been proposed but up to now fishing in Lake Kleifarvatn, viewing geothermal manifestations in Seltún and the birds of Krísuvík cliffs have drawn most tourists. The Krísuvík Organization which is a rehabilitation centre for young drug addicts and alcoholics, is located in Krísuvík.

The Krísuvík land is shown in Figure 3. The total land is shown as the larger strip in the figure. The ownership of the smaller patch of land shown was transferred from the state to Hafnarfjördur township in 1941. Furthermore, all rights to geothermal utilization outside the transferred land were sold to Hafnarfjördur township at the same time with the proviso that the state had the right to re-purchase the rights should they be needed for mining or related activity and that the Hafnarfjördur township was making use of what it needed. In 1973 Hitaveita Reykjavíkur (The Reykjavík Municipal Heating Services) was afforded the right of exploration and utilization for space heating of houses with a special agreement that no other use would be made of the resource unless adequate resources were left intact for space heating.

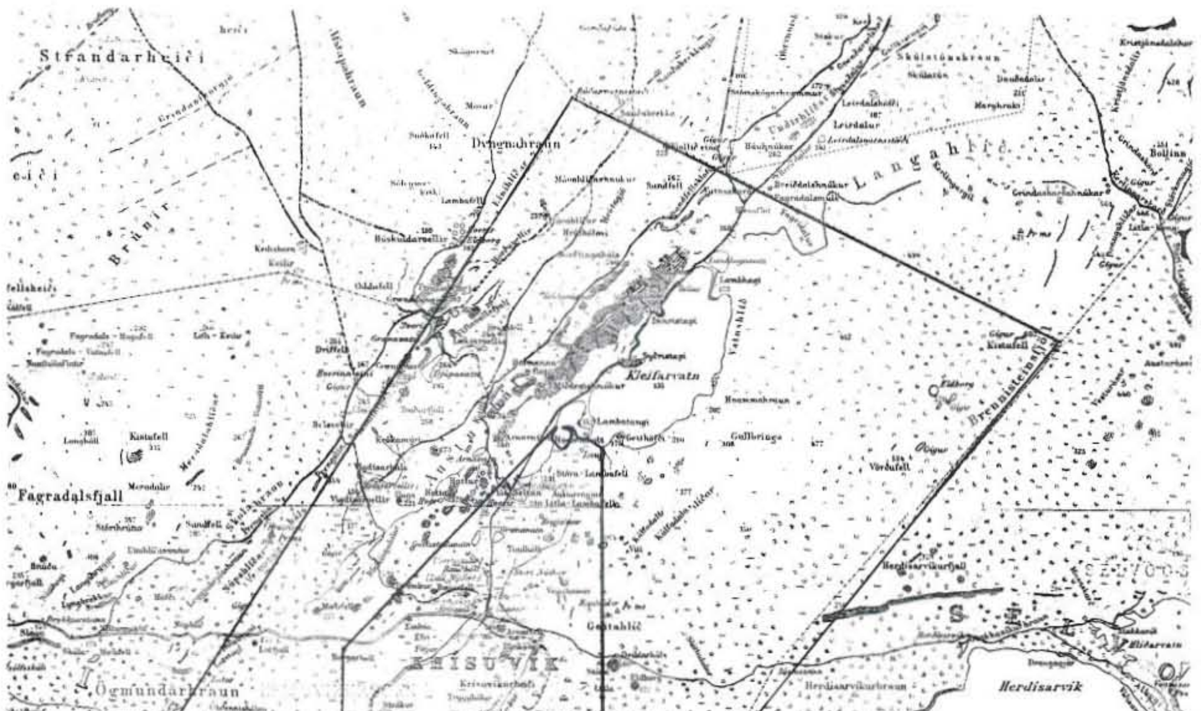

FIGURE 3: Map showing the Krísuvík land and its boundaries (Stefánsson et al., 1982)

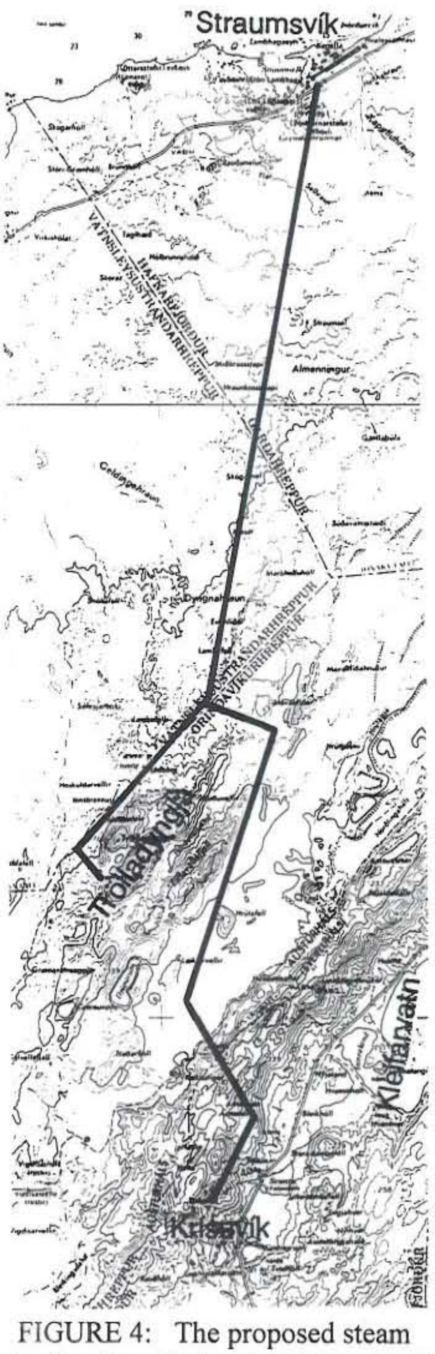

FIGURE 4: The proposed steam pipeline from Krísuvík to Straumsvík (Ármannsson et al., 1994)

The temperature of the fields is probably 230-260°C and the fluid appears to be dilute and easily exploited. In spite of relatively intense exploration over the last 50 years, knowledge of the area is scarcer than would be expected. In the past, ideas of creating a tourist paradise in Krísuvík have been put forward. Árni Óla (1944) proposed a health resort with sulphur steam baths and hot spring clay baths besides space heating and manufacturing. Checchi and Company and the Architect Collaborative Inc. (1975) proposed a multi resort and an Icelandic geosciences research centre in Krísuvík. The most promising use of the geothermal heat is probably a future space heating plant for the capital area. In the past the lack of a good source of fresh groundwater for heat exchangers was considered a great drawback, but now a closed circuit distribution system recycling the fresh ground water could be designed and the demand for fresh groundwater supplies would not be so great. Another possible use is for industry in Straumsvík on the north coast of the Reykjanes Peninsula, which would involve building a steam pipeline (Ármannsson et al., 1994) (Figure 4). Such exploitation would need to be on a large scale because of the distance to Straumsvík, the pressure drop in the pipe and high costs. A small local plant serving tourism and greenhouses is yet another possibility. Least attractive perhaps is power production on a large scale, especially as space heating possibilities for the capital area need to be given priority. It would take 5-8 years to start large scale exploitation and the exact rights to ownership and utilization have to be established before this is possible. The area needs to be explored before a decision can be made. The Krísuvík organization utilizes a well drilled in 1995 and a diesel turbine for power production. It is desirable that a small steam turbine be installed. The present well could produce 1 MWe, and wells for further small production could be drilled without much additional exploration. There is no river draining Lake Kleifarvatn. Therefore, water level variations are great. The lake serves as a precipitation gauge showing long term changes in the piezometric surface. There is some fishing in Lake Kleifarvatn, and the profits from egg collection in the cliffs are used to support a local rescue squad. Hot spring clay has been mined and used for clay baths. The winter garden idea is probably out of date; untouched nature is more attractive to the modern tourist.

3. HISTORICAL OVERVIEW (Prepared by Ármannsson and Thórhallsson, 1996)

A recent report by Ármannsson and Thórhallsson (1996) gives an historical overview of the exploration and exploitation of the Krísuvík area. The following is based on this report and most of the original references can be found there.

During the earlier centuries sulphur used to be mined for the Danish kings.

1857 British mining companies obtained mining rights, including those for "The Krísuvík sulphur company" (1869-1879). Germans also held the rights for some time .

1882 Sulphur mines used up and sulphur mining discontinued. The mines were taken over by "The Borax Company" which intended to mine borax as was done in Italian geothermal areas. But Icelandic geothermal areas are different and no borax was found so this activity was discontinued in 1884.

1940 Road constructed on the bank of Lake Kleifarvatn.

1941 Hafnarfjördur township acquired part of the Krísuvík land and the Lake Kleifarvatn fishing rights, acquisitioned by the government in 1936 and 1940 on behalf of the township. The borders of the land are unclear and hotly disputed.

1944 Ideas on large scale exploitation presented (Óla, 1944).

1945-1950 Hafnarfjördur township had 19 wells drilled using own rig to prepare for power production. Project was abandoned but well KV-14 still spews steam over tourists.

1951 "Plan for power production in Krýsuvík" published.

1952 Proposed law for the exploitation of geothermal steam in Krísuvík presented to parliament. A 5.5 MW station which could be increased to 11 MW used for greenhouses and space heating was proposed but the proposal was not passed.

1959 "Report on the possibility of production of salt in Iceland" was published. The Krísuvík area potential was deemed "insufficiently economic".

1960 Two wells of 1200 m depth and one shallow well drilled by the government. Information on temperature and geological sections obtained but the wells collapsed upon initiation of flow. Well KR-2 still breathes out a little steam which is used to heat a kiosk in the parking area.

1964 A well was drilled at a small distance from Krísuvík farm, used for space heating of houses and livestock facilities, and greenhouses. However farming and greenhouses did not prove successful in Krísuvík.

1964-1965 Exploration for a possible space heating plant for the Hafnarfjördur township was carried out.

1971 Four slim exploration wells drilled to about 800 m depth. Aquifers cemented to obtain drill cuttings. Information on temperature and geological cuttings obtained for all the wells but none on flow and enthalpy (Arnórsson et al., 1975).

1973 Contract between Hafnarfjördur and Reykjavík signed. Reykjavík district heating planned to build a pipeline from one of their areas and to supply Hafnarfjördur with space heating and acquired rights to exploitation for space heating in Krísuvík instead.

1974 "Draft pre-feasibility study on the production of alumina in Iceland" published. The proposed plant was to utilize geothermal steam from the Krísuvík area and supply the aluminium smelter at Straumsvík with sufficient raw material for its production. The plan was abandoned for many reasons, one being environmental considerations regarding the dumping of red clay.

1975 The Krísuvík land became a part of the Reykjanes country park. Utilization of geothermal steam exempt from limitations. In 1975 Checchi and Co. and the Architects Collaborative Inc. (1975) recommended Krísuvík as the best area in Iceland for a "winter garden".

1981 The report "On geothermal heat for fish meal factories " recommended Krísuvík as an economic area for such production.

1983 Orkustofnun published "Economic estimate for the building of a steam pipeline from Straumsvík to Trölladyngja". In the same year Orkustofnun prepared to drill an exploratory well in Trölladyngja but the project was abandoned due to lack of funds.

1984 Krísuvík recommended as a site for "geothermal fishmeal and fish oil factory".

1986 The report "Vatnsleysa-Trölladyngja. Freshwater and geothermal investigation" (Orkustofnun and Vatnaskil Consulting Engineers, 1986) published.

1991 The report on "Vegetation changes in the Krísuvík land 1945-1990" (Gísladóttir, 1991) was presented.

1994 The report "Krísuvík-Trölladyngja. Potential steam production and transmission." (Ármannsson et al., 1994) was published.

1994-1995 Hot spring clay from Krísuvík used for clay baths at the Laugardalur swimming pool, Reykjavik.

1995 Idea for ethanol production using lupin as raw material and geothermal steam from Krísuvík as an energy source presented. In the same year a shallow well was drilled for the Krísuvík Organization for space heating. It produces 5 kg/s of dry steam.

4. WEATHER CONDITIONS

On the Reykjanes Peninsula there are two meteorological stations, at the Reykjanes lighthouse and Keflavík airport, respectively. Precipitation is measured in Grindavík, Straumsvík and Svartsengi. The frequency of wind direction at Keflavík airport from 1981 to 1995 is presented in Figure 5 while in

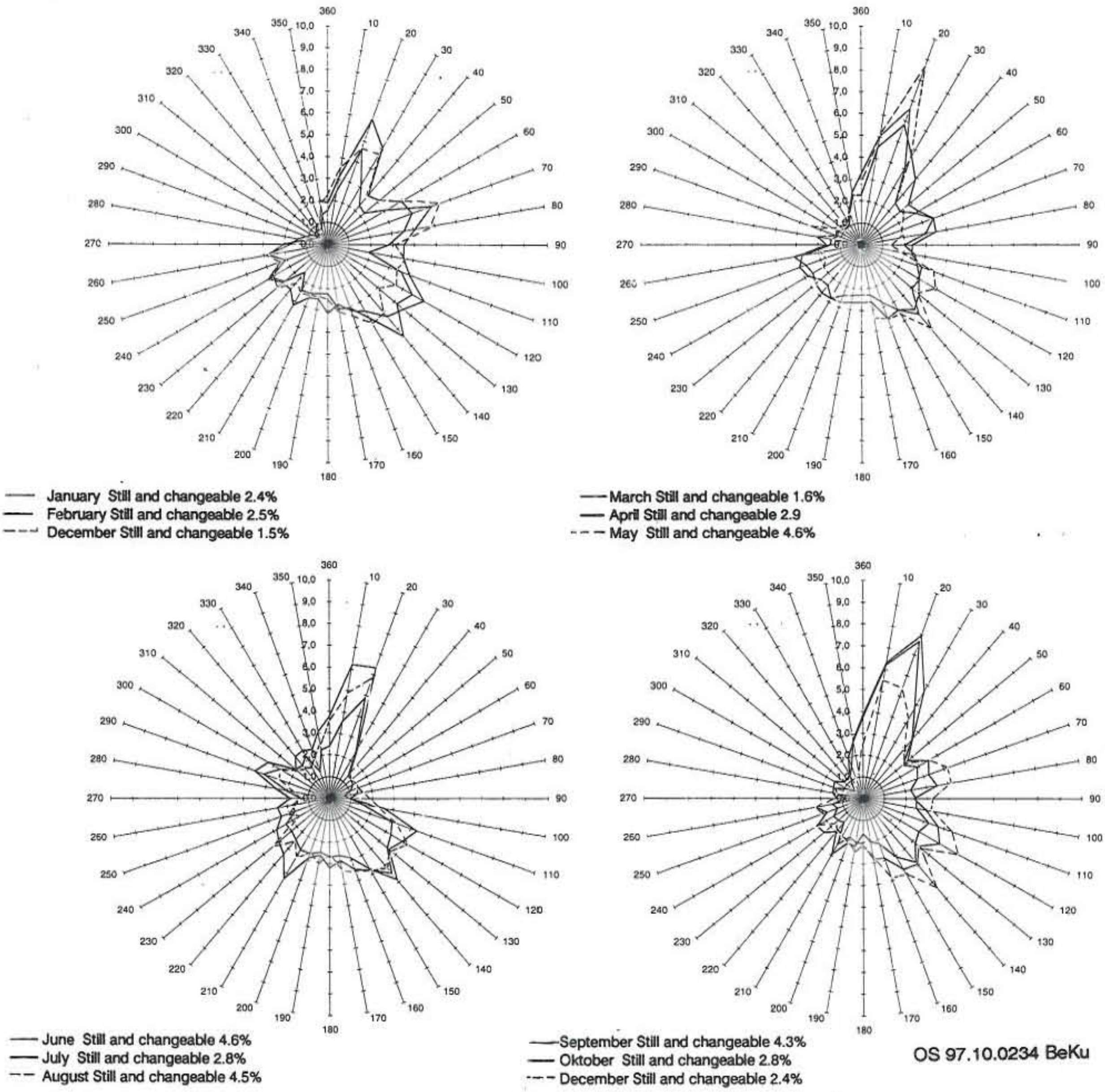

FIGURE 5: Frequency of wind directions on the Reykjanes Peninsula

Figure 6 the average precipitation in Grindavík during the period 1991-1996 is presented. These measurements can be used to estimate precipitation in Krísuvík.

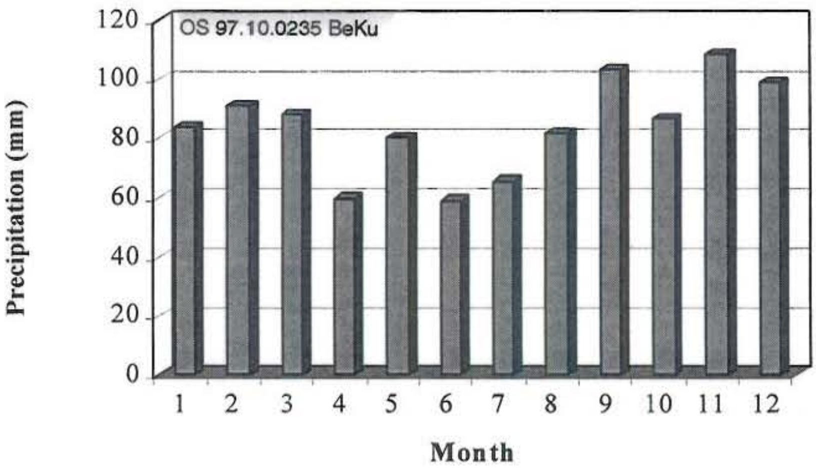

FIGURE 6: Monthly precipitation in Grindavík during the period 1991-1996

5. GAS CONCENTRATION IN STEAM AND GAS EMISSIONS TO THE ATMOSPHERE

Geothermal power generation using a standard steam-cycle plant will result in the release of non-condensable gases, and fine solid particles to the atmosphere. In vapour-dominated fields and fields in which all waste fluids are reinjected, gas in steam will be the most important discharge from an environmental perspective (Webster and Timperley, 1995). The most significant ongoing gas emissions will be from the gas exhausters of the power stations, but discharge often occurs during well drilling, bleeding, clean-outs and testing (Table 1). Although mainly carbon-dioxide the geothermal gases can include high concentrations of hydrogen sulphide gas.

TABLE 1: Chemical analysis of gas and steam from the Trölladyngja field (Orkustofnun and Vatnaskil Consulting Engineers, 1986) and Seltún and Hveradalur, Krísuvík field (Ólafsson, 1991)

Gas	Method	Trölladyngja	Sog	Seltún	Hveradalur
CO_2	Volume-% in gas	89.24	89.03	84.25	88.92
H_2S	Volume-% in gas	1.35	1.21	11.18	8.15
H_2	Volume-% in gas	4.30	0.30	3.98	2.37
O_2	Volume-% in gas	0.49	0.63	0.02	0.02
CH_4	Volume-% in gas	0.18	0.33	0.03	0.03
N_2	Volume-% in gas	4.35	8.31	0.54	0.51
Ar	Volume-% in gas	0.10	0.20		
Rn	dpm/l in gas	13646	16508	1692	4452
CO_2	mg/kg in steam	13214	7064	10440	8180
H_2S	mg/kg in steam	16	117	1420	820
Hg	ng/kg in steam	2500	850	970	

The impact of hydrogen sulphide discharge will depend on the local topography, wind patterns and land use (Figure 7), but include an unpleasant odour, equipment corrosion, eye irritation and respiratory damage in humans. Geothermal gases may also contain ammonia gas (NH_3), trace amounts of mercury (Hg), boron (B) vapour, hydrocarbons such as methane (CH_4) and ethane, or arsenic (As) and radon (Rn).

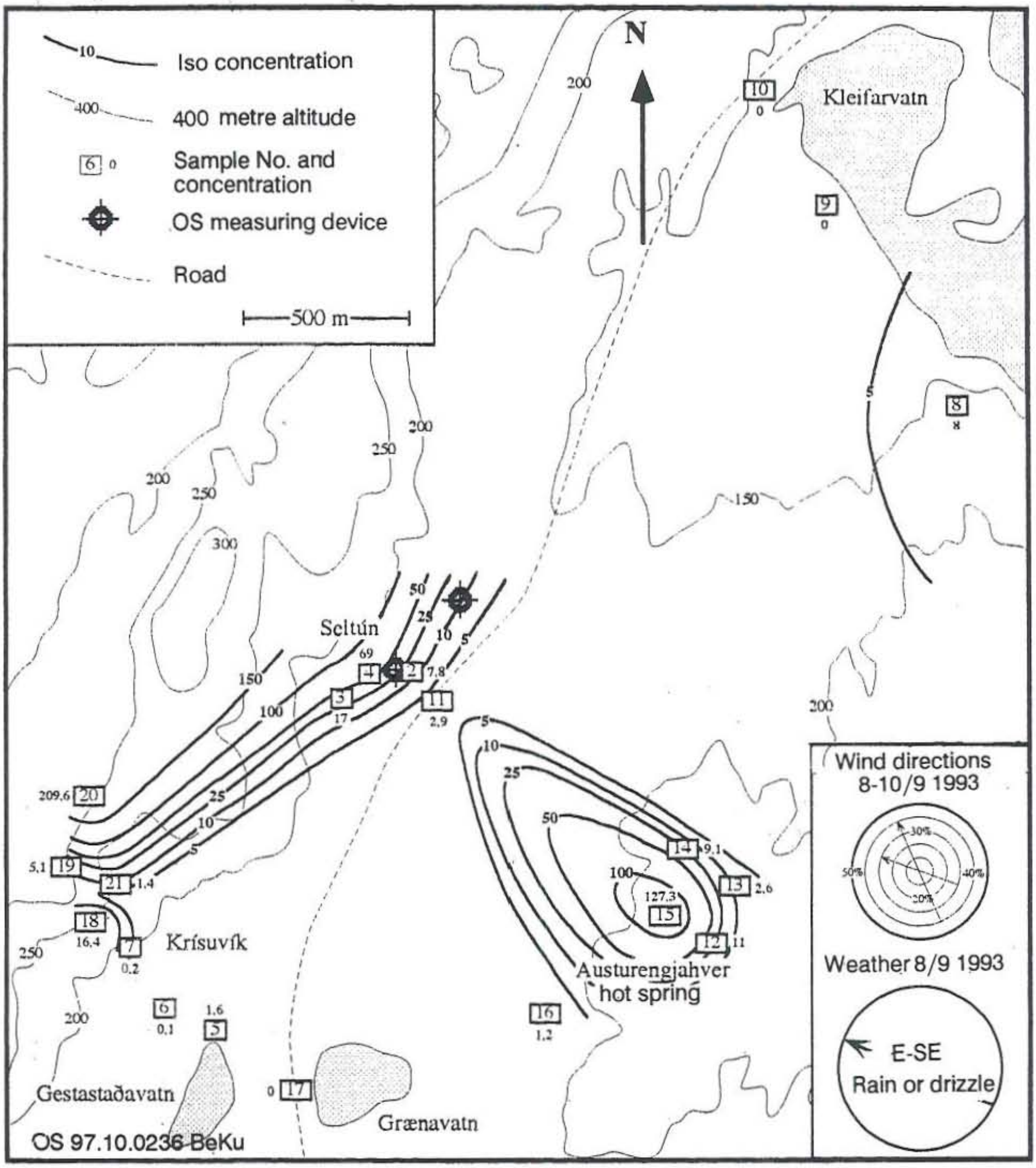

FIGURE 7: Hydrogen sulphide (ppb H_2S) in atmospheric air in Krísuvík on September 8, 1993 (Ívarsson et al., 1993)

Boron, ammonia and to a lesser extent mercury are leached from the atmosphere by rain, leading to soil and/or vegetation contamination. Boron can have a serious impact on vegetation. Contaminants leached from the atmosphere can also affect surface waters and have an impact on aquatic life. Binary plants, in which the geothermal fluid is passed through a heat exchanger and reinjected without exposure to the atmosphere, will discharge neither gas nor fluid during normal operations. Ammonia and boron are generally low in Icelandic geothermal fluids (Ármannsson and Kristmannsdóttir, 1992).

H_2S in air was measured in Krísuvík August 5, 1993 and September 8-9, 1993, when SO_2 and Hg were also monitored in two locations for 24 hours (Ívarsson et al., 1993). The H_2S distribution on September 8 along with information on weather is shown in Figure 7. Such distribution is very much dependent on the weather and monitoring over at least 6 months is needed to establish the probable distribution and movement of these gases within the area.

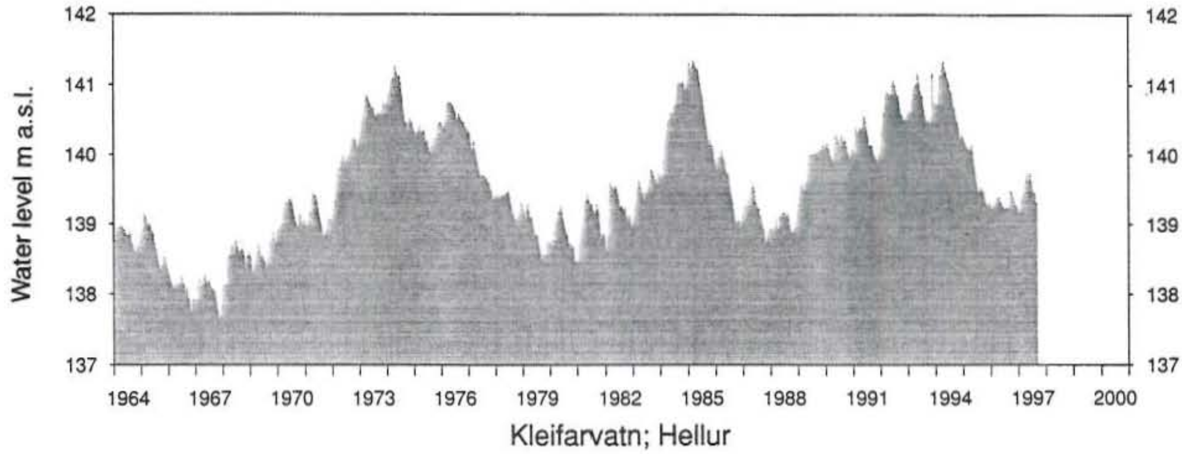

FIGURE 8: Water level changes in Lake Kleifarvatn between 1964 and 1997 (Áráttan, 1997)

6. GROUNDWATER AND EFFLUENT WATER

Groundwater on the surface is scarce in the area. Lake Kleifarvatn, Lake Graenavatn, Lake Gestastadavatn and a small stream are the only surface manifestations in the Krísuvík area, and Lake Djúpavatn in the Trölladyngja area.. The water level variation of Lake Kleifarvatn from 1964 to 1997 is shown in Figure 8. The highest levels were recorded in 1994-1995 and the lowest levels in 1968. Effluent water can have an impact on local and regional surface waters such as rivers and lakes unless all of it is reinjected. The chemical composition of the effluent depends largely on the geochemistry of the reservoir and the operating conditions used for power generation. Most of the effluent waters include high concentrations of one or more of the following chemical contaminants: boron, arsenic, hydrogen sulphide, mercury and ammonia. If released into a river or a lake these contaminants may damage aquatic life, terrestrial plants and/or human health. The disposal of highly saline effluent water can also have an adverse effect on water quality. In natural geothermal features, the impact of such contaminants may be controlled by deposition near the feature or fixation in soils and sediments. Mercury and arsenic are precipitated in silica sinters for example and ammonia is readily taken up by soils. Steam condensates will typically have relatively high concentrations of hydrogen sulphide, mercury, ammonia, and to a lesser extent boron and arsenic.

Table 2 shows the chemical composition of Krísuvík well water. The samples from the wells were collected at different depths. Thermal waters from wells in the Krísuvík high-temperature area display some variation in dissolved solids content (TDS) but the water from the Trölladyngja well is more saline. The thermal water is fairly low in dissolved solids although there may be slight mixing of sea water with fresh water. By contrast other drilled high-temperature areas in Iceland have a relatively homogenous hot water chemistry. The concentration range of species like chloride of 50-1100 ppm must be considered unusually high for a single hydrothermal system. (Arnórsson et al.,1975). Waters from wells in the Krísuvík area show considerable scatter in their Cl/B ratio, indicating non-constancy in some of the variables that influence the chloride and boron concentrations in the waters.

TABLE 2: Chemical composition (in ppm) of thermal waters from the Krísuvík high-temperature area

Loca-tion	pH/°C	SiO_2	B	Na^+	K^+	Ca^{++}	Mg^{++}	CO_2 total	SO_4^{--}	H_2S total	Cl^-	F^-	TDS	Sampl. depth (m)	T(sampl. depth) (°C)
Spring	6.48/23	133		42	3.5	32.4	32.5	14.5	29	<0.1	42.3	0.1	552		
Spring	6.98/23	77		34.3	2.8	52.4	21.2	14.1	69.5	<0.1	21.2	0.1	426		
Well 3		142			10.8	24.6	1.4	316	31.3	<0.1	34.4	0.1	610	200	105
Well 3	6.91/20	154		148	12.8	19.1	1.3	310	31.9	<0.1	70.4	0.15	654	300	115
Well 5	8.35/20	222	1.25	206	21.5	9.4	0.24	96	157	3.3	102	0.34	856	200	173
Well 5	8.80/20	226	1.23	205	12.9	9.1	0.24	55	175.3	0.3	122		850	350	154
Well 5	8.80/20	220	1.18	210	13.8	10.6	2.22	63	178.2	4.4	118	0.45	861	470	151
Well 5	8.60/20	210	1.15	200	12.9	10	0.23	72	141.6	0.2	151.5		822	650	151
Well 5	8.85/20	164	0.59	233	16.7	16.5	0.51	63	324.7	1.3	52	0.6	896	800	151
Well 6	7.85/20	205	0.65	680	40.4	90.8	0.5	55.7	103.1	<0.1	1234	0.2	2563	200	183
Well 6	8.35/20	514	0.79	700	119	42.4	0.38	62.2	49.6	6.6	1094	0.5	2605	500	258
Well 6	7.30/20	304	0.39	596	64	0	0.44	59.5	40.1	1.7	914	0.3	2020	800	218
Well 7	8.00/20	50		30.6	1.7	18.4	10.4	110	7.9	<0.1	16.1	0.2	208	325	30
Well 7	7.15/20	178	0.14	160	8.2	15.3	1.4	120	75.1	<0.1	163.2	0.4	692	475	139
Well 8	8.90/18	210	0.24	140	8.3	5.5	0.3	66.9	90	<0.1	96.8	0.7	600	240	129
Well 8	6.82/18	332	0.52	227	21.5	11.5	0.13	121	240	<0.1	246.4	0.7	1000	450	192
Well 8	6.83/18	332	0.5	230	20.8	12.5	0.14	117.5	106.3	<0.1	245.6	0.8	1000	700	184
Well 8	6.90/18	298	0.53	226	21.3	17	0.23	121	104	<0.1	244	0.8	1030	920	170
Well 14	9.23/23	490	1.77	465	57.2	10.4	0.04	49.8	92.4	9.9	759	0.3	1876		100

7. NATURAL CONDITIONS AND PROTECTION

Natural surface features such as hot springs, mud pools, geysers, fumaroles and steaming ground are associated with most geothermal systems (Brown, 1995). Because of their unique nature these are often tourist attractions, or are used by the local residents. Geothermal development that draws from the same reservoir can potentially affect these features. These visible signs of geothermal activity are part of a country's heritage and in any geothermal development they must be taken into account during environmental impact assessment. Before any development takes place, the natural features associated with a geothermal field are catalogued with as much information and for as long as possible to provide a data baseline for later comparison. During the exploration phase, the heat flow of natural features is estimated, sampled for, and the chemical analysis corrected. This data can be used to monitor the features. Geothermal features do change, e.g self-sealing is followed by movement such as earthquakes which can cause breakout and thus affect surface manifestations.

In water-dominated geothermal systems, experience has shown that natural features tend to change with the exploitation of a deep reservoir. Quite often they change to a vapour-dominated system and steam pillows are formed causing hot springs to change to fumaroles. Since there is a possibility of a change in the natural features, it is important to have a system for ranking them in order of priority of preservation. Development may or may not proceed depending on the balance of the economics of the energy production versus the heritage value of the natural features.

The natural features found in Krísuvík are extensive post-glacial lava fields and steep-sided mountains. Minor post-glacial volcanic edifices on fissures are particularly abundant within and in the vicinity of the Krísuvík area. Other natural features found in Krísuvík are thermal manifestations including steam vents, mud pools, sulphurous deposits and warm springs of carbonate water. Lake Kleifarvatn is another feature. The steam vents, mud pools and warm springs are the major tourist attractions in this area. Some monitoring of natural manifestations has been carried out up to now and it is included in plans for environmental work at Orkustofnun. This monitoring should be continued and funds should be set aside for it. This system is probably water-dominated, and there is a possibility of the natural features declining with exploitation. If Iceland is serious with its plans to develop tourism in Krísuvík, then funds for this monitoring should be made available and work continued.

8. GEOPHYSICAL STUDIES

Some gravity measurements were carried out in the early seventies (Arnórsson et al., 1975). These measurements show a sharp change in the Bouguer anomaly a short distance to the east of the geothermal areas. The cause of this change is not yet clear and a more detailed study needs to be carried out before drilling is considered there.

Figure 9 shows a resistivity map of the Krísuvík-Trölladyngja area at 300 m below sea level (Georgsson, 1987). The reversed temperature profiles (Figure 2) are thought to have resulted from lateral flow with none of the wells having struck the upflow. Some of the resistivity lows appear to represent upflow.

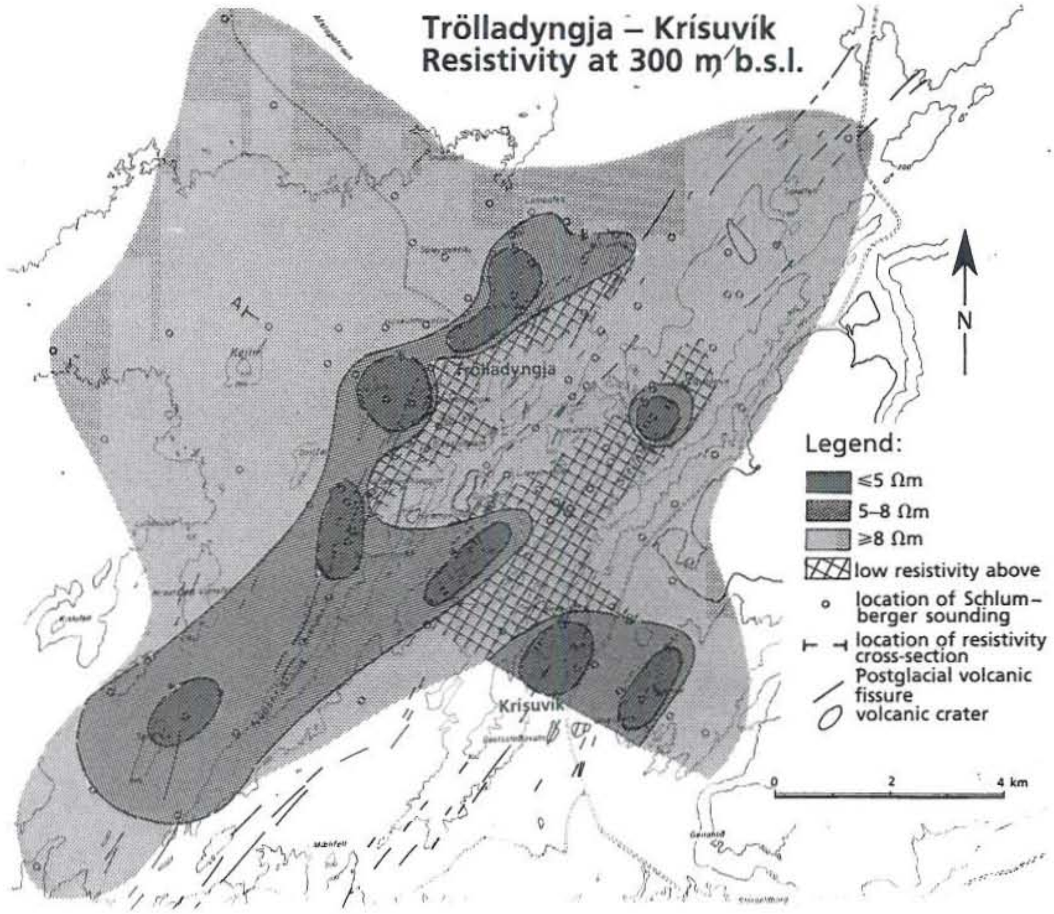

FIGURE 9: Resistivity map of the Krísuvík and Trölladyngja area at 300 m below sea level (Georgsson, 1987)

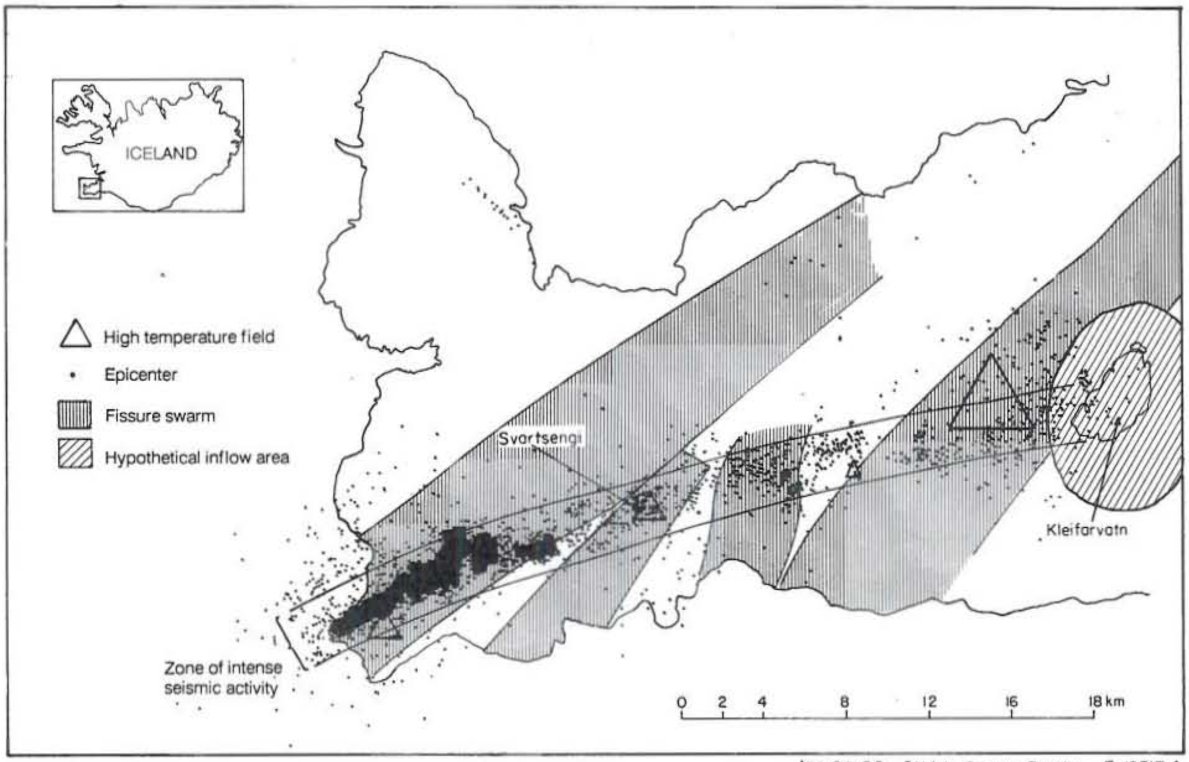

FIGURE 10: Volcanic systems and epicenters of earthquakes on the Reykjanes Peninsula measured during the seventies (Kjaran et al., 1980)

The area is located on a magnetic high (Arnórsson et al., 1975). In most geothermal areas minor magnetic lows are observed and interpreted to be due to the disappearance of magnetite caused by hydrothermal alteration. No such lows have been observed in Krísuvík in spite of widespread hydrothermal alteration. However, it is questionable whether the existing measurements allow such details.

Reflective seismic measurements were carried out over the area in the early seventies (Arnórsson et al., 1975). These revealed a complex structure where the thickness of the surface layer varies from about 200 m at Seltún, and possibly shallower at Sydri Stapi, to about 700 m at Slagi. The depth to the seismic layer 3 varies from about 2.1 km at Seltún to about 3.4 km at Lake Djúpavatn.

Microearthquake activity in and near the Svartsengi geothermal field was monitored during two periods, in the summers 1972 (Klein et al., 1977) and 1993 (Brandsdóttir et al., 1994). Seismic monitoring was facilitated by the installation of a network of portable seismographs. Refraction and seismic noise measurements were also made in order to obtain information on the regional seismic structure of the crust and to gather information pertinent to the siting of future seismograph sites. Figure 10 shows epicenters located on the Reykjanes Peninsula in the seventies (Kjaran et al., 1980).

Seismicity along the Reykjanes Peninsula was low in 1993 and mostly confined to small swarms in the Krísuvík region and beneath the mountain Fagradalsfjall. No detectable microearthquakes occurred within the Svartsengi geothermal field. Thus, fluid injection in Svartsengi during that period did not induce earthquakes.

Seismograms from earthquakes occurring in Krísuvík and Reykjanes exhibit a large variety in compressional and shear wave attenuation. This along with large variations in seismic coda, reflects the heterogeneous crustal structure within the western volcanic zone. However, further analysis is needed in order to confirm this interpretation.

9. CHANGES IN NATURAL ACTIVITY

9.1 Hydrothermal eruptions

Although relatively rare, hydrothermal eruptions do occur and hence need to be assessed. Eruptions occur when steam pressure in the near surface aquifers becomes greater than the overlying lithostatic pressure and the overburden is then ejected to form a crater. The resulting vents have been known to vary in diameter and in depth although most eruptions are relatively shallow. In assessing the likelihood of a hydrothermal eruption, hazard evidence of previous hydrothermal eruptions, increasing steam flow to the surface from reservoir pressure drawdown or an expanding steam zone are some of the factors to be considered. Other points to consider are, shallow gas pockets, kicks or blowouts during drilling. Drilling can also cause eruptions if the casing string is set too shallow, or if the casing develops a leak. Reinjection under pressure of fluids at temperatures >100°C also needs care as there is a possibility that such water will rise rapidly to the surface and heat the local groundwaters resulting in an eruption.

9.2 Subsidence

Withdrawal of fluid from any type of underground reservoir will normally result in a reduction of pressure in the formation pore space and this can lead to subsidence. Subsidence has been observed in groundwater reservoirs and geothermal reservoirs. Subsidence has a number of implications for geothermal development and also for the effect on the surrounding area as it can have serious consequences for the stability of pipelines, drains and well casing in a geothermal field. If a field is close to a populated area, then it can lead to instability in dwellings and other buildings. In more remote areas, where there may be no habitation, the local surface watershed systems may be affected. Before exploitation, a baseline levelling survey and gravity measurements with installation of levelling stations need to be undertaken. There should be a number of separate surveys to cover as long a time as possible before exploitation so that the local tectonic changes in level, if any, can be subtracted from those due to exploitation.

9.3 Induced seismicity

By their nature geothermal fields usually occur in regions of high seismic activity (Figure 10). In such a case there is a natural occurrence of earthquakes that are not related specifically to the exploitation of the geothermal field. Microearthquakes are seismic events that are of a very low magnitude and can only be detected instrumentally. Seismic activity seems to be present in geothermal systems whether they are being actively exploited or not and is thought to be related to the flow of water through subsurface channels (Brown,1995). Injection of fluids into deep formations, on the other hand, has been recognized as a cause of seismicity, but there has been no record of geothermal production causing damaging levels of seismicity anywhere in the world. As mentioned earlier, a study to monitor microearthquake activity in Svartsengi geothermal field in Iceland showed that there were no detectable microearthquake occurrences in that field (Brandsdóttir et al., 1994).

9.4 Thermal emissions

The efficiency of geothermal power plants is much lower than that of other types of power plants. Waste heat per MW of electricity generated in geothermal power plants is much larger than in other types of power plants and needs to be dissipated in an environmentally acceptable way. A portion of that waste heat contained in the water effluent is nowadays used for power generation through binary cycle generation plants. In this way its temperature and waste heat will be reduced. Also, most geothermal developments now dispose of geothermal wastewater by deep re-injection, from which the environmental impact due to heat is negligible.

In many geothermal fields there are areas of steaming ground, springs, and other features where special thermal habitats have been established. The roots of most plants cannot survive temperatures much above 50°C and, in addition, the soil in this type of ground is frequently very acidic. In these cases only very tolerant species can survive and a unique flora may evolve. At a temperature between about 50 and 70°C, only mosses and lichens can survive. Above this temperature vegetation is generally absent. Changes in thermal areas, such as increased steam flow due to exploitation, may change the distribution of these thermally adapted plants with the possibility of rendering some of the species vulnerable to extinction. Most of the vegetation in the Krísuvík-Trölladyngja area is considered to be in either a poor or a very poor condition (Gísladóttir, 1991). Overgrazing by sheep kept by hobby farmers has caused extensive degradation in this area. Moss heath is the vegetation community that covers the largest and most continuous areas in the Krísuvík-Trölladyngja area. *Racomitrium lanuginosum* is the dominant species in the moss heaths, and is most common on Postglacial lavas. The dry species *Empetrum nigrum* and *Carex bigelowi* are the most frequently distributed mosses in the heath. The vegetation around the hot ground is sparse and mostly dominated by *Ophioglossum azoricum, Plantogo major, Callitriche stagnalis* and *Juncus articulatus.* Vegetation on gravelly flats covers a fairly large area. The extensive areas in the southern part from Lake Kleifarvatn to the sea in the south are covered by mires and heaths. The vegetation cover is sparse, whereas single hardy plants dominate those areas (Figure 11).

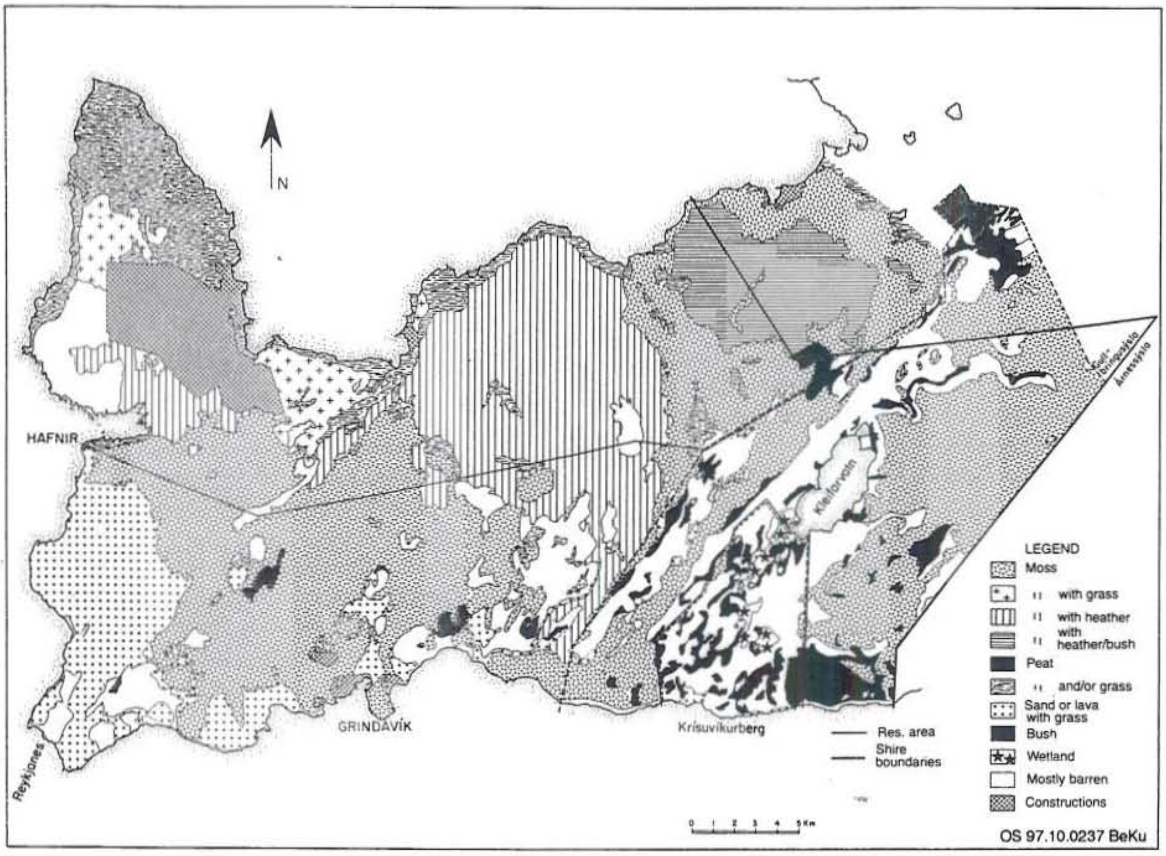

FIGURE 11: The flora of the Reykjanes Peninsula (Egilsson, 1989a)

9.5 Water usage

Water is required for drilling, reinjection, well testing, and for cooling in the power stations. The impact the requirements will have on the water situation depends on the locality. In arid areas the problem of suitable water can be acute, and geothermal water produced from the first wells has been used as a water supply for subsequent drilling. Water is fairly scarce in Krísuvík despite high rainfall. In Trölladyngja, a fresh water well was drilled to supply water for drilling fluid as there was no other source.

9.6 Solid wastes

Geothermal development produces significant amounts of solid wastes and suitable disposal methods need to be found because of the heavy metals produced (Brown, 1995). These heavy metals must be disposed of safely. Other solid wastes include drilling muds and cement not normally considered hazardous. The other principal solid waste is construction debris and normal maintenance debris. Maintenance debris can be considered hazardous due to the presence of asbestos in insulation material. Disposal of hazardous solid wastes on site is a big problem. Reinjection is one solution to the disposal of heavy metals. When transporting waste, care must be taken to avoid spills. Solid waste disposal sites need to be periodically monitored and such sites could be a long term liability.

10. COST OF PRELIMINARY ASSESSMENT BEFORE DRILLING

Orkustofnun has made separate estimates of the cost of the minimum exploration and environmental assessment work necessary before drilling can start for the Krísuvík and Trölladyngja areas. The cost for the different items for the two areas has been added up and is presented in Table 3. According to this estimate, the total minimum cost for the two areas is close to 18 million ISK or about USD 250,000.

TABLE 3: Cost of preliminary environmental assessment before drilling (in Icelandic kr)

Item	ISK
Description of geothermal manifestations	4,873,319
Geochemistry	2,534,666
Geophysics	4,661,000
Microearthquake activity	748,144
Atmospheric gas	1,916,159
Levelling and gravity	1,609,800
Remote sensing (temperature)	918,000
Microorganism study	726,787
Total	**17,987,876**

11. ENVIRONMENTAL IMPACT OF DRILLING

11.1 Overview

In recent years there has been a remarkable growth of interest in environmental issues such as sustainability and better management of development in harmony with the environment. Associated with this growth of interest has been the introduction of new legislation derived from new national and international legislation, that seeks to influence the relationship between development and the environment. Environmental impact assessment (EIA) is an important example. EIA legislation was introduced in Iceland in 1993 while in Kenya it is at a very advanced stage.

Introduction of compulsory EIA met with a strong resistance from many quarters, particularly in United Kingdom. Planners argued with partial justification that they were already making such assessments. Many developers saw it as yet another costly and time-consuming constraint on development. There are many definitions of environmental impact assessment. They range from the often quoted and broad definitions e.g. that of Munn (1979) which refers to the need "to identify and predict the impact on the environment and on man's health and well-being of legislative proposals, policies, programmes, projects and operational procedures and to interpret and communicate information about the impacts", to the narrow U.K. Department of the Environment/Welsh office (1988) operational definition: "the term environmental assessment describes a technique and a process by which information about the environment effects of a project is collected, both by the developer and from other sources, and taken into account by the planning authority in forming their judgements on whether the development should go ahead." United Nations Economic Commission for Europe (1991) defines EIA as "an assessment of the impact of a planned activity on the environment." In essence EIA is a systematic process that examines the environmental consequences of development actions and alternatives in advance.

The EIA methodology approach in the 1970s followed in the tracks of economic science in the direction of models, matrices, numbers, networks, input and output (Gilpin, 1995). Methodology, like cost benefit analysis which compares the social costs with the social benefits of a project all expressed as far as practicable in monetary terms, have been used. Others like opportunity cost, the multiplier, contingent valuation, travel cost approach and hedonic price technique are sparingly used because of their complexity in application. Leopold et al. (1971), working with the US Geological Survey produced a methodology in which matrices are used for the entire field of EIA. Of all the methodologies checklists have tended to survive as a guide to the potential impacts of a project (Appendix I: Checklist used for the project). For this project a checklist has been used for impact identification. The checklist is used because unlike other mentioned methodologies, it is simple and descriptive. For impact assessment of drilling, matrices are quite useful and are used for this study because they are more detailed (Table 4).

11.2 Road construction

The amount of land that is disturbed by road construction during geothermal development can be quite large (Brown, 1995); estimated is about 12 hectares for road construction alone when drilling 15 wells. It is worth noting that the general topography of the geothermal area has a large effect on these figures. By their nature, geothermal systems are often located in volcanic environments (The Krísuvík-Trölladyngja areas is no exception) where the terrain is steep and access difficult. Furthermore, such an environment may also have severe erosion problems, particularly if the rainfall is high. (Rainfall in Krísuvík-Trölladyngja is 1500-2000 mm/year). Stabilization of the roads in such an environment is difficult and the land affected by the development is correspondingly increased.

Road construction in these steep environments normally involves extensive intrusion into the landscape and can often cause slumping or landslides with consequent loss of vegetation cover. The lack of vegetation can then cause greatly accelerated erosion with the possibility of further slumping or landslides. Parts of the Krísuvík-Trölladyngja area are highly susceptible to erosion as they are steep with very fragile soils which are easily erodible. The area is devoid of appropriate vegetation cover, exposing it to the agents of erosion. For drilling pads in the steep part of the area, the solution to erosion and landslides will be to drill a number of deviated wells from a single drilling pad. In this way a large volume of the reservoir can be tapped at depth, while requiring only a small area which can be situated on stable land surface. During well testing, care should be taken not to discharge the waste water directly to steep areas but to sumps made to contain this waste water. Failure to do so can cause serious gullying.

TABLE 4: Matrix used for impact analysis

IMPACT	Execution									Operation				End	
	Road construction	Pad construction	Cable tool drilling	Transport	Water provision	Drilling	Casing	Cementing	Demobilization	Warm up	Initiation of flow	Flow test	Logging	Final road track	Equipment
Change in landscape	Y	Y	N	N	P	N	N	N	N	N	N	N	N	Y	Y
Increased earthquake activity	N	N	N	N	N	N	N	N	N	N	P	P	N	N	N
Changes in groundwater flow	N	N	P	N	P	P	N	N	N	N	N	N	N	N	N
Changes in effluent flow to groundwater	N	N	P	N	Y	Y	N	N	N	N	N	N	N	N	N
Changes in amount of water	N	N	N	N	N	Y	N	P	N	N	Y	Y	N	N	N
Emission	N	N	N	N	N	Y	Y	N	N	N	Y	Y	N	N	N
Odour	N	N	N	N	N	P	N	N	N	N	Y	Y	N	N	N
Local climate change	N	N	N	N	N	N	N	N	N	N	P	P	N	N	N
Noise	N	N	N	N	N	N	N	N	N	N	P	P	N	N	N
Changes in vegetation	N	N	N	N	N	Y	Y	Y	N	N	Y	Y	N	N	N
Changes in fauna	P	P	N	N	P	N	N	N	N	N	Y	Y	N	N	N
Effect on outdoor amenities and tourism	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Aesthetics-appearance	N	N	N	N	N	N	N	N	N	N	N	Y	N	Y	Y
Light and glare	N	N	P	N	N	P	P	P	P	N	N	N	N	N	N

Y = yes : N = no: P = Possibly.

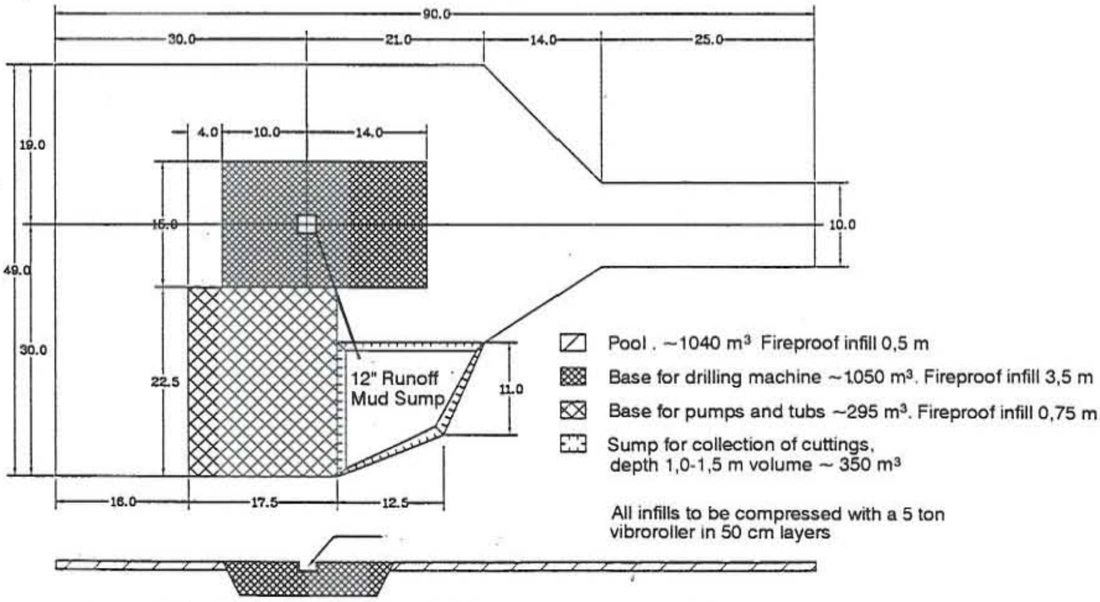

FIGURE 12: Drill pad for a high-temperature well (Thórhallsson, pers. comm.)

11.3 Drill site

One drill pad occupies about 0.4 hectares and this area is cleared of vegetation and compacted (Figure 12). The exposure of the area around each well site will create a major erosion hazard. Erosion of cut slopes takes place by runoff and slumping, but much of the sediment is deposited at the foot. Erosion of the fill slopes is more serious because of the lack of compaction and because the sediment is likely to be carried further downslope. Runoff which accumulates on the pad itself usually finds its way out through the fill slope and, where this is not vegetated, the potential for gully erosion is high.

11.4 Cable tool drilling

The cable tool rig is not a true drill in the strict sense of the word since it does not rotate, but employs a heavy hammer bit that pounds and crushes the rock. This drilling method is common for cold water drilling and before rotary equipment was taken into use in Iceland it was extensively used for geothermal drilling. The cable tool drilling rigs have the advantage of being cheap to buy and requiring only two men to operate. Among the disadvantages of this drilling method are the slow penetration rate compared with rotary drilling especially at depths below 200-300 m, and that in geothermal drilling blow-out prevention equipment cannot be adapted. The cable tool rig is therefore unsuitable for drilling in areas where the water temperature exceeds 100°C and lower temperature wells, in which free-flow may be dangerous when using this method.

The main role of the cable tool rig in geothermal drilling in Iceland is to pave the way for the rotary drilling equipment. This means that the rig is brought to the drillsite to start drilling the first 25-70 m and to set the conductor pipe to keep the loose surface layers from falling into the hole. The rotary drilling rig is very ineffective at shallow depths as sufficient weight cannot be applied to the drill bit, so it is necessary to get the hole started by another drilling method. This also mitigates the erosion impact in the loose soil.

11.5 Transportation

It is important to understand the traffic impacts in drilling activity. The area before drilling starts has a certain amount of traffic known to the area. When drilling starts the traffic increases as the rig and all its accessories are transported to the drill site.

The rotary drill rig is transported on set trailers pulled by a truck. Transport takes 2-4 days depending on the number of trucks and the distance. About 130 tons of casing, 140 tons of cement with an additional 25 tons of drilling mud and 30 tons of diesel oil and some lubrication oil are expected to be transported to the drill rig during drilling. The rig will be removed in 2-3 days after drilling is finished. This can lead to an increase in dust, noise, vehicular emissions and increased traffic. Occasional traffic delays will occur at various points in the project area. The assessment of significance will focus on who will be affected to what degree and whether the change is significant. Some of the affected groups are people at home, work places. Special interest groups are children, elderly and disabled and sensitive locations like schools, hospitals places of worship. In the Krísuvík area there is a rehabilitation centre for drug addicts and also open spaces, recreational sites, sites of ecological or nature conservation value and sites of tourist or visitor attraction. Secondary impacts like vibration accidents, safety and hazardous loads are also possible.

11.6 Drilling fluids

Water is required for drilling. A typical shallow well requires 1000 m^3/day, some or all of which may be lost to the formation. A deeper well may require up to 3000 m^3/day (Brown, 1995) for periods up to several months. Completion testing and injection testing can use up to 10,000 m^3/day of water. In

Iceland up to 40 l/s or 3500 m³ of water are required for 24 hours of drilling. If this water is discharged, care must be taken to have it disposed of into a well designed for this purpose, as the quality of the water can be affected by suspended solids and chemical content change (Brown,1995). The waste water from drilling can create serious gullying if discharged directly to the surface, e.g. into valleys. This can be a problem in the steep parts of Krísuvík if proper disposal methods are not applied.

After use drilling muds are produced as solid alkaline waste that may contain many other chemicals (Table 5) Ármannsson (1997). Drilling muds are either lost to the circulation in the well or end up in the drilling sumps as solid waste for disposal. A drilling mud like bentonite is mostly used when hole clearing is inadequate or when well stability is a problem.

Aerated water or mud and foam are sometimes used for pressure balancing. Air or foam drilling is used in holes with low water tables or vapour-dominated reservoirs. Air only drilling requires very large compressors which may be very noisy. Foam drilling can have some impacts on the vegetation around and a large area can be covered by the foam causing an eyesore but fortunately such impacts are not permanent.

TABLE 5: Chemical composition of bentonite and perlite (% of mass) (Ármannsson, 1997)

Material	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI[1)]	Water solubility	Acid solubility
Bentonite	64.1	20.0	3.66	0.16	1.52	2.38	2.18	0.49	6.26		
Perlite	73.0	12.5	0.7	0.1	1.0	0.5	4.5	4.8	1.3	0.1	0.5

1) LOI = Loss on ignition

11.7 Drilling

Typically, drilling involves the preparation of a rectangular flat area of ground. This area is required to accommodate the drill rig and the associated equipment including drill pipes. As drilling takes place cuttings from the drill head are flushed out with water, frequently mixed with drilling detergent to assist in the collection of cuttings. The detergent used must be capable of withstanding high temperature. Bentonite drilling mud mixed with some barium is often used. If the well erupts, a heavy substance barium sulphate is usually added. This is essentially an inert material but can smother plants and does not support plant growth and in this respect is similar to a hard compacted surface. Other wastes produced include petroleum products from lubricants and fuels plus cement wastes as spills. Air pollution can result from non-condensable gas emissions and exhaust smoke from generators and compressors. In vapour-dominated reservoirs, air only drilling takes place and this requires large compressors which, in effect, increases noise to unbearable levels. A drill rig is seen from afar during drilling and may be regarded as visual pollution but it is removed after drilling. Some people on the other hand find drill rigs magnificently beautiful.

11.8 Casing and cementing

Conductor casing, the largest diameter casing used in a well is required only where the surface soils are so incompetent that the washing and eroding action of the drilling mud would create a large cavity at the surface. Conductor casing controls such erosive action. Surface casing is of a smaller diameter and its function is to protect the fresh water table and provide an anchor for blowout preventer equipment. The amount of surface casing required, therefore depends on the depth of the freshwater table with a minimum of 60 m and a maximum of 400 m and is cemented all the way to the surface. If the fresh water table is below the surface casing, the control authority requires that the fresh water be protected by setting either intermediate or production casing and cementing it with enough cement to completely fill the casing wellbore annulus from the shoe to the surface (Corsi, 1995).

The cementing of casing in wells is carried out for a number of reasons. Where conductor casing is required, it must be cemented in order to prevent the drilling fluid from circulating outside the casing and, thus, cause surface erosion which the casing was designed to prevent. Surface casing must be cemented in order to seal off and protect freshwater formations. Cement also effectively protects the casing from corrosive environments, notably corrosive fluids which may be present in the surface formations.

11.9 Demobilization

Demobilization can bring about loss of habitat which can be associated with leaving abandoned plants, equipment and scrap without any attempt to rehabilitate them. During demobilization, a slotted liner is put in, the drill rig is transported away and flow equipment is erected i.e. pipes, additional vents, and atmospheric separators (silencers). An aerated shelter at the wellhead is desirable (Figure 13). Unplanned, careless and disorganized removal of physical facilities can cause further loss of habitat. Once the structures are removed the sites can be left to undergo a succession or be rehabilitated to achieve comparable status with the neighbouring area.

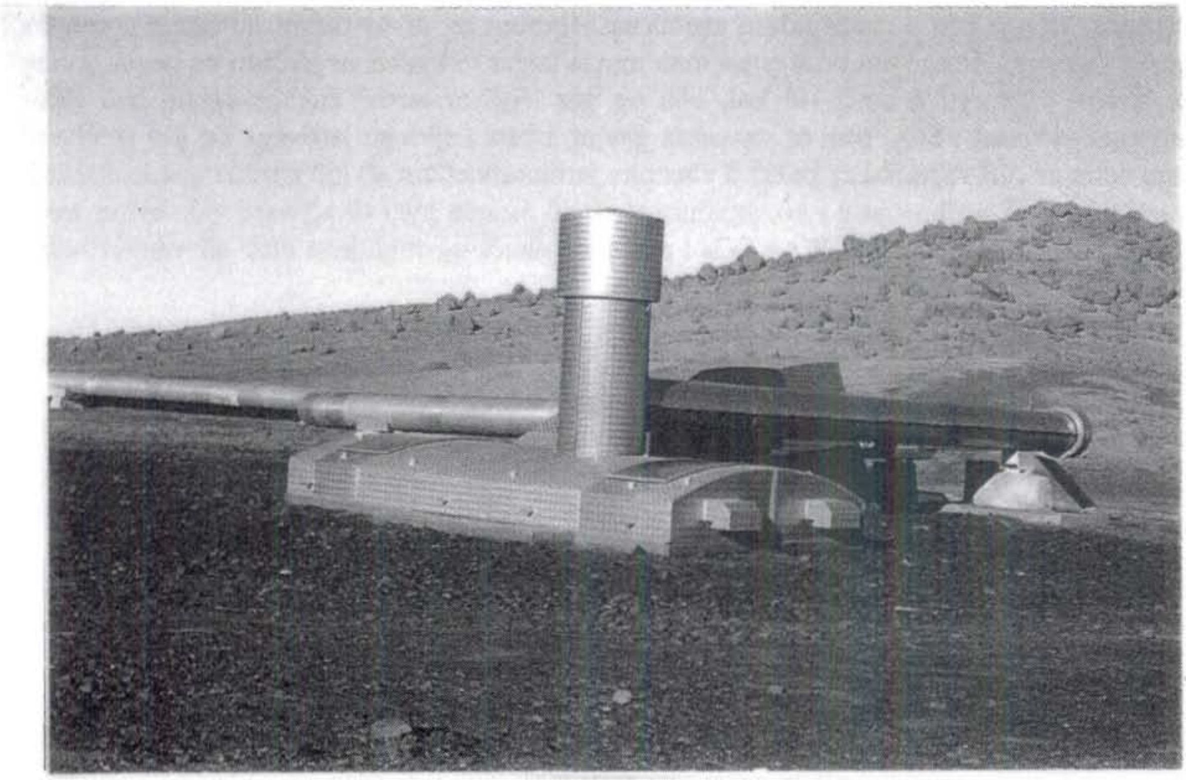

FIGURE 13: An aerated shelter for a high-temperature wellhead

11.10 Warm up, flow initiation and flow

The main impacts of well testing are water effluent which may contain toxic chemicals, and noise. In Iceland there are aerated shelters at the wellheads (Figure 13). After completion tests a well is normally closed in order to warm up and to build up pressure. This is common with wells which can self-discharge. For wells which cannot self-discharge, it is common practise to compress them using compressors and leave them for awhile to build up pressure. Drilling soap is normally added during compression time. Some wells have to be airlifted to initiate flow. Noise impact can be experienced from the large compressors used. Testing of wells has often had a deleterious effect on local vegetation with trees and other plants being scalded by escaping steam and spray. This effect is more severe during the vertical discharge of wells which is carried out in order to clean them. It is advisable that vertical discharge take as short a time as possible, preferably not more than one hour. The waste water from a tested well can cause serious gullying when discharged directly to a steep area, very possible in the fragile soils found in the Krísuvík-Trölladyngja area.

12. ENVIRONMENTAL ASSESSMENT FOR DRILLING

12.1 Checklist

The key elements of the project are all included in the checklist. Those impacts that could result if the project were implemented are also discussed where appropriate. Only those elements of the environment which may be impacted or might be considered as producing cumulative effects are included in the discussion. Since exploration for the project is sparse, it is not realistic to estimate, for example, the amount of water that might be available for use should implementation start immediately (Appendix I).

12.2 Natural conditions

12.2.1 Earth (land)

During road construction and drill site preparation, unstable earth conditions and changes in geological substructure can occur. The Krísuvík-Trölladyngja field has steep terrain and difficult access. With high rainfall (1500-2000 m) in the two fields, erosion by water is likely when the area is opened for road and pad construction. These fields display a high erosion hazard as part of the area is steep with very fragile soils which are easily erodible. The area is generally devoid of appropriate vegetation cover, so it is exposed to erosion agents. Careful attention should be given to re-vegetation with grass and trees on the cut slopes, fill slopes and well pads themselves. For drilling pads in the steep part of the area, the solution to erosion and landslides will be to drill a number of deviated wells from a single drilling pad. In this way a large volume of the reservoir can be tapped at depth, while requiring only a small area which can be situated on stable land at the surface. During well testing care should be taken not to discharge the waste water directly to steep areas but sumps should be made to contain this waste water, as failure to do this can cause serious gullying. Some rare bacteria species have been found in Icelandic geothermal fields (Pétursdóttir, 1995). Therefore, it is recommended that bacterial counts be made and the bacteria monitored if interesting results are obtained. This is because these can be either rare species or strains of bacteria which probably can be utilized in bio-technology in future.

12.2.2 Air

During drilling, air pollution can result from non-condensable gas emissions, exhaust smoke from generators, compressors, and vehicles. There may be objectionable hydrogen sulphide odours. During well testing, steam and spray can have an adverse effect on the vegetation with trees and grass being scalded. Hydrogen sulphide produces an unpleasant odour. Eye irritation and respiratory damage may not be of any significance as the Trölladyngja area is not inhabited and the population of Krísuvík is very small. As drilling is a temporary activity, no significant long term air quality impacts are expected. Hydrogen sulphide, sulphur dioxide and possibly mercury in atmospheric air should be monitored.

12.2.3 Water

Water is required as a drilling fluid. The wells to be drilled in this area will be deep and may require up to 3000 m^3/day for periods of several months depending on the number of wells to be drilled. Completion testing and injection testing can use up to 10,000 m^3/day of water. This will have an impact on the volume of water in the stream at Krísuvík if the water is extracted from there and Lake Kleifarvatn will be similarly affected. At Trölladyngja a fresh water well was drilled to supply water for drilling fluid and which may solve any problems in that field. Fresh water wells can be drilled for Krísuvík too. The amount of water used as drilling fluid is enormous and should be discharged with utmost care into well designed sumps or possibly re-injected as this can affect the quality of the water, particularly in Krísuvík where there is a stream. The discharge to the surface can lead to siltation and deposition from the stream and just possibly Lake Kleifarvatn. For Trölladyngja the casing programme should be such that there is no danger of pollution of groundwater. A detailed study on groundwater in these two areas is required.

12.2.4 Noise

The relative remoteness of the Krísuvík-Trölladyngja fields ensures that there will be no serious noise impacts during drilling, well testing, tripping and cementing. Some temporary noise impact may be felt at the rehabilitation center and the coffee shop where visitors stop to see well KV-14 spitting steam and to have refreshments. The noise impact will decline when all the wells have been drilled and tested. In Trölladyngja, noise impact will not be of any significance as the area is not inhabited.

12.2.5 Flora

The flora of Iceland consists of 438 species. Of these 63% or 273 species are found in the Reykjanes country park (Figures 14 and 11) (Kristinsson, 1986). Although moss covers the lava fields, the carpet is broken by sharp joints, and in deep depressions where soil accumulates, species like dwarf shrubs and low herbs become frequent. On the plateau east of Lake Kleifarvatn, snow beds are frequent in the moss heath, intermingled with dwarf willows and mosses. The largest continuous heaths are in Postglacial lava fields in the Krísuvík-Trölladyngja area. Grass species, mosses and Carex are most important in the grass dominated heath. In general the flora of the Reykjanes country park can be classified as follows: Mosses 45.5%, open country vegetation 11.5%, the rest 22% (grass, bush, wetland, etc.) or 78% vegetated (Thorvaldsdóttir, 1987). Further classification of the vegetation is given in Table 6.

TABLE 6: Vegetation in the Reykjanes country park, 1964 and 1988 (Gísladóttir, 1991)

Extent	**1964**		**1988**		**Difference**	
	(Ha)	**(%)**	**(Ha)**	**(%)**	**(Ha)**	**(%)**
Completely vegetated	847	22.2	513	13.4	-333	-8.7
< 1/3 barren	442	11.6	928	24.3	486	12.7
1/3-2/3 barren	318	8.3	446	11.7	127	3.3
> 2/3 barren	454	11.9	172	4.5	-281	-7.4
Completely barren	1745	45.7	1747	45.7	2	0
Water	14	0.4	14	0.4	0	0

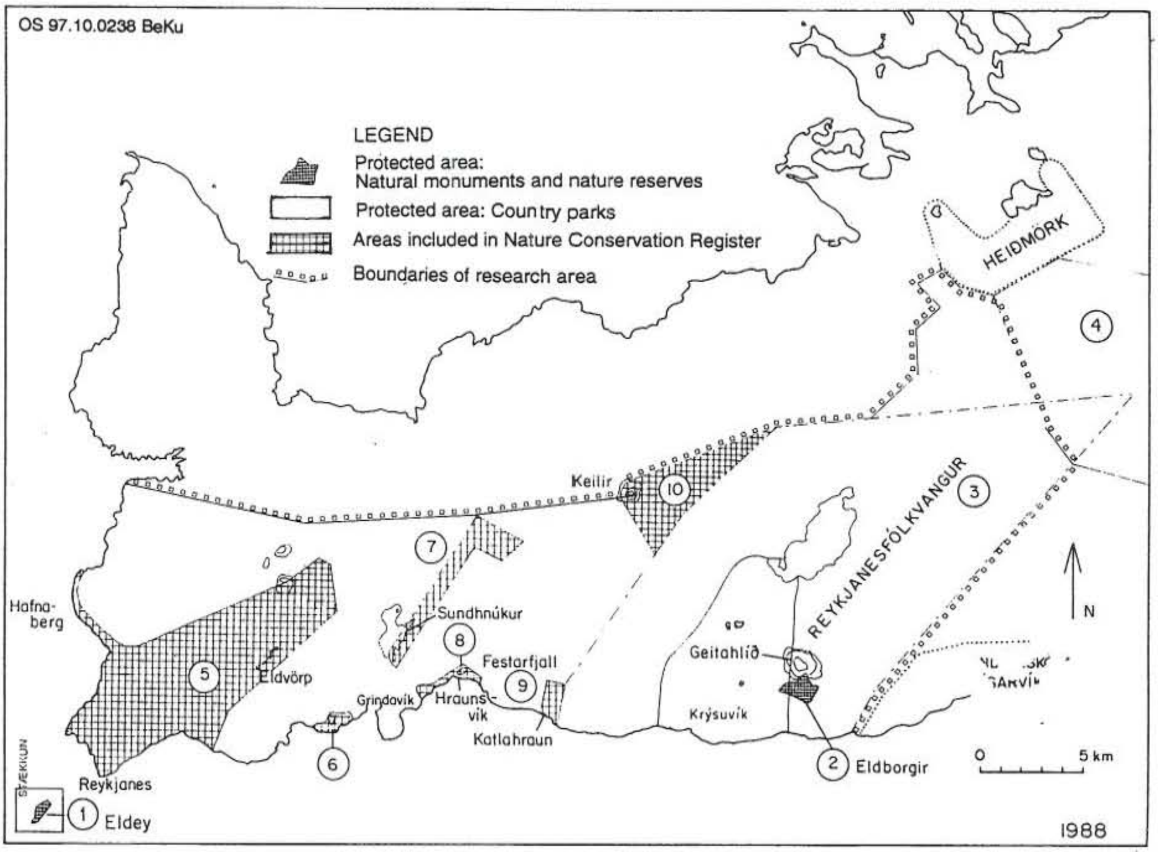

FIGURE 14: Map of the Reykjanes Peninsula showing the country park and protected areas and the research area for studies on vegetation (modified from Egilsson, 1989b)

For this type of vegetation very little disturbance is expected except during drill-site preparation and road construction, which may cause slight reduction in vegetation cover in Krísuvík, but will be of little significance in the Trölladyngja area. The pads can be vegetated with grass after drilling and well testing. Trees can be planted on the pads and the hilltops. With the large amount of rainfall in the Krísuvík area, afforestation in that area should be quite easy. The only possible problems are the hobby farmers who keep sheep in this area; the sheep graze on the planted trees. It is strongly recommended that this practise be stopped in Krísuvík in order to revegetate the area and leave sheep farming to serious farmers who earn a living and keep their sheep on appropriate land. During drilling and well testing, care should be taken to avoid damage to the grass when disposing of drilling effluents and waste waters. A detailed study on the continuation of hobby sheep farming in the Krísuvík-Trölladyngja area is required. In the study it should be investigated whether there is any benefit from such farming to the economy of the country, employment, and of course the environment in a fragile area like Krísuvík-Trölladyngja. The detailed study should also include the potential effect of changes in the thermal areas, such as increased steam flow due to exploitation, the change of distribution of the thermally adapted plants, and to whether some of the species could be rendered extinct.

12.2.6 Animal life

Wild mammals on the Reykjanes Peninsula are foxes which are rare, minks that are common, rats and mice about which there is little information although field mice are expected to be common (Petersen and Ólafsson, 1986). On the whole peninsula at least 43 bird species are known to nest, 26 of them every year. In Krísuvíkurberg there is some utilization of eggs and in 1987, 10-12,000 eggs were taken there. Proceeds go to the local rescue squad (Skarphédinsson and Einarsson, 1989). A list of nesting birds from Krísuvíkurberg to Hafnaberg is presented in Table 7. Cliff birds are considered separately in Table 8 and a generalized map of nesting distribution in the peninsula is shown in Figure 15. The cliff birds found under the low mountains along the shore cliffs in Krísuvík have become a big tourist attraction in the area. There will be no impact in this area as it is unlikely that drilling will take place near the cliffs. If wells will be sited near the cliffs in future, then a detailed EIA will be required. This is important because one of the bird species, the Red phalarope, is now a very rare bird, possibly facing extinction.

TABLE. 7: Cliff birds found on the southern Reykjanes Peninsula (Skarphédinsson and Einarsson, 1989)

Name of bird	Krísu-víkur-berg	Slagi	Festar-fjall	Haga-fell	Thor-björn	Hál-eyja-berg	Krossa-víkur-berg	Vala-hnjúk-ur	Karl-inn	Hafna-berg	Total	Eldey
Fulmar	3000	283	643 (400)	30	136	11	46	48 (70)	31 (70)	10-20	~4000	~170
Gannet											14531	14531
Shag	~150										~150	
Herring gull	~150	5	91		3		1	6+	1	1-2	~260	
Kittiwake	3200		33					577 (300)	38 (400)	4000	~40000	3000
Razorbill	7000	15 (8)						4 (8)	7	500	~7500	
Common Murre	11000									800	~14300	2500
Thick-billed Murre	3000									150	~4150	100-200
Black guillemot						1	1	<20			100-200	
Puffin								30 (8)			1000-2000	
Total	**~57000**	**303**	**~1300**	**30**	**139**	**12**	**48**	**~730**	**480**	**5500**	**87000**	**21200**

12.2.7 Light and glare

There will be some light or glare while drilling in these two areas but this will not be of any significance as the areas are remote with only a few people at the rehabilitation centre in Krísuvík. The light from the drilling rig can also cause some interference to shipping particularly in small harbours because the pilot may confuse the drilling rig with the harbour. But at other times it may assist in estimating the distance from the ship sailing on the sea, to the mainland. If ships are well informed, such a light is likely to be an advantage.

12.2.8 Transportation

There will be some increased traffic generated on the main roadway in the project area due to the transportation of the drill rig, together with all its accessories to the area (see notes on 10.5).

12.2.9 Utilities

Water for drilling in Krísuvík may be obtained from the small stream, Lake Kleifarvatn or probably by drilling a fresh water well. In Trölladyngja a fresh water well was drilled for water as drilling fluid, but a detailed study should be conducted to find out if this one fresh water well will be able to serve all the wells to be drilled in the area.

TABLE 8: Nesting birds on southern Reykjanes Peninsula from Krísuvíkurberg to Hafnaberg (Skarphédinsson and Einarsson, 1989)

Name of bird	Zoological name	Year	Occasional	Former
Fulmar	Fulmarus glacialis	X		
Manx shearwater	Puffinus puffinus		?	
Gannet	Sula bassana	X		
Shag	Phalarcocorax aristotelis	X		
Mallard	Amas platyrhynchos		X	
Eider	Somateria mollisima	X		
Red breasted merganser	Mergus serrator		X	
White tailed eagle	Haliaetus albicilla			X
Gyrfalcon	Falco rusticolus			X
Merlin	Falco columbarius	X		
Ptarmigan	Lagopus mutus	X		
Oystercatcher	Haematopus ostralegus	X		
Eurasian golden plover	Pluvialis apricaria	X		
Ringed plover	Charadrius hiaticula	X		
Whimbrel	Numenius phaeopus	X		
Common snipe	Gallinago gallinogo	X		
Redshank	Tringa totanus	X		
Purple sandpiper	Calidris maritima	X		
Red phalarope	Phalaropus fulicarius	X		
Northern phalarope	Phalaropus lobatus	X		
Great skua	Stercorarius skua	X		
Arctic skua	Stercorarius parasiticus	X		
Great black-backed gull	Larus marinus	X		
Lesser black-backed gull	Larus fuscus	X		
Herring gull	Larus argentatus	X		
Glaucous gull	Larus hyperboreus	X		
Mew gull (Common gull)	Larus canus		?	
Black legged kittiwake	Rissa tridactyla	X		
Arctic tern	Sterna paradisea	X		
Razorbill	Auka torda	X		
Great auk	Pinguinus impennis			X
Common murre	Uria aalge	X		
Thick-billed murre	Uria lomvia	X		
Black guillemot	Cephus grylle	X		
Puffin	Fratercula arctica	X		
Swallow	Hirunda rustica		X	
Raven	Corvus corax	X		
White wagtail	Motacilla alba	X		
Meadow pipit	Arthus pratensis	X		
Wheatear	Oenanthe oenanthe	X		
Starling	Sturnus vulgaris	X		
Snow bunting	Plectrophenas nivalis	X		
Total		**32**	4+2	**5**

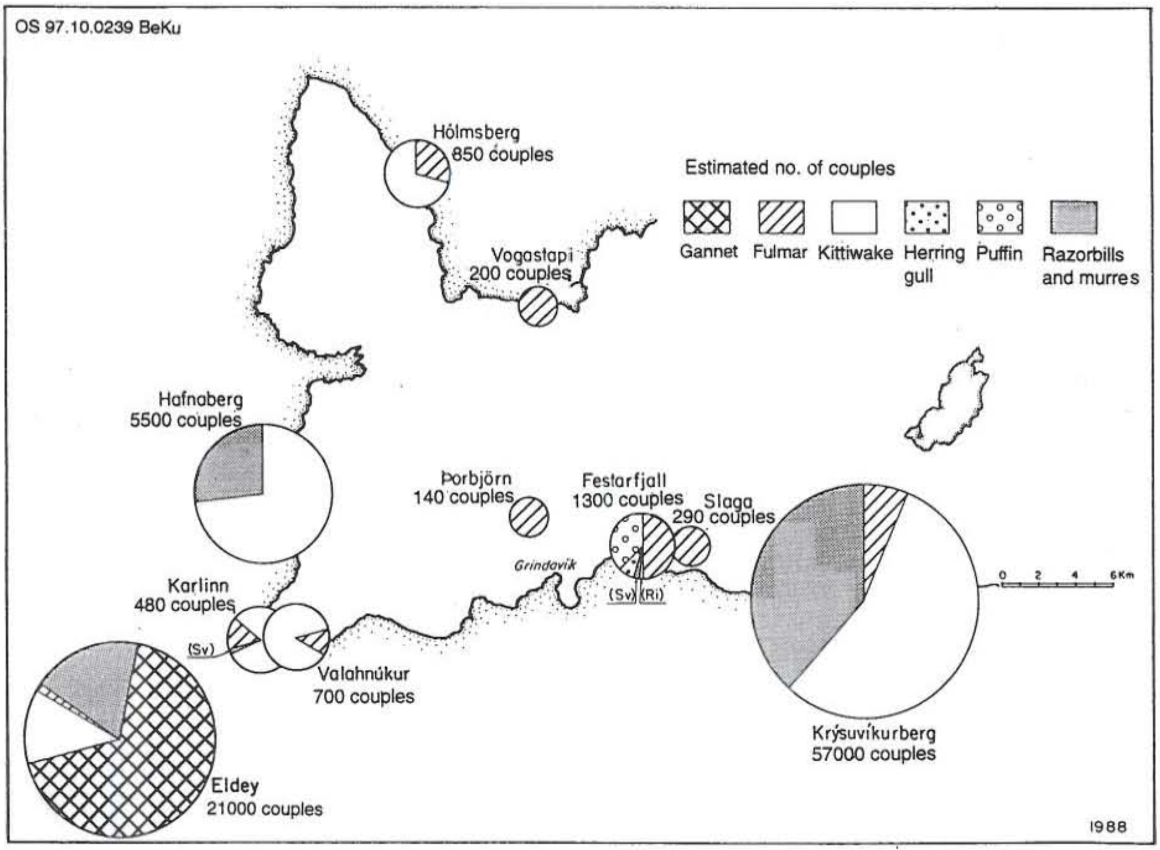

FIGURE 15: Nesting distribution of cliff birds on the Reykjanes Peninsula (Skarphédinsson and Einarsson, 1989)

12.2.10 Aesthetics

Visual quality may be diminished by loss of naturalness and the imposition of man-made structures like drill sites, drilling rig, and accessories creating artificial landscape elements in the project area but all these are temporary and will disappear when drilling is completed. Scenic value like that of the numerous small hot springs, mud pools, fumaroles, boiling pools and all other natural geothermal manifestations attracts tourists and should be protected. A detailed study should be conducted in Krísuvík to find out if these unique features will or will not decline when drilling takes place as this will interfere with the deep reservoir. The well drilled in Krísuvík in 1960 KV-14 is a big tourist attraction and is also used to heat a coffee shop in the parking area.

13. PLANNING

The law on environmental impact assessment in Iceland is No. 63/1993. Article one states that the objective of this act is to ensure that prior to a decision concerning projects which may have significant effects on the environment, natural resources and community by virtue of their location, resulting activities, nature or size, the projects shall be subjected to an environmental impact assessment and to ensure that such an assessment is invariably a part of the planning process. In article 5 the law defines the projects which are subject to environmental impact assessment. Drilling for geothermal and drinking water falls under annex 11, under the list of projects and operations that may have significant environmental effects or not. A geothermal power plant with a 10 MWe production capacity or a geothermal plant expected to produce 25 MWth will automatically be subjected to EIA.

There were plans to put up a big tourist multi resort and an Icelandic geoscience research center in Krísuvík as this area was selected as the best in a study of possible areas. (Checchi and Company and the Architect Collaborative Inc.,1975). The climate, and its closeness to Reykjavík and Keflavík makes Krísuvík close to the hubs of foreign and local tourist activity. The drilling of geothermal wells should, therefore, not conflict with the tourist industry and, if anything, should benefit the tourist resort centre. Drilling should not interfere either with the recreation and fishing activity in Lake Kleifarvatn by Icelanders. Krísuvík has a combination of resources and scenic beauty, backed by advantages of a central location vis-a-vis existing markets.

Landownership in the Krísuvík-Trölladyngja area requires urgent attention because, up to now, ownership rights are not clear, particularly so in Trölladyngja. It is absurd to transport steam all the way from Krísuvík to Straumsvík instead of getting it from Trölladyngja which is quite close, just because of the grey area in landownership or utilization rights. For instance Krísuvík and Lake Kleifarvatn are owned by Hafnarfjördur township (see Chapter 2).

Some monitoring of natural manifestations has been done and is included in plans for environmental work at Orkustofnun. However, it has been difficult to finance as the power companies are not interested in supporting research until they have obtained the right for exploitation. Therefore, it is suggested that the government shoulder the cost of the monitoring but charge the exploiter for it when he gets the rights.

14. NECESSARY ACTION

1. A detailed study of the water supply for drilling is required in Krísuvík. In Trölladyngja a freshwater well was drilled to provide water for drilling, and this is still in existence.

2. A study will be required on how to get rid of effluent water in the Krísuvík-Trölladyngja area.

3. Monitoring of steam flow and gas concentrations in steam needs to be carried out in more locations and more frequently than up to now.

4. Monitoring of gas emissions to the atmosphere should be carried out. A short term check has been performed but much more information is needed.

5. Some monitoring of natural manifestations has started and plans for it are included in plans for environmental work at Orkustofnun. This monitoring should be continued and funds set aside for it.

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APPENDIX I: Checklist used for environmental assessment of drilling in the Krísuvík-Trölladyngja geothermal field (based on Roberts, 1991)

Environmental impacts:

		Yes	Maybe	No
1.	**Earth**. Will the proposal result in:			
a.	Unstable earth conditions or in changes in geologic substructures?	X		
b.	Disruptions, displacements, compaction or over covering of the soil?			X
c.	Change in topography or ground surface relief features?			X
d.	The destruction, covering or modification of any unique geologic or physical features?			X
e.	Any increase in wind or water erosion of the soil, either on or off the site?	X		
f.	Changes in deposition or erosion of beach sands, or changes in siltation, deposition or erosion which may modify the channel of a river or stream or the bed of the ocean or any bay, inlet or lake?			X
g.	Exposure of people or property to geologic hazards such as earthquakes, landslides, mudslide, ground failure or similar hazards?			X

			Yes	Maybe	No
2.	**Air.** Will the proposal result in:				
	a.	Substantial air emissions or deterioration of ambient air quality?			X
	b.	The creation of objectionable odours?		X	
	c.	Alteration of air movement, moisture, or temperature, or any change in climate either locally or regionally?			X
3.	**Water.** Will the proposal result in:				
	a.	Changes in currents, or the course of direction of water movements in either marine or fresh water?		X	
	b.	Changes in absorption rates, drainage patterns, or the rate and amount of surface runoff?		X	
	c.	Alterations to the course or flow of flood waters?			X
	d.	Change in the amount of surface water in any water body?	X		
	e.	Discharge into surface waters or in any alteration of surface water quality, including but not limited to temperature, dissolved oxygen, or turbidity?	X		
	f.	Alteration of the direction or rate of flow of ground waters?	X		
	g.	Change in the quantity of ground waters, either through direct additions or withdrawals, or through an interception of an aquifer by cuts or excavations?			X
	h.	Substantial reduction in the amount of water otherwise available for public water supplies?			X
	i.	Exposure of people or property to water related hazards such as flooding or tidal waves?			X
4.	**Plant life.** Will the proposal result in:				
	a.	Change in the species diversity, or number of any species of plants (including trees, shrubs, grass, crops and aquatic plants)?		X	
	b.	Reduction of the numbers of any unique, rare, or endangered species of plants?		X	
	c.	Introduction of new species of plants into an area ,or a barrier to the normal replenishment of existing species?		X	
	d.	Reduction in acreage of any agricultural crop?			X

			Yes	Maybe	No
5.	**Animal life.** Will the proposal result in:				
	a.	Change in the diversity of species, or numbers of any species of animals (birds, land animals including reptiles, fish and shellfish, benthic organisms or insects)?		X	
	b.	Reduction of the numbers of any unique, rare or endangered species of animals?			X
	c.	Introduction of new species of animals into an area, or result in a barrier to the migration or movement of animals?			X
	d.	Deterioration to existing fish or wildlife habitat?			X
6.	**Noise**. Will the proposal result in:				
	a.	Increase in existing noise levels	X		
	b.	Exposure of people to severe noise levels			X
7.	**Light and glare**. Will the proposal produce new light or glare?		X		
8.	**Land use**. Will the proposal result in a substantial alteration of the present or planned land use of an area?	Present:			X
		Planned			X
9.	**Natural resource**. Will the proposal result in:				
	a.	Increase in the rate of use of any natural resource?	X		
	b.	Substantial depletion of any nonrenewable natural resource?			X
10.	**Risk of upset.** Will the proposal involve:				
	a.	A risk of an explosion or the release of hazardous substances including but not limited to, oil pesticides chemicals or radiation in the event of an accident or upset conditions.			X
	b.	Possible interference with an emergency response plan or an emergency evacuation plan?			X
11.	**Population.** Will the proposal alter the location, distribution, density, or growth rate of the human population of an area?				X
12.	**Housing**. Will the proposal alter the location, distribution, density, or growth rate of the human population of an area?				X

			Yes	Maybe	No
13.	**Transportation/circulation.** Will the proposal result in:				
	a.	Generation of substantial additional vehicular movement?	X		
	b.	Effects on existing parking facilities or demand for new parking?			X
	c.	Substantial impact upon existing transportation systems?			X
	d.	Alterations to present patterns of circulation or movement of people and /or goods?			X
	e.	Alterations to waterborne, rail or air traffic?			X
	f.	Increase in traffic hazards to motor vehicles, bicyclists or pedestrians?		X	
14.	**Public service.** Will the proposal have an effect upon, or result in a need for new or altered governmental services in any of the following areas:				
	a.	Fire protection?			X
	b.	Police protection?			X
	c.	Schools?			X
	d.	Parks or other recreational facilities?		X	
	e.	Maintenance of public facilities including roads?			X
	f.	Other government services?			X
15.	**Energy.** Will the proposal result in:				
	a.	Use of substantial amounts of fuel or energy?		X	
	b.	Substantial increase in demand upon existing sources of energy, or require the development of new sources of energy?			X
16.	**Utilities.** Will the proposal result in a need for new systems or substantial alterations to the following utilities:				
	a.	Power or natural gas?			X
	b.	Communications systems?			X
	c.	Water?	X		
	d.	Sewer or septic tank?		X	
	e.	Storm water drainage?		X	

		Yes	Maybe	No
f.	Solid waste and disposal?	X		
17.	**Human health**. Will the proposal result in:			
a.	Creation of any health hazard or potential health hazard (excluding mental health)?			X
b.	Exposure of people to potential health hazards?		X	
18.	**Aesthetics.** Will the proposal result in the obstruction of any scenic vista or view open to the public, or will the proposal result in the creation of an aesthetically offensive site open to the public view?		X	
19.	**Recreation.** Will the proposal result in an impact upon the quality or quantity of existing recreational opportunities?			X
20.	**Cultural resources.**			
a.	Will the proposal result in the alteration of or the destruction of a pre-historic or historic archaeological site?			X
b.	Will the proposal result in adverse physical or aesthetic effects to a pre-historic or historic building, structure, or object?			X
c.	Does the proposal have the potential to cause a physical change which would affect unique ethnic cultural values?			X
d.	Will the proposal restrict existing religious or sacred uses within the potential impact area?			X
21.	**Mandatory findings of significance.**			
a.	Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of fish or wildlife species, cause a fish or wildlife population to drop below self sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of history or prehistory?			X
b.	Does the project have the potential to achieve short-term, to the disadvantage of long-term, environmental goals?		X	
c.	Does the project have impacts which are individually limited, but cumulatively considerable?			X
d.	Does the project have environmental effects which will cause substantial adverse effects on human beings, either directly or indirectly?			X