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PRELIMINARY ENVIRONMENTAL IMPACT ASSESSMENT FOR THE HÁGÖNGUR HIGH-TEMPERATURE AREA, CENTRAL ICELAND

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ABSTRACT

The Hágöngur high-temperature geothermal field is located near the western edge of Vatnajökull glacier, Central Iceland. It is one of 30-40 known high-temperature geothermal fields in Iceland. The first exploration well was successfully finished in September, 2003. Further exploration is expected. In this report, a preliminary Environmental Impact Assessment (EIA) is carried out on environmental effects due to a proposed geothermal power plant. A standard checklist for geothermal power projects was used for classification of possible impacts. Some possible environmental impacts are discussed and potential mitigating measures are suggested. The result of this study suggests that further studies be carried out on access road planning, visual impact, tourism and effluent discharging.

1. INTRODUCTION

This report is done in fulfilment of a fellowship awarded to the author for the UNU Geothermal Training Programme, being held in Iceland in 2004. The environmental aspects of the Hágöngur geothermal field were studied, with emphasis on a preliminary EIA for producing geothermal power in this area. In 2002, geothermal exploration of the Hágöngur area was started by Landsvirkjun (the National Power Company), with a detailed exploration plan, including drilling two exploration wells in the area. One exploration well was successfully completed in September, 2003. This preliminary EIA report is based on a proposal of an 80-120 MWe geothermal electric power generating plant in the area.

The Hágöngur area is located at the western edge of Vatnajökull glacier, about 40 km northeast of Lake Thórisvatn. It is one of the 30-40 known high-temperature areas in Iceland, shown in Figure 1. As part of the central highlands, this area is remote from habitation at an elevation of about 800 m a.s.l. Háganga (plural - Hágöngur) is the name of two similar mountains, the North-Háganga, reaching an elevation of 1278 m a.s.l., and the South-Háganga, with an elevation of 1284 m a.s.l. Their geological structure is rhyolite and they are cone-shaped and steep. They are very prominent, freestanding mountains and the distance between them is about 4 km. A lava field called Svedjuhraun.

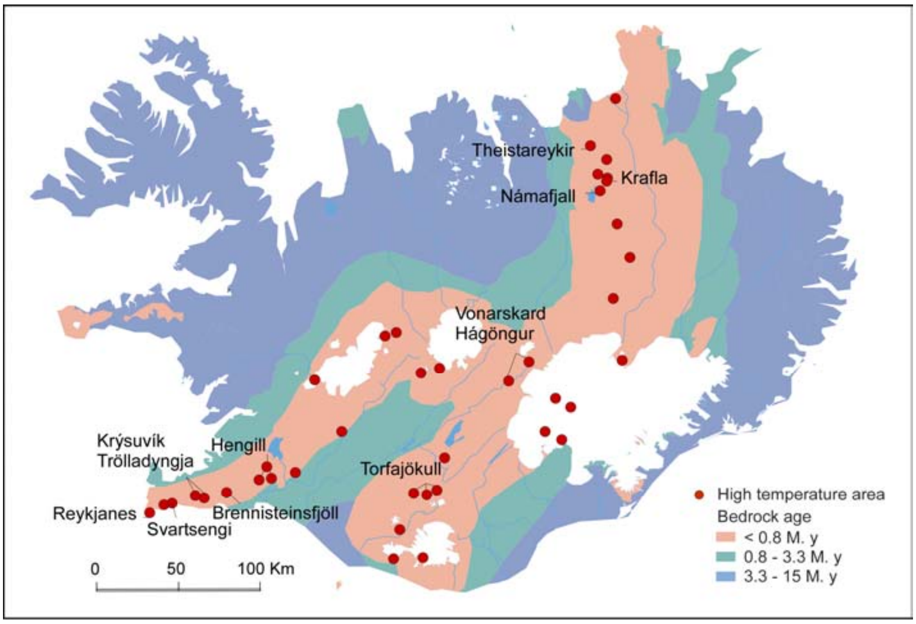

FIGURE 1: High-temperature geothermal fields in Iceland

is found 5 km east of them. South of the mountains there is also a widespread lava field called Hágönguhraun.

Hágöngulón reservoir, a part of a hydropower project, was dammed up in 1998 and a large area below 816 m a.s.l. disappeared under water, including some of the geothermal manifestations, the springs and the western edge of Svedjuhraun lava field (Figure 2).

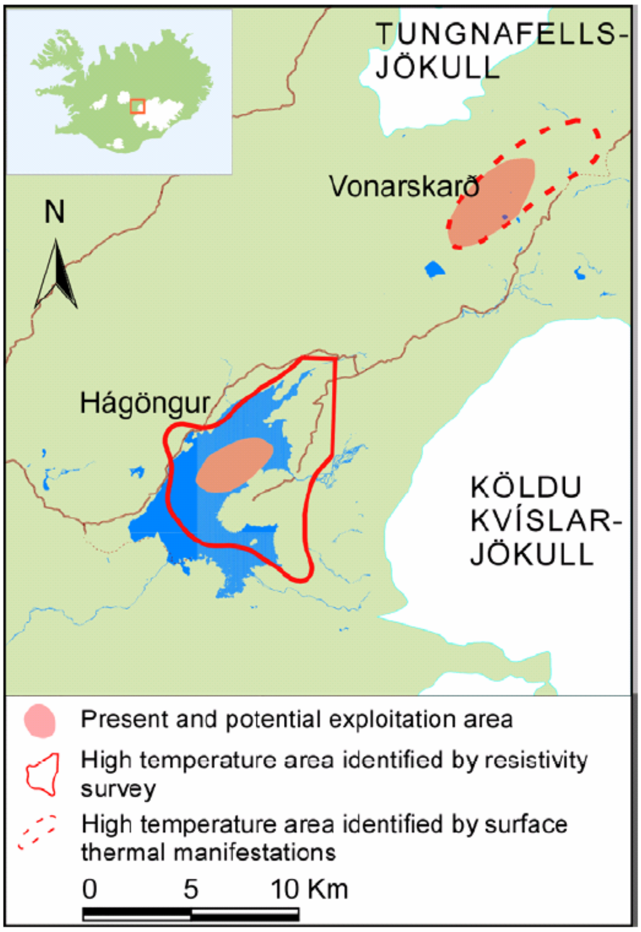

FIGURE 2: Location of the Hágöngur geothermal area in Iceland (modified from Björnsson, 2004)

A volcanic system with a central volcano is likely for the area, with a possible caldera formation, though no signs of the caldera are seen on the surface. This is suggested by the rhyolite formations which line up in a half-circle (including the N- and S-Háganga silicic formations) (see Figure 3). Surface manifestations of geothermal activity are mainly found in three locations, two of which are now located underneath the Hágöngulón reservoir. The third location is on the western outskirts of the Svedjuhraun lava flow. Cold, older patches of geothermal alteration have been found in many places, particularly by Kvíslarhnjúkar, northeast of Hágöngulón Reservoir, but also in the Hágöngur mountains. Resistivity measurements suggest a geothermal area, 28-50 km^2 in size. The chemical composition of the escaping steam suggests a temperature of about 300°C deep down inside the geothermal system (Björnsson, 2004).

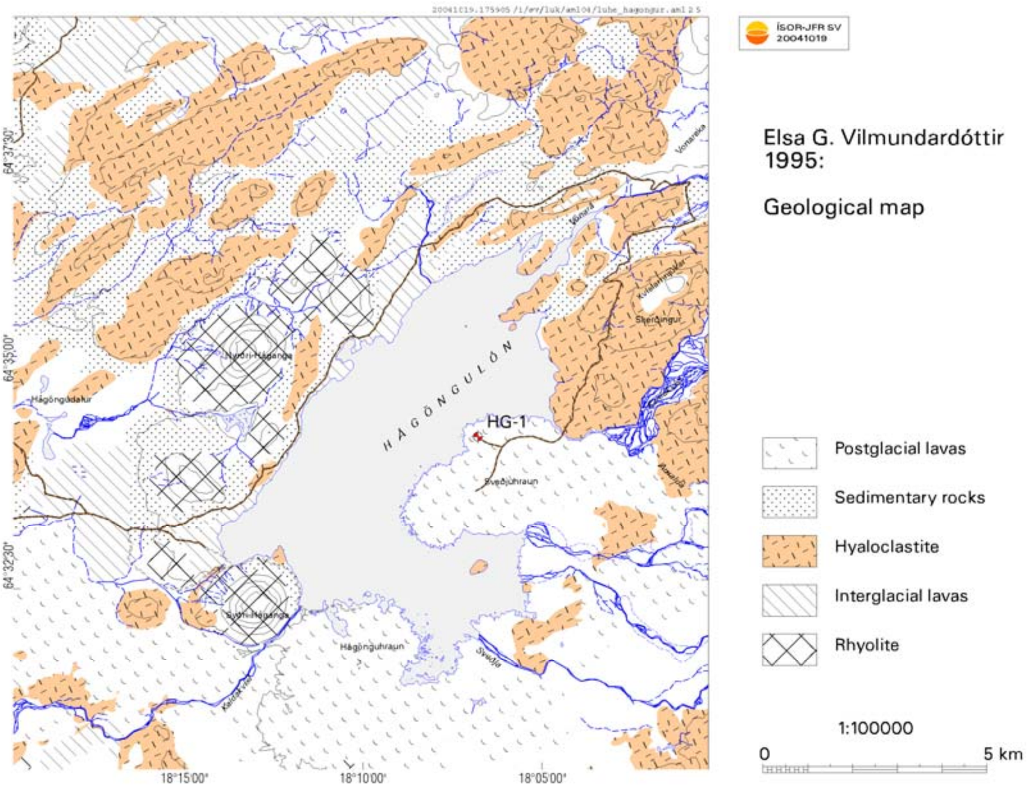

FIGURE 3: Geological map of the Hágöngur area (Vilmundardóttir and Kaldal, 1995)

2. GEOTHERMAL EXPLORATION IN THE HÁGÖNGUR GEOTHERMAL AREA

Due to its location in the central highlands, geothermal exploration in the Hágöngur area was sporadic until about a decade ago. The Hágöngur area is now being explored by Landsvirkjun (The National Power Company of Iceland) in association with plans to build a 80-120 MWe geothermal power plant, but the start was associated with plans by Landsvirkjun to construct a hydro dam near S-Háganga mountain and partially submerge the thermal area. That project was completed in 1998. The following sections are mainly taken from a paper by Jónsson et al. (2004) where the results of the geothermal exploration are summarized and the drilling of the first exploration well described.

2.1 Geological settings (Jónsson et al., 2004)

General geological investigations have been sporadic and scarce in the Hágöngur high-temperature area, confined to the northern margin of the Eastern Volcanic Zone with an abundance of exposed Pleistocene and Holocene volcanics. A published geological map of Central Iceland shows general age-relationships and lithological classification of the larger units is shown (Jóhannesson and Saemundsson 1989). The naming and definition of relationships of adjacent central volcanoes is vague in light of limited investigations. It is expected that the Hágöngur area is an independent central volcano (Jóhannesson and Saemundsson, 2003) but it has also been suggested that the Hágöngur area is in direct relationship with and a part of an elongated central volcano from Tungnafellsjökull (including Vonarskard – see Figure 2) from the northeast, extending southwards to the Hágöngur area (Fridleifsson et al., 1996). A simplified geological map is shown in Figure 3.

All exposed volcanic formations in the area have normal magnetization and thus are younger than 700,000 years (Piper, 1979). The rhyolites in the mountains N-Háganga and S-Háganga are

surrounded by younger basaltic formations (200-300,000 years), and are thought to be 300-500,000 years old. Interglacial lava flows are conspicuous in the area and two successions are especially notable; the Krosshnúkar-tholeiite (~200,000 years) and the Hágöngur-tholeiite and the Hágöngur-porphyritic basalt (~100,000 years). Extrusive volcanic activity seems to have been dormant for the last 100,000 years in the Hágöngur central volcano (Vilmundardóttir and Kaldal, 1995).
Near the Hágöngur area and partially within the defined area, younger volcanics have been described (sub-glacial hyaloclastites <10,000 years old) but based on their composition it can be concluded that they owe their origin to the Bárdarbunga central volcano. Porphyritic Holocene lava flows (Svedjuhraun lava field and Hágönguhraun lava field in the area) are from the Bárdarbunga central volcano east of Hágöngur.

The Hágöngur high-temperature area stands out and is unique in many ways compared to other high-temperature areas in Iceland. It is almost entirely buried in glacio-fluvial sediments, supposedly filling an old lake basin. Any direct connection to recent volcanic or tectonic activity is lacking. The rhyolite domes of S-Háganga and N-Háganga with smaller unnamed rhyolite domes are lined on a semi-circumferential line in the western part of the area. The domes are probably intrusive and it is tempting to conclude that their formation is related to subsidence and eventually a caldera formation in later stages of evolution and development of the central volcano.

2.2 Distribution of the geothermal manifestations (Jónsson et al., 2004)

The first attempt to map the distribution of geothermal surface manifestations dates from 1995 (Gudmundsson, 1995). Three individual clusters of steam and mud pools were the only surface manifestations noted, two of which are now located underneath the Hágöngulón Reservoir. The third cluster is on the western outskirts of the Svedjuhraun lava flow. One small cluster emerges in the fluvial sediments north of the Svedjuhraun Holocene lava field comprising two patches (distance, 10-20 m) with steam and mud pools. The largest cluster in the fluvial sediments west of Svedjuhraun is comprised of about five patches of steam vents and mud pools, fringed by hydrothermal alteration minerals and encrustations. The size of the largest patch is about 50 m × 200 m. The third one was evidently buried by the Svedjuhraun lava field (~2000 years BP), but the thermal flux has managed to diffuse through the lava succession and thermal alteration, mineral encrustations and steam outflow are now noted in the near centre of the Svedjuhraun lava tongue. An attempt was made, on the grounds of the distribution of the thermal manifestations, to estimate the size of the geothermal area. It was then estimated to be at least 10 km^2 and possibly 40 km^2 as indicated in Figure 4 with elliptical lines, showing the minimum and maximum extent of the system.

In the following year, the three areas were mapped (Fridleifsson and Víkingsson, 1997) with sub-centimetre precision GPS, and a geothermal map was produced. Older patches of cold geothermal alteration have been found in many places, particularly at Kvíslarhnjúkar, northeast of Hágöngulón Reservoir, but also in the Hágöngur mountains.

2.3 Gas concentration in the steam (Jónsson et al., 2004)

Several gas samples were collected at the Hágöngur geothermal area in 1995. For comparison of the chemical composition of the steam, a sample was also collected from a steam-vent in the Vonarskard high-temperature area. The gas fraction in the steam at Hágöngur is comparable to other high-temperature areas. However, gas ratios differ from those in other areas with methane and nitrogen being exceptionally high and considerably higher than in the Vonarskard area. With respect to hydrogen and hydrogen sulphide, the Hágöngur samples are much lower than for that from Vonarskard. Another notable distinguishing feature is the unusually high concentration of mercury in the steam samples from the Hágöngur field. A difference by an order of magnitude is observed

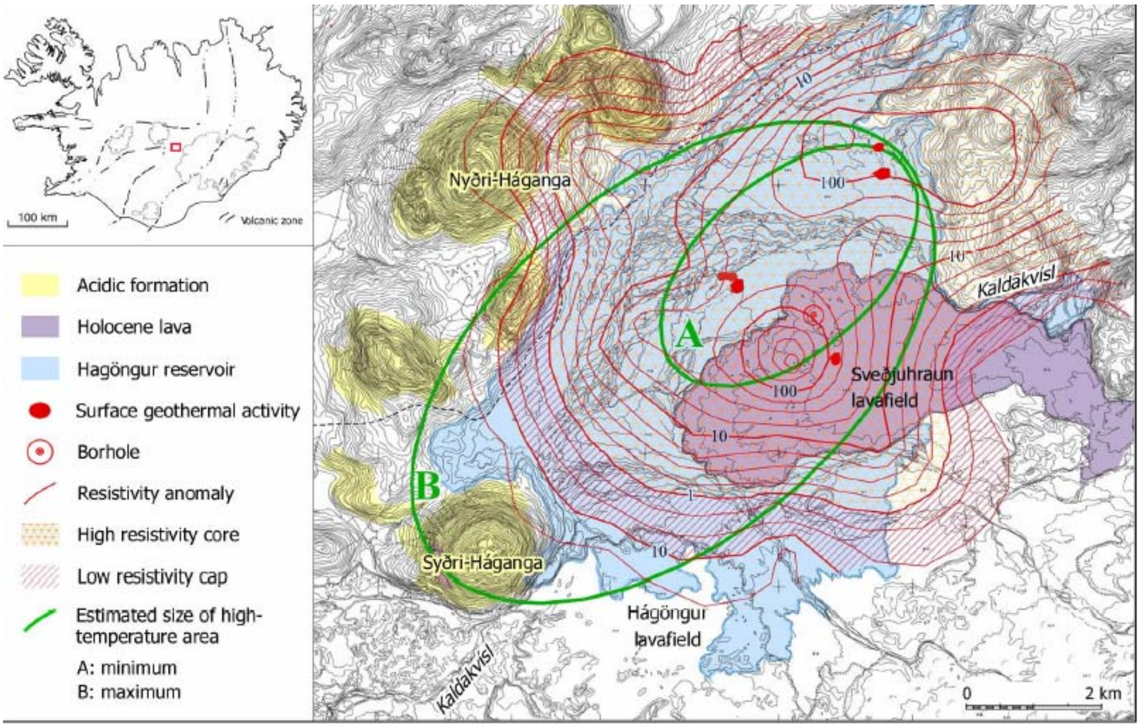

FIGURE 4: Location of the Hágöngur high-temperature area and a simplified geological map with resistivity anomalies (Karlsdóttir, 2000) in the Hágöngur area at sea level (Jónsson et al., 2004)

compared to the Vonarskard sample. Measured values of other chemicals were comparable and similar to values in other high-temperature areas in Iceland (Fridleifsson, et al., 1996).

The three water samples were congruous, while one sample showed increased silica due to mixing of thermal runoff water (Fridleifsson, et al., 1996).

Temperature in geothermal reservoirs can be calculated from the composition and concentration of gas collected from steam vents (Arnórsson and Gunnlaugsson, 1985) and from the chemical composition of geothermal water (Arnórsson, 1995). Several chemical gas thermometers were applied to the samples from the Hágöngur high-temperature area and the results are shown in Table 1, indicating subsurface temperatures of around 290°C.

TABLE 1: Results of gas chemical geothermometers on samples from the Hágöngur high-temperature area (Fridleifsson et al., 1996)

Sample	Location	CO_2 (°C)	H_2S (°C)	H_2 (°C)	CO_2/H_2 (°C)	H_2S/H_2 (°C)	Average (°C)
95-0127	Hágöngur	281	293	288	292	283	287±5
95-0128	Hágöngur	286	297	294	298	291	293±5
95-0129	Hágöngur	303	311	298	295	286	299±5
95-0130	Hágöngur	282	297	287	290	277	287±6
95-0133	Hágöngur	310	299	294	288	290	296±7
95-0135	Vonarskard	284	324	311	321	299	308±17

2.4 Resistivity survey (Jónsson et al., 2004)

In order to establish a fuller knowledge of the internal structure of the Hágöngur high-temperature area, a transient electromagnetic (TEM) resistivity survey was conducted in April 1998 to obtain reliable data on the size and thermal conditions of the geothermal system. The results of the TEM survey were reassuring and revealed a high-resistivity core of about 28 km^2 at about 1000 m depth. Including the low-resistivity cap surrounding the high-resistivity core, the size or the confinement of the high-temperature area is in the vicinity of 50 km^2 (shown in Figure 4), equivalent to the resistivity depicted at the same level in the Krafla high-temperature area in Iceland (Karlsdóttir, 2000). The resistivity anomaly at sea level in Figure 4 is indicated, with the low-resistivity cap and high-resistivity core marked separately. Exploration well HG-01 is located near the centre of the high-resistivity core.

2.5 The drilling of the first exploration well HG-01 (Jónsson et al., 2004; Seifu, 2004)

In 2002, approval by the Skipulagsstofnun - National Planning Agency, and the permission of the local authorities was granted for continued development of the Hágöngur area, including drilling the first exploration wells. Logistic planning, the building of roads and bridging the glacial river Kaldakvísl followed. A new 10 km track was built to the HG-01 and HG-02 drill sites. Drilling of shallow wells to acquire water for borehole circulation and cooling started in June 2003, and a drillrig was erected on the well site. The well sites were located and preparations for the drilling operation were launched in mid-summer 2003. The first exploration borehole was sited in the central part of the resistivity anomaly. Drilling of well HG-01 commenced in late July the same year and the well was completed in early September. The well was drilled down to 2360 m. A preliminary comparison of the measured temperatures and the deduced temperature from surface samples indicates equilibrium.

The stratigraphy shows basaltic extrusives and thick acidic units in the upper 700 m and basaltic hyaloclastite and lava formations down to 1900 m. From 1900 m, basaltic intrusives prevail with 100 m thick acid intrusion at the very bottom. The hydrothermal alteration shows a progressive increase in alteration from the smectite-zeolite zone near the surface succeeded by a chlorite-epidote zone below 580 m depth.

Since completion of drilling, samples of gases and fluid have been collected, and temperature and pressure have been monitored during the well's warming up. After discharge, deliverability has been monitored continuously and samples taken to estimate properties and quality of the well's fluid.

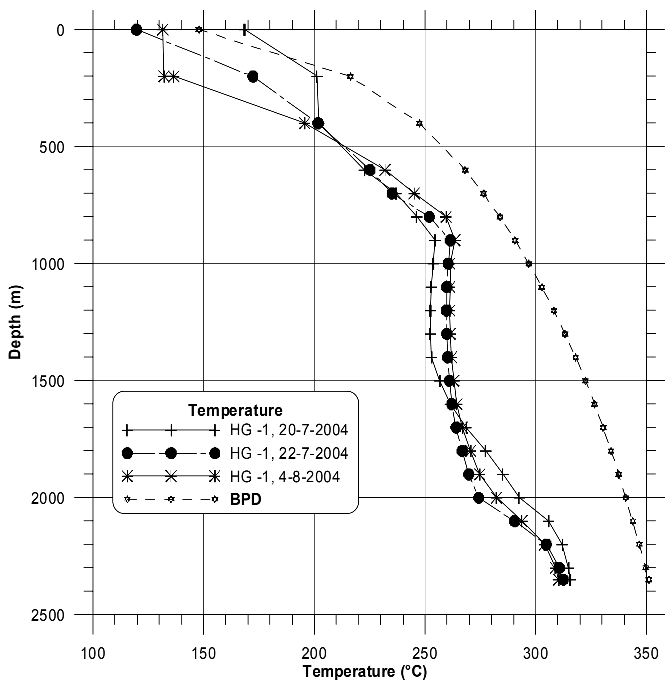

FIGURE 5: Downhole temperature profiles recorded under well shut-in condition in well HG-01 after discharge (Seifu, 2004)

Figure 5 shows downhole temperature profiles, measured at static conditions in well HG-01 (Seifu, 2004). After discharge the results of these surveys show gradual increase in temperature from 200 down to 900 m depth. Starting from 900 to about 1700 m the temperature is nearly constant at around 260°C. This is possibly due to downflow from the aquifer at around 900 m depth. Below 1700 m, the temperature increases very gradually down to 2360 m. The maximum temperature recorded at the bottom depth was 315.6°C. The Boiling Point for Depth (BPD) versus the measured temperature curves indicate that the well is still far from boiling conditions at all depths. The well intercepts the reservoir at 900 m depth. The well drilled in Hágöngur is promising but more wells are needed for prediction of the field's capabilities (Seifu, 2004).

3. ENVIRONMENTAL ASPECTS OF THE HÁGÖNGUR GEOTHERMAL AREA

3.1 Hágöngulón hydropower reservoir

Hágöngulón reservoir is part of the Vatnsfell hydropower project. The water collected in the Hágöngur area comes from the Vatnajökull glacier during the summer. The reservoir entered service in 1998. The maximum water level is at 816 m a.s.l. and the minimum water level is 798 m a.s.l. Surface geothermal manifestations are at 806 m a.s.l., so they appear when the water level is lower than that. The reservoir area is 37 km^2. The reservoir storage is 4×10^8 m^3. The drainage area is 600 km^2. The average water flow into the Hágöngulón reservoir is 22 m^3/s. In summer, the water flow is more than 100 m^3/s. During the winter about 25-30 m^3/s of the water is sluiced from the Hágöngulón reservoir along the Kaldakvísl River to Lake Thórisvatn. Almost all the water in the reservoir is diverted to Lake Thórisvatn in the wintertime.

3.2 Weather conditions

The weather in the Hágöngur area is typical highland weather for Iceland. The climate conditions are controlled by altitude and distance from the sea. The mean annual temperature is around 0-1°C. There are two meteorological stations near this area. They are Thúfuver and Veidivatnahraun. The meteorological station at Veidivatnahraun is about 27 km to the southwest from Hágöngur. The meteorological station at Thúfuver is about 24 km to the west from Hágöngur. A new weather station was set up in the Hágöngur area in autumn 2004.

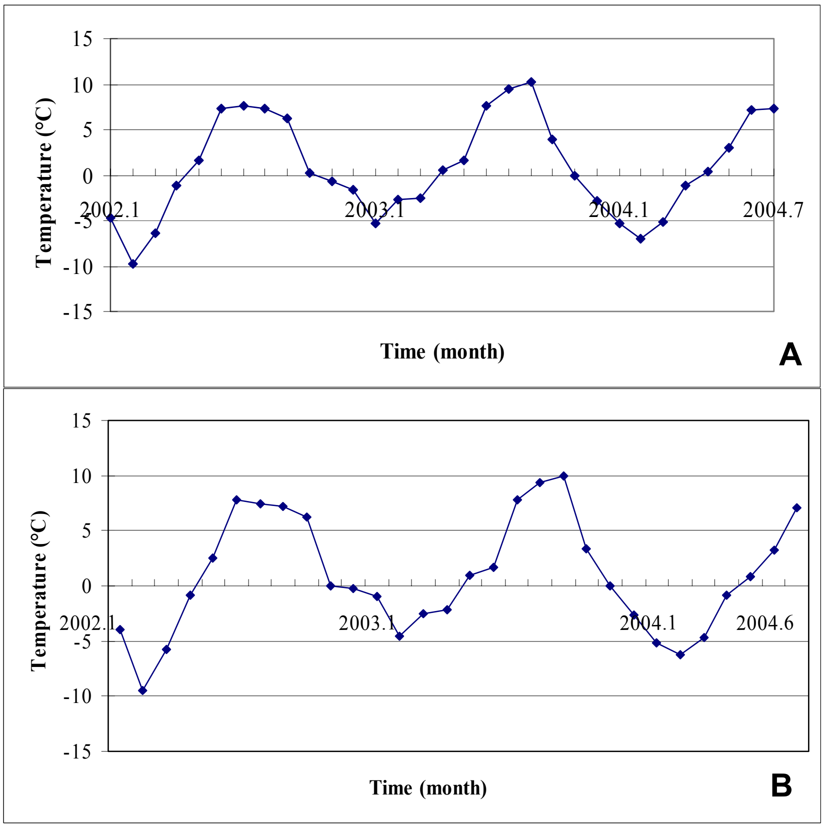

FIGURE 6: Monthly temperatures in a) Thúfuver; and b) Veidivatnahraun

According to the data collected from 2002 to 2004, August is the warmest month and the mean annual August temperature is 7-10°C, although on certain days it can reach 15-20°C. The coldest month is February. Frosts may occur during all the summer months although it is least likely in July. Figure 6 shows the monthly average temperature curve in both weather stations.

Annual precipitation is probably between 800 and 1200 mm. Precipitation data was gathered in 2002-2003 at the Thúfuver and Veidivatnahraun meteorological stations (Table 2). The maximum monthly precipitation was about 230 mm in September 2003, and minimum about 21 mm in March 2003. Figure 7 shows monthly precipitation from 2002 to 2003 in the Veidivatnahraun and Thúfuver area.

TABLE 2: Annual precipitation

Meteorological station	**Annual precipitation (mm)**	
	2002	**2003**
Thúfuver	900	1217
Veidivatnahraun		835

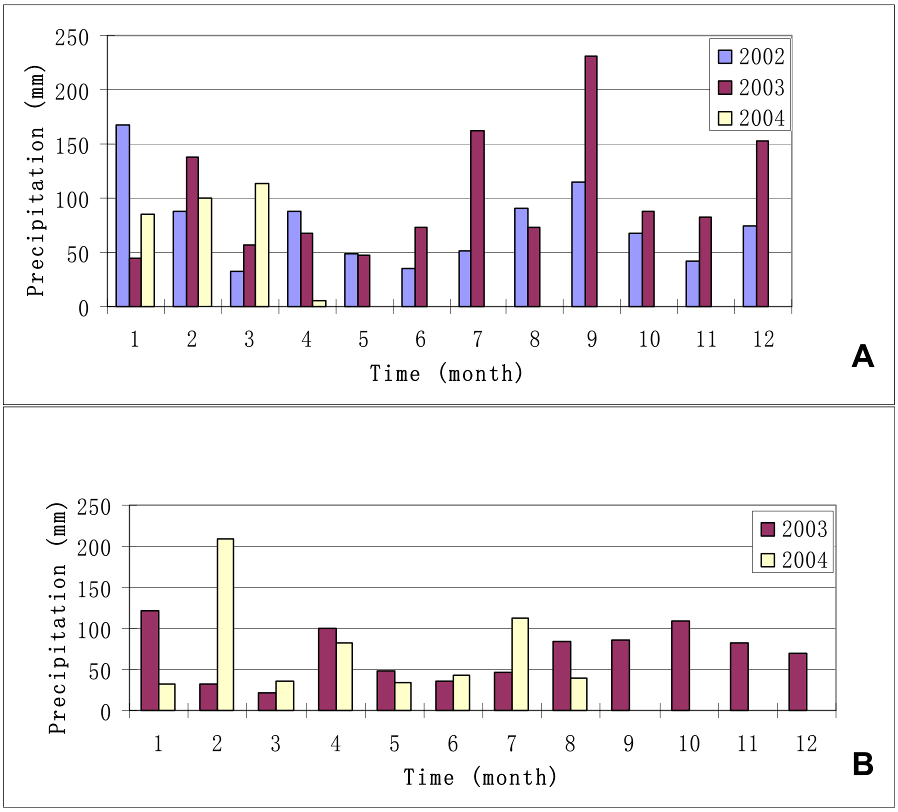

FIGURE 7: Monthly precipitation in a) Thúfuver; and b) Veidivatnahraun

Humidity in Iceland is generally high due to high precipitation. Humidity data for this area was collected in the period 1.1.2002 - 31.6.2004 at the Veidivatnahraun meteorological station. 100% humidity was recorded many times, the minimum in June 2004, about 45%. Monthly humidity at the Thúfuver and Veidivatnahraun stations for the monitoring periods is shown in Figure 8.

Wind conditions were measured in 2002-2004 at Thúfuver and Veidivatnahraun. Hourly wind direction and wind speed were noted to make a wind rose plot, and it is seen that the most common wind directions are northeasterly and southeasterly. Figures 9 and 10 show the yearly wind pattern at the stations nearest to the Hágöngur area.

3.3 Atmospheric conditions

There are no industrial or other air polluting activities in the Hágöngur area. Some gas emissions from geothermal manifestations occur when they show up from the Hágöngulón reservoir. In addition, a small amount of steam from the exploration well discharges into the atmosphere in order to keep the well warm.

3.4 Hydrology (Hjartarsson, 1994)

The mean precipitation in the Hágöngur area is around 1200 mm. Most of it falls as snow in the winter and runs off the area by ablation during winter and spring. Most of the summer precipitation seeps into the ground and maintains the groundwater. Surface runoff is scarce in the centre of the Hágöngur area. There are springs and spring fields in many places. Flow from springs is estimated 14-15 m^3/s. The temperature of the springs in the southern and eastern parts of the area is 2-4°C, which is normal. The temperature of springs in the northwestern part of the area is 5-10°C. Hydrological investigations reveal three defined groundwater flows in the mapped area:

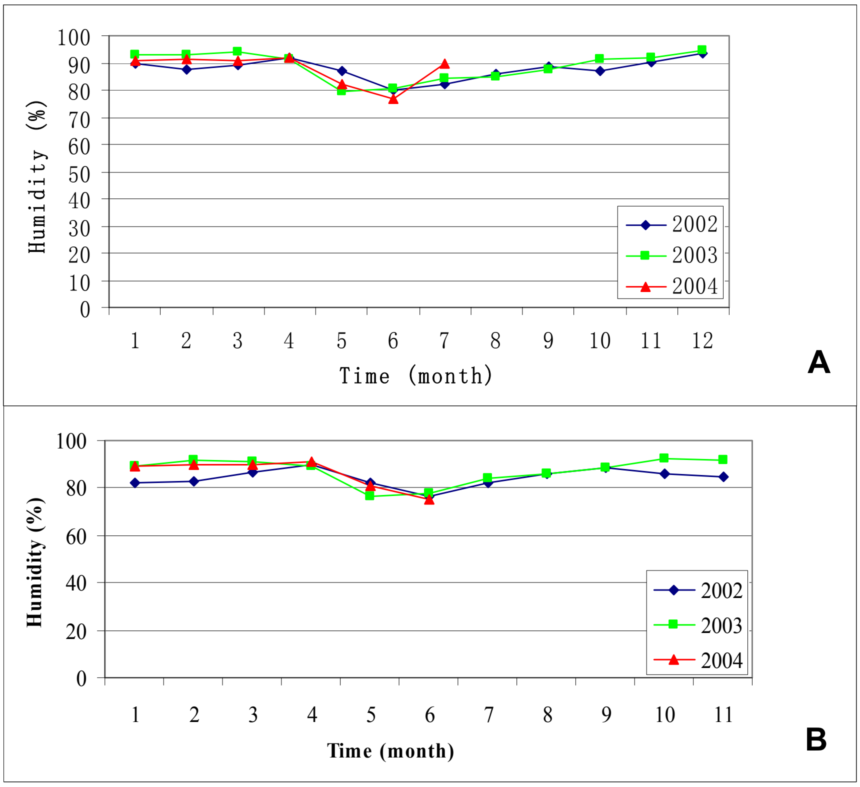

FIGURE 8: Monthly humidity in a) Thúfuver; and b) Veidivatnahraun

- First is the Tungnafell-flow along the swarm of fractures from Tungnafellsjökull with a flow of 10 m^3/s and temperature 5-10°C. The characteristics of the Tungnafell-flow indicate it is a confined aquifer, the water is under pressure, it is high in CO_2, SO_4, and Na amongst other components and there are calcite deposits in some springs.
- Second is the Hágöngur-flow, of 1-2 m^3/s and temperature 2-4°C, from Köldukvíslarbotnar through the acidic rocks of the Hágöngur area down to Lake Kvíslavatn. In the Hágöngur-flow, the K/Na ratio is unusually high. It is suggested that this is because the groundwater flows through acidic rocks like the rhyolites of the Hágöngur mountains, rhyolites having a higher K/Na ratio than the basaltic rocks in the area.
- Third is the Svedjuhraun-flow 1.5 m^3/s and 2-4°C that emerges from under the western edge of the lava-field.

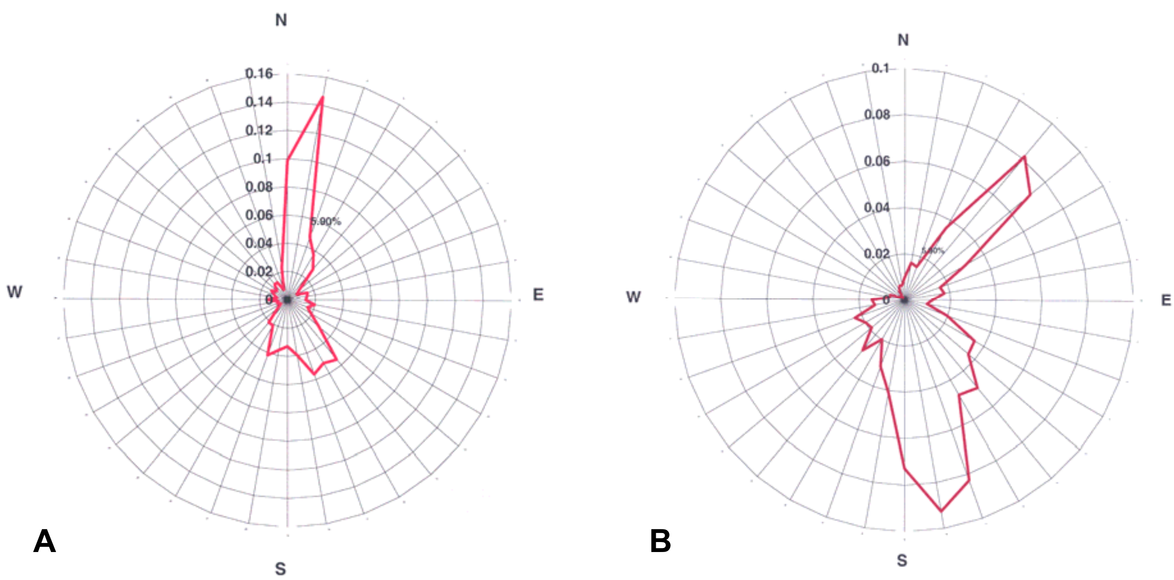

FIGURE 9: Frequency of wind directions in a) Thúfuver; and b) Veidivatnahraun,

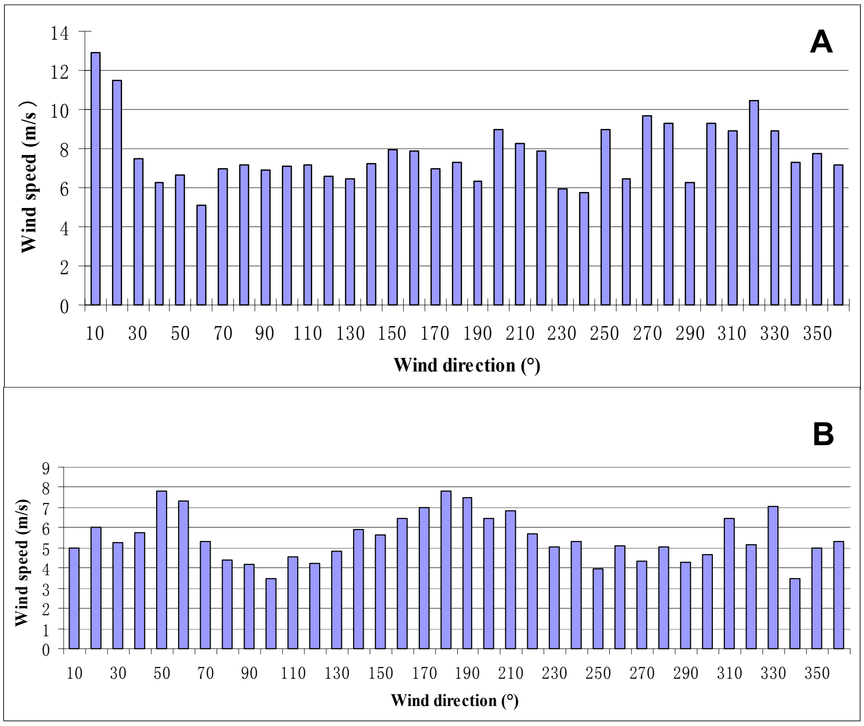

FIGURE 10: Wind speed according to wind direction in a) Thúfuver; and b) Veidivatnahraun

The temperature of the warm springs in the northwestern part of this area is unusually high. It is estimated that a flow of 126 MWt that amounts to 300 l/s of 100°C hot water, would be needed to heat up the 10 m^3/s of these 3°C "cold" springs to 5-10°C. Temperature measurements in springs and boreholes show that this "warm" water is found in an area extending from Tungnafellsjökull south to Thjórsárver east of the river Thjórsá. A number of fractures with a NE-SW direction run from Tungnafellsjökull through this same area, and probably play a role in the flow of this "warm" groundwater. This "warm" spring water also differs in chemical composition regarding Cl, Na, CO_2 and SO_4 concentration. Water samples were collected from both geothermal water and river water. The main chemical components are shown in Table 3.

3.5 Noise

The Hágöngur area is a remote area far from habitation. The natural background sound is low. The only possible noise source at present is the borehole discharge.

3.6 Vegetation (Magnússon and Elmarsdóttir, 1996)

Icelandic flora consists of 438 species. However, in the Hágöngur area, the flora is typical for poorly vegetated highland areas in Iceland and 52 plant species and 46 mosses have been registered. In Iceland continuous vegetation is seldom found above 650-700 m a.s.l. The Hágöngur reservoir area is about 800 m a.s.l. For comparison, 187 plants and 101 mosses were identified in another hydropower reservoir area 440-480 m a.s.l. by the river Blanda in the north highlands. In Þjórsárver an area about 600 m a.s.l. and west of Hágöngur, 170 plants and 197 mosses were registered. Of the plants registered in the Hágöngur area, most common are thrift (*Armeria maritima*), moss campion (*Silena acaulis*), curved sedge (*Carex maritima*), alpine hair-grass (*Deschampsia alpina*), alpine mouse-ear (*Cerastium alpinum*), tufted saxifrage (*Saxifraga caespitosa*), broadleaved willow (*Salix callicorpea*), least willow (*Salix herbecea*), alpine bistort (*Bistorta vivipara*), northern rock-cress (*Cardaminopsis petraea*), starry saxifrage (*Saxifraga stellaris*), creeping bentgrass (*Agrostis stolonifera*), alpine meadow-grass (*Poa alpina*) and purple saxifrage (*Saxifraga oppositifolia*). All the plants found in the area seem to have been discovered before in this part of the highlands and none of them are considered rare.

TABLE 3: Chemical samples from well HG-01 and the nearby water bodies

	Sample no.	2003-0697	2004-0005	2004-0277	3276	3283	3285	3286
	Location	HG-01	HG-01	HG-01	River Thjórsá	River Vonará	River Svedja	Spring Svedjuh. lind
Components	pH/(°C)	9.18/19.6	9.11/22.3	9.2/23.4	8.98/6.4	8.45/4.2	7.29/4.3	8.5/2.2
	CO_2 (mg/l)	70.9	65.9	72.8	23.4	31.3	16.3	19.4
	H_2S (mg/l)	21.1	19.6	19.8				
	B(mg/l)	3.2	3.48	3.24				
	Conductivity ((µs/cm)/°C)	1258/25	1325/25	1214/25				
	SIO_2 (mg/l)	569	626	655	15.4	14.89	7.82	13.18
	Total solids (mg/l)	1090	1310	1260				
	O_2 (mg/l)				9.23	9.49	9.52	9.89
	$\delta^{18}O$ (‰ SMOW)				-12.47	-12.21	-13.15	-12.9
	Na (mg/l)	210	228	232	10.08	9.53	3.47	5.53
	K (mg/l)	40	43.3	43.5	0.8	0.47	0.29	0.26
	Mg (mg/l)	0.003	0.002	0.003	0.438	2.572	1	1.928
	Ca (mg/l)	0.864	0.7	0.78	2.92	5.18	5.64	3.66
	F (mg/l)	2.74	2.72	2.81	0.129	0.104	0.053	0.132
	Cl (mg/l)	261	273	279	2.25	2.6	1.49	3.27
	SO_4 (mg/l)	10.9	11.1	11.1	2.21	4.78	9.2	3.13
	Al (mg/l)	0.908	0.97	1.024	0.103	0.039	0.249	0.036
	Mn (mg/l)	0.00082	0.0005	0.0008				
	Fe (mg/l)	0.0108	0.13	0.01	0.11	0.026	0.356	0.02
	δD (‰ SMOW)				-92.6	-90.3	-93.5	-93.2

The most common moss found in the Hágöngur area is *Racomitrium ericoides* typical for sandy areas. Other common mosses are *Philonotis fontana*, *Philonotis tomtella*, *Pholia wahlenbergii* and *Drepanocladus uncinatus*. These species grow in moist areas in depressions or by running water. The moss flora is typical for sandy areas, riverbanks and other poorly vegetated areas in the highlands. Some of the mosses hadn't been previously registered in the region, but they are not rare species.

Generally vegetation is scarce in the area with few species compared to other areas in the highlands of Iceland. This is probably due to high altitude, inclement weather conditions and volcanism. The Svedjuhraun lava is partly covered by sand with little vegetation except moss and scrubs by the fresh water springs at the west edge of the lava, but these are submerged by reservoir water most of the time. Twelve species of lichen were found on the edge of the lava field most of them of the genus *Peltigera* and *Stereocoaulon*.

3.7 Microbiology

Most of the geothermal surface manifestations have been submerged by the Hágöngulón reservoir. An investigation of the microbiology of the hot springs was carried out before the area was submerged. It showed that the area was not of special value in a microbiological respect (Pálsson et al., 2002).

3.8 Animal life

In general, there are few species in the area. Other areas in the highlands have more vegetation. The fauna is limited by the habitat and food supply and it is evident that few species can thrive in an area with so scarce vegetation (Pálsson et al., 2002). Fox faeces were identified in Svedjuhraun lava but no foxes (*Alopex lagopus*) were seen in the area.

Eight bird species were registered in the Hágöngur reservoir area and a total of 11 species were registered in surrounding areas. They include 7 individuals of snow bunting (*Plectrophenax nivalis*), 2 individuals of white wagtail (*Motacilla alba*) and 2 individuals of wheatear (*Oenanthe oenanthe)*. Individual birds of other species detected were purple sandpiper (*Calidris maritim*) and pink-footed goose (*Anser brachyrhynchus*), *Hitrionicus hitrionicus,* ptarmigan (*Lagopus mutus*), ringed plover (*Charadrius hiaticula*), meadow pipit (*Anthus pratensis*), lesser black-backed gull (*Larus fuscus*) and arctic skua (*Stercorarius parasiticus*) (Gíslason et al., 1996).

There are 307 individual species of insects and arachnids that have been captured in nets or picked from the surface in the Hágöngur area and 1400 arthropods have been captured in Barber traps in the reservoir area. In both cases, *Chironomidea diptera* were most frequent. Eighteen species of them have been registered. In the water five spawn of *Salmo trutta* were registered and athropods *Chironomidea diptera* were most common (Gíslason et al., 1996).

3.9 Natural conditions and protection

There are no nature reservation or monument areas in the general Hágöngulón reservoir area according to The Nature Conservation Register (Nature Conservation Council, 1996). Lava fields (the Svedjuhraun lava) and hot springs (a patch on the Svedjuhraun lava) are protected by Icelandic law on nature conservation. The Hágöngur area is just at the western edge of a large nature conservation strategy area. Future roads and power lines may cross the protected area.

4. PHYSICAL PLANNING (LAND USE)

The reservoir area, the Svedjuhraun lava field and a 2 km wide belt around the reservoir are defined as a construction zone in a regional plan for Central-Iceland. This plan also shows a construction zone around the main road and a proposed power line across the highlands. It also shows an access road to the Hágöngur reservoir. A geothermal power plant is not allowed for in the regional plan.

A geothermal power plant is allowed for in the Svedjuhraun lava in the local municipal plan of Ásahreppur (2002-2014). This area, the reservoir, and its surroundings are defined as an industrial area in the local plan. The proposed access road and power line to the development site are allowed for. They run through a wilderness area, a local conservation provision and an industrial area (Pálsson et al., 2002).

5. ENVIRONMENTAL IMPACT OF GEOTHERMAL POWER UTILIZATION

Geothermal power plants do have some environmental impacts. However, these impacts should be balanced against geothermal energy's advantages over conventional power sources when conducting assessments of a power plant project's environmental impacts. The primary impacts of geothermal plant construction and energy production are gaseous emissions, land requirement, noise, visual impact and potential ground subsidence, see also Appendix I.

5.1 Gaseous emissions

Geothermal fluids contain dissolved gases, mainly carbon dioxide (CO_2) and hydrogen sulphide (H_2S), small amounts of ammonia, hydrogen, nitrogen, methane and radon, and minor quantities of volatile species of boron, arsenic, and mercury. Geothermal power provides significant environmental advantages over fossil fuel power sources in terms of air emissions because geothermal energy production releases no nitrogen oxides (NOx), no sulphur dioxide (SO_2), and much less carbon CO_2 than fossil-fuelled power. The reduction in nitrogen and sulphur emissions reduces local and regional impacts of acid rain, and reduction in carbon-dioxide emissions reduces contributions to potential global climate change. Geothermal power plant CO_2 emissions can vary from plant to plant depending on both the characteristics of the reservoir fluid and the type of power generation plant. Binary plants have no CO_2 emissions, while dry steam and flash steam plants have CO_2 emissions on the order of 0.1 kg/kWh, less than one tenth of the CO_2 emissions of coal-fired generation (see Table 4). According to the Geothermal Energy Association, improved and increased injection to sustain geothermal reservoirs has helped reduce CO_2 emissions from geothermal power plants (Shibaki and Beck, 2003).

TABLE 4: Comparison of CO_2 emissions by power source

Power source	**CO_2 emissions (kg/kWh)**
Geothermal	0.09
Natural Gas	0.60
Petroleum	0.89
Coal	0.95

Hydrogen sulphide (H_2S) emissions do not contribute to acid rain or global climate change but do create a sulphur smell that some people find objectionable. The range of H_2S emissions from geothermal plants is 0.03–6.4 g/kWh. Hydrogen sulphide emissions can vary significantly from field to field, depending on the amount of hydrogen sulphide contained in the geothermal fluid and the type of plant used to exploit the reservoir. The removal of H_2S from geothermal steam is mandatory in the United States. The most common process is the Stretford process, which produces pure sulphur and is capable of reducing H_2S emissions by more than 90%. More recently developed techniques include burning the hydrogen sulphide to produce sulphur dioxide, which can be dissolved, converted to sulphuric acid and sold for income.

5.2 Landscape impacts and land use

Geothermal power plants require relatively little land. Geothermal installations do not require damming of rivers or harvesting of forests, and there are no mineshafts, tunnels, open pits, waste heaps or oil spills. An entire geothermal field uses only 0.5-3 ha. per MW versus 2-4 ha. per MW for nuclear plants and 8 ha. per MW for coal plants (Shibaki and Beck, 2003).

Geothermal plants can be sited in farmland and forests and can share land with cattle and local wildlife. For example, the Hell's Gate National Park in Kenya was established around an existing 45-MWe geothermal power station, Olkaria I. Land uses in the park include livestock grazing, growing of foodstuffs and flowers, and conservation of wildlife and birds within the Park. After extensive environmental impact analysis, a second geothermal plant, Olkaria II, was approved for installation in the park in 1994 and is already producing. A third power station, Olkaria III is now under construction.

Geothermal plants are also benign with respect to water pollution. Production and injection wells are lined with steel casing and cement to isolate fluids from the environment. Spent thermal waters are injected back into the reservoirs from which the fluids were derived. This practice neatly solves the water-disposal problem while helping to bolster reservoir pressure and prolong the resource's productive existence.

5.3 Noise

Noise occurs during exploration drilling and construction phases. Noise levels from these operations can range from 45 to 120 dB(A). For comparison, noise levels in quiet suburban residences are on the order of 50 dB(A), noise levels in noisy urban environments are typically 60–70 dB(A), and the threshold of pain is 120 dB(A) at 2,000–4,000 Hz. Site workers can be protected by wearing ear mufflers. With best practices, noise levels can be kept to below 65 dB(A), and construction noise should be practically indistinguishable from other background noises at distances of one kilometre (Shibaki and Beck, 2003).

5.4 Ground subsidence

In the early stages of geothermal development, geothermal fluids were withdrawn from a reservoir at a rate greater than the natural inflow into the reservoir. This net outflow caused rock formations at the site to compact, particularly in the case of clays and sediments, leading to ground subsidence at the surface. Key factors causing subsidence include (Shibaki and Beck, 2003):

- A pressure drop in the reservoir as a result of fluid withdrawal. The level of subsidence in water-dominated areas is much higher than in vapour-dominated areas because the total mass withdrawal is much larger;
- The presence of a highly compressible geological rock formation above or in the upper part of a shallow reservoir;
- The presence of high-permeability paths between the reservoir and the formation, and between the reservoir and the ground surface.

If all of these conditions are present, ground subsidence is likely to occur. In general, subsidence is greater in liquid-dominated fields because of the geological characteristics typically associated with each type of field. Ground subsidence can affect the stability of pipelines, drains, and well casings. It can also cause the formation of ponds and cracks in the ground and, if the site is close to a populated area, it can lead to instability of buildings. The largest recorded subsidence in a geothermal field is at Wairakei in New Zealand. Here the ground subsided as much as 13 metres. Monitoring has shown that a maximum subsidence rate of 45 cm/year occurred in a small region, outside the production area, with subsidence of at least 2 cm/year occurring all over the production field. Effects of the subsidence in the Wairakei region included:

- The creation of a pond about 1 km in length and 6 m in depth in what was originally a fast-flowing stream;
- Cracking of both a nearby highway and the main wastewater drain on the site;
- Compressive buckling and tensile fracturing of steam pipelines;
- Fissures in surroundings fields.

Although Wairakei presents an extreme example, little is currently known about how to prevent or mitigate subsidence effects. The only action is to try to maintain pressure in the reservoir. Fluid re-injection can help to reduce pressure drop and hence subsidence, but its effectiveness depends on where the fluid is re-injected and the permeability conditions in the field. Typically, re-injection is done at some distance from the production well to avoid the cooler rejected waste fluid from lowering the temperature of the production fluid. Re-injection may not prevent subsidence (Shibaki and Beck, 2003).

6. THE HISTORY OF ENVIRONMENTAL IMPACT ASSESSMENT IN ICELAND

A formal EIA system was introduced in Iceland by the Act on Environmental Impact Assessment from 1993. This Act was reviewed in 1997 in order to draft a new EIA Bill. The existing system uses screening lists similar to the EC Directive 85/337/EEC. There is also provision for ministerial discretion over other projects. Public participation is advised after the documentation is submitted. The Planning and Building Act, 1997, has provisions for assessing land-use plans and individual policies and projects within the plans. The National Planning Agency, under the Ministry of the Environment, enforces the Act. The process is mandatory and the proponent is responsible for the preparation of the EIA study. A new Act on EIA no. 106/2000 came into effect in Iceland in 2000, replacing Act no. 63/1993. The following sections summarize regulations and legislation on EIA and their use in Iceland, and are taken from a paper by Andrésdóttir et al. (2003).

6.1 Environmental regulations and Environmental Impact Assessment (Andrésdóttir et al., 2003)

The planning of a geothermal power plant can be subject to a wide range of legislation. In some cases, this can lead to a complicated and long-term process of permit applications, environmental studies and development planning before consent for the project is granted. In Iceland Environmental Impact Assessment (EIA) has been carried out for the drilling of exploration wells, geothermal power plants, and extensions of such projects. Official handling of permit applications, environmental assessment plans and EIA of comparable geothermal projects can vary greatly and obtaining consent for similar geothermal projects has been known to take anywhere from a few months to a couple of years.

6.2 Icelandic legislation (Andrésdóttir et al., 2003)

The following is a list of Icelandic laws that primarily concern geothermal project development in Iceland:

- Act on Research and Use of Underground Resources No. 57/1998: According to this act the developer must apply for an exploration permit before starting further research and drilling of exploration wells. The developer must apply for a utilisation permit before starting construction of a power plant. Developers earn priority to utilization permits by obtaining exploration permits in geothermal areas.
- Energy Act No. 65/2003: Developers planning to exploit geothermal resources for producing more than 1 MW electric power must apply for operation permits according to this act.
- Environmental Impact Assessment Act No. 106/2000: According to this act, projects that may have significant effects on the environment are subject to EIA. Developers are responsible for the EIA and bear the cost. The Planning Agency delivers a ruling on the EIA and decides whether a project can be accepted or is opposed.
- Planning and Building Act No. 73/1997: According to this act, to obtain development permits substantial development projects shall be in accordance with development plans and decisions on Environmental Impact Assessment.
- Nature Conservation Act No. 44/1999: Certain types of landscape and habitats enjoy special protection according to this act. Amongst these are hot springs and other thermal sources, surface geothermal deposits, volcanic craters and lava fields – all of which are frequent features in high-temperature geothermal areas.

7. THE GEOTHERMAL POWER PLANT

In recent years, there has been a growing interest in Iceland in the exploration and utilization of high-temperature geothermal energy as a clean and renewable energy source. The national policy is to increase the use of domestic energy sources, in real terms and in proportion to imported fossil fuel and by the year 2000, the proportion of renewable energy had reached 70% of Iceland's total energy budget. In 2003, electricity production in Iceland from geothermal energy amounted to around 17% of the total production. Current utilization of geothermal energy for heating and other direct uses is considered to be only a small fraction of what this resource can provide.

Typical modern geothermal power plants are essentially composed of two major structures: (1) production wells with a steam gathering and separating system and a waste fluid disposal system, (2) a power house with turbines and generators and cooling system. Older power plants did not have injection wells and a waste fluid piping system. Various methods have been employed to dispose of the waste fluid from such plants, such as infiltration (Krafla, Iceland), evaporation (Cerro Prieto, Mexico), discharge into nearby rivers (Wairakei, New Zealand). In a conventional power plant about 2/3 of the steam is condensed in the cooling towers and about 1/3 escapes into the atmosphere. Other escape routes for steam and gas are: (1) drains and pots, (2) gas ejectors and (3) silencers. Further steam and gas may escape into the atmosphere from wells undergoing tests, from wild bores and in solution in surplus condensate from cooling system (Hietter, 1995).

The Hágöngur geothermal power-generating project is planned for approximately 16 or 24 production wells with a capacity of 80 MWe on the Svedjuhraun lava field and a possible expansion to 120 MWe at a later stage. Two to three developing stages are needed depending on the final capacity. Each stage involves a 40 MWe capacity. The potential design of well pads is up to five wells per pad and approximately five well pads are needed for 120 MWe. The wells will be 2000-2500 m deep, some vertical and some directional. Three possible ways of wastewater disposal should be considered. One injection well will probably be needed for every 3-5 production wells. The development and utilization of a geothermal power project involves three phases (1) the drilling, (2) construction and (3) operation phase.

8. ENVIRONMENTAL IMPACT ASSESSMENT

Geothermal power development, though dubbed a “clean energy” source, still has some negative impacts associated with its development, although most of them can be mitigated. Most of the environmental impacts associated with geothermal development are associated with high-temperature geothermal systems. While some impacts can be mitigated successfully, others may not, and may be permanent. The checklist (Brown, 1995) is given in Appendix II.

8.1 Land requirements

Land is required for drill pads, access roads, steam pipes, power plant and power lines. Estimation of land required for geothermal development is an important task in EIA. For a 120 MW_e power plant at Hágöngur at least 4-5 drill pads are expected with 5-6 vertical and directional wells at each site. Typically, each drill pad is on average about 3500 m^2 in Iceland. And in this project 10.000-15.000 m^2 of land is needed for the drill pad construction at each site. The construction of drill pads, pipelines, roads, buildings and power transmission lines will in all affect approx. 600,000 m^2 of land (VGK Engineering, 2003).

The landscape in these areas will become compacted and changed, and close to the drill site there will be some deposition of waste soils. Surface discharge of wastewater should be carried out in such a way that it is not discharged directly to steep areas but sumps should be made to contain this waste water, as failure to do this can cause serious erosion.

During operation, subsidence and induced seismicity are possible effects on the land of the power plant and surrounding areas. A monitoring program for subsidence in this area is recommended.

The non-vegetated lava is a fairly unique natural phenomenon, which can easily be destroyed by any construction activities.

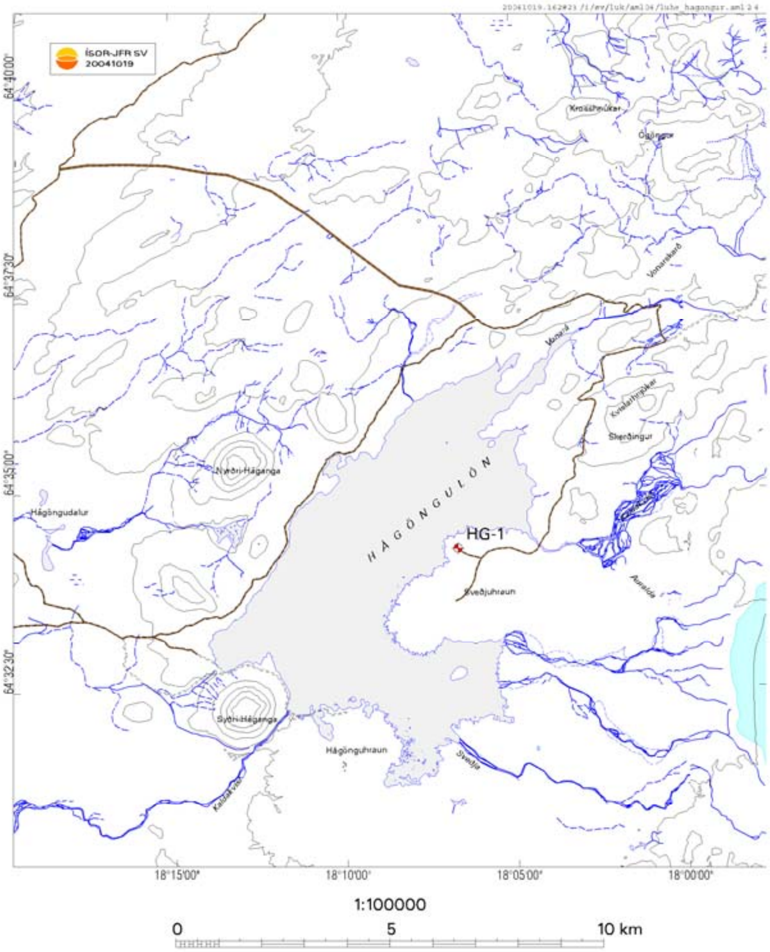

FIGURE 11: Possible routes for access roads

Two possible sites for an access road to the construction site are shown in Figure 11, the first one is the existing dirt mountain track from the Sprengisandur highland route, and goes northeast around the reservoir. This road seems too long for the power line connection. The second one is a new route directly east from the Sprengisandur highland route. The road according to this plan will be about 15 km long and may have a mild effect on landscape. The planned power line could follow the same route which is the shortest distance connecting it to the proposed power line across the central highlands.

8.2 Energy resources

Based on the estimated size of the Hágöngur high-temperature area and utilization in other high-temperature areas in Iceland, it has been estimated that the Hágöngur area can sustain 250-400 MWe electric power production for 50 years. An 80-120 MWe geothermal project is therefore not expected to have a significant effect on the geothermal reservoir.

8.3 Atmospheric air

In high-temperature geothermal fields, power generation using a standard steam-cycle plant may result in the release of non-condensable gases (NCG) and fine solid particles (particulates) into the atmosphere (Webster, 1995). During the drilling phase, air pollution can result from non-condensable gas emissions, exhaust gas from the power generators, compressors, and vehicles.

Hydrogen sulphide will be released to the atmosphere during power plant operation. As regards H_2S concentration in steam samples from the area it is similar to the concentration of H_2S in steam flow in other geothermal fields in Iceland. Thus, the H_2S concentration in the atmosphere in this field is likely to be acceptable as in the other fields. The "greenhouse gases" consist mainly of carbon dioxide (CO_2) and some methane (CH_4). But a prediction of the amount of carbon dioxide released to the atmosphere per kilowatt of electricity shows it as approximately 20 times smaller than the amount of "greenhouse gases" released from a fossil-fuel power plant for an equivalent amount of electricity. The concentration of other gases in the steam from this field is very low.

Objectionable H_2S odours may be detected, as this gas produces an unpleasant odor. Eye irritation and respiratory damage are not likely to be of any significance as the Hágöngur area is not inhabited, with spare vegetation distribution and little tourism. During the operation phase no significant impacts on air quality are expected. Long term monitoring of H_2S, SO_2 and possibly heavy metals such as mercury in atmospheric air should be implemented.

Fugitive dust will be generated from travel on dirt roads, earth moving activities during construction and decommissioning activities, especially in dry and windy weather. Small quantities of critical air pollutants will be released from mobile construction equipment and other vehicles, but this impact will be below the level of significance.

8.4 Water

In most cases and unless the hot water is used in a cascaded manner, the wastewater after electricity generation has temperatures that are above 100°C. This, in addition to the chemical components of the water, may have detrimental impacts on the flora and fauna of the area if released on the surface. In some cases, waste fluid is disposed of into a surface stream, which forms ponds and disappears underground to emerge into groundwater through fractures, which according to some studies may affect a neighbouring water body (Ármannsson and Kristmannsdóttir, 1992).

The water from the geothermal power plant constitutes three parts, (1) the cooling water, (2) the water from condenser and (3) the brine from the separator. The cooling water is water drawn from fresh water wells, and is used for cooling. It is warm but low in chemicals. Usually it causes thermal pollution without proper treatment (Webster, 1995). However, as in this case there is a large hydropower reservoir in the area and very low wild life density. It is possibly better to discharge the cooling water directly into the cold water of the Hágöngulón reservoir, where there is low risk of thermal pollution. It is important to compare different methods of discharge and assess their impact.

The concentration of chemical components in the water from the separator is high. One way of disposing of the brine is to mix it with the water from the condenser and discharge the mixture into the lava field to make a "blue lagoon". Letting the water filter through the lava into the groundwater has a potential for polluting the shallow aquifer both thermally and chemically. In addition, there is a possibility of directly discharging the brine into the Hágöngulón reservoir. The brine water would be diluted quickly by the large amount of water in the Hágöngulón reservoir. For reasons of environmental impact, it is best if all the brine is re-injected. It is a possible alternative, but drilling and operation costs are high. Re-injection requires one re-injection well for every three to five production wells. It is suggested that re-injection at three different depths, shallow, deep and very deep, should be compared and the impact assessed (see also Table 5).

8.5 Noise

Noise is one of the main environmental interferents in the whole process of geothermal power development. Drilling noise has been found to rarely exceed 90 dB except for the air drilling technique. The loudest noise has been measured from discharging wells without silencers during flow tests when it sometimes exceeds 120 dB(A). However, silencers can bring down the noise levels to about 85 dB(A) which is an acceptable level. It is claimed that with modern designs this noise level can be brought below 70 dB(A). Construction also causes different levels of noise, and fortunately this noise occurs only for a period of time. Another noise source is the pump house of the power

TABLE 5: Comparison of advantages and weaknesses of injection at different depths

	Injection		
Depth	Shallow	Deep	Very deep
	Above 400 m	400-800 m	800-2000 m
Advantage	Low cost, reduces possible impact on surface waters	Decreased risk of chemical and thermal pollution of ground water	Decreased effect on groundwater, sustainable utilization of geothermal system
Weakness	Risk of chemical and thermal pollution of ground water aquifer	More expensive, risk of scaling problems	High cost, possible scaling, cooling of geothermal system

station. This noise can be controlled using proper sound insulation. Those working within or near noise sources are required to put on proper ear safety gear and shorten continuous working periods. The Hágöngur area is a remote area and far from habitations. The natural background noise is low. The noise may drive away wild animals such as birds. There is a possibility that some tourists may be attracted to this place to experience the sound of the well discharge and others may be affected by the loud noise in such an otherwise very quiet area. None of these possible impacts will be significant.

8.6 Vegetation

Generally vegetation is scarce in this area with few species compared to other areas in the highlands of Iceland. This is probably due to high altitude, inclement weather conditions and volcanism. The Svedjuhraun lava is partly covered by sand with little vegetation except moss and scrubs by the fresh water springs at the west edge of the lava, but these are submerged by reservoir water most of the time. Twelve species of lichen were found on the edge of the lavafield. All are common and fairly typical for this region. Geothermal utilization in the Hágöngur area will have little effect on vegetation.

8.7 Animal life

Only fox traces, 11 bird species and 18 species of common insects and arachnids have been registered in this area. In the waters five spawn of *Salmo trutta* in the water have been registered, and of arthropods *Chironomidae diptera* were most common. The effect of noise from drilling, well testing and road construction may drive the animals away. In this area there are few birds so this impact will not be significant. The most important effect of geothermal power plant operation on the environment is air pollution. Care should be taken that the concentration of pollutant gases such as H_2S is kept at a safe level. The sensibility threshold of animals to gas odours is the same as for humans. Up to now, no air pollution damage has been reported from Icelandic geothermal operations, so significant air pollution is not considered likely in this field.

8.8 Visual impact

The visual impacts in Hágöngur area will be very noticeable due to the nature of the landscape. The poor vegetation provides no cover for the pipeline system. Painting pipes to closely blend in with the blackish surrounding lavas is one way of mitigating the negative visual impacts. Another way of mitigating the visual impact is using curved or broken line roads. Other visual impacts are due to the roads, the power lines, power plant buildings and emission of steam. It is recommended that a detailed visual impact assessment be carried out after the decision to build a power plant has been made.

8.9 Tourism

The Hágöngur area has not been a popular tourist attraction. It is a remote, uninhabited wilderness area with a typical highland landscape. The area is not easily accessible especially not in the wintertime. After the road to the area was improved and a new road to the exploratory drill site was built, more people have visited this area. The Hágöngulón reservoir and further development in the area might bring in an increased number of tourists. There are some potential tourist attractions inherent in developing a geothermal power project in the Hágöngur area, such as the power plant itself and improved access to the area.

9. CONCLUSIONS AND RECOMMENDATIONS

1. The environmental impact of the Hágöngur geothermal power project does not seem significant. The environment of this area is very desolated with sparse vegetation, few wild animals and is situated far from habitation. With proper mitigation introduced, most of the environmental impact can be reduced.
2. Discharge of warm cooling water directly into the Hágöngulón reservoir is a good method of disposal. It can help melt snow and ice during the wintertime. For financial reasons, surface discharge of brine from the power plant is proposed for the first stage rather than re-injection.
3. A shorter route than the existing mountain track to the development site is needed for a road and power line to save money and to reduce disturbance to the environment. As no nature reservation area will be affected, the best route for the access road can be planned over the shortest possible distance. The power line could follow the same route.
4. The development of the geothermal power project may bring more tourism and visitors.
5. If the decision is made to build a geothermal power plant in the Hágöngur area, it is recommended that main features of a complete EIA include studies of the visual impact of construction, disposal of cooling water and brine, the influence on tourism and the monitoring of water quality in the Hágöngulón reservoir area.

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APPENDIX I: Geothermal utilization that may concern the environment

The drilling phase	The construction of roads Transportation of drill rigs, all necessary equipment and material Drilling and testing of wells Shallow fresh wells for drilling Installation of well head silencers and borehole housings to be installed at each well Excavation of material for constructing drill pads and roads Increased traffic
The construction phase	The construction of powerhouse and living house Overhead power lines for connection to the power transmission system Installation of turbines Steam transmission pipes from wells to separator stations Steam separator station Pipes for transporting steam and water from the steam separator station to the power house Control pressure stations and 2-3 steam exhaust stacks Fresh groundwater supply system with wells and a water pipe from there to water tanks. Water tanks for collecting cooling water Waste discharge system (water and solid) Discharge transmission pipes from the power plant to discharge system for discharge of effluent water, condensate water and cooling water. Camps for workers during construction Increased traffic
Operation phase	Water supply for cooling water Disposal of warm cooling water Solid wastes Fluid withdrawal and mass removal from the geothermal reservoir Waste liquid disposal Emission of steam Emission of non-condensable gases Increased traffic

Appendix II: Environmental Impact Checklist for geothermal utilization in the Hágöngur area

Subjects	*Drilling*			*Construction*			*Operation*		
	Yes	Maybe	No	Yes	Maybe	No	Yes	Maybe	No
1. Earth. Will the proposal result in:									
a. Unstable earth conditions or in changes in geologic substructures?		√		√				√	
b. Disruptions, displacements, compaction or over covering of the soil?	√			√					√
c. Change in topography or ground surface relief features?		√			√			√	
d. The destruction, covering or modification of any unique geologic or physical features?		√			√			√	
e. Any increase in wind or water erosion of soils, either on or off the site?		√			√				√
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, in let or lake?			√			√			√
g. Exposure of people or property to geologic hazards such as earthquakes, landslides, mudslides, ground failure, or similar hazards?			√			√			√
2. Air. Will the proposal result in:									
a. Substantial air emissions or deterioration of ambient air quality?		√			√			√	
b. The creation of objectionable odours?	√				√		√		
c. Alteration of air movement, moisture, or temperature, or any change in climate, either locally or regionally?		√				√		√	
3. Water. Will the proposal result in:									
a. Changes in currents, or the course of direction of water movements, in either marine or fresh waters?			√			√			√
b. Changes in absorption rates, drainage patterns, or the rate and amount of surface runoff?		√			√			√	
c. Alteration to the course or flow of flood waters?			√			√			√
d. Change in the amount of surface water in any water body?	√				√		√		
e. Discharge into surface waters, or in any alteration of surface water quality, Including but not limited to temperature, dissolved oxygen or turbidity?	√					√		√	
f. Alteration of the direction or rate of flow of ground waters?		√				√		√	
g. Changes in the quantity of ground waters, either through direct additions or withdrawals, or through interception of an aquifer by cuts or excavations?		√			√		√		
h. Substantial reduction in the amount of water otherwise available for public water supplies?			√			√			√
i. Exposure of people or property to water related hazards such as flooding or tidal waves?			√			√			√

4. Plant Life. Will the proposal result in:									
a. Changes in the diversity of species, or number of any species of plants (including trees, shrubs, grass, crops, and aquatic plants)?			√			√		√	
b. Reduction of the numbers of any unique, rare or endangered species of plants?			√			√			√
c. Introduction of new species of plants into an area, or in a barrier to the normal replenishment of existing species?			√			√		√	
d. Reduction in acreage of any agricultural crop?			√			√			√
5. Animal life. Will the proposal result in:									
a. Change in the diversity of species, or number of any species of animals (birds, land animals, such as reptiles, fish and shellfish, benthic organism or insects)?			√			√			√
b. Reduction of the numbers of any unique, rare or endangered species of animals			√			√			√
c. Introduction of new species of animals into an area, or in a barrier to the mitigation or movement of animals?			√			√		√	
d. Deterioration to existing fish or wildlife habitat?			√			√		√	
6. Noise. Will the proposal result in:									
a. Increases in existing noise levels?	√			√			√		
b. Exposure of people to severe noise levels?			√			√			√
7. Light and glare. Will the proposal produce new light or glare?	√			√			√		
8. Land use. Will the proposal result in a substantial alteration of the present or planned land use of an area?									
Present:			√			√		√	
Planned:			√			√			√
9. Natural resources. Will the proposal result in:									
a. Increases in rate of use of any natural resources?		√			√		√		
b. Substantial depletion of any non-renewable natural resources?			√			√			√
10. Risk of upset. Will the proposal involve:									
a. A risk of an explosion or the release of hazardous substance (including, but not limited to, oil accident, chemical or radiation in the event of an accident or upset conditions)?			√			√			√
b. Possible interference with an emergency response plan or emergency evacuation plan			√			√			√
11. Population. Will the proposal alter the location, distribution, density, or growth rate of the human population of an area?		√			√			√	
12. Housing. Will the proposal affect existing housing, or create a demand for additional housing?		√		√			√		

13. Transportation/circulation. Will the proposal result in:									
a. Generation of substantial additional vehicular movement?		√		√				√	
b. Effects on existing parking facilities, or demand for new parking?			√		√			√	
c. Substantial impact upon existing transportation systems?			√		√			√	
d. Alteration to present patterns of circulation or movement of people and/or goods?			√			√		√	
e. Alteration to waterborne, rail or air traffic			√			√			√
f. Increase in traffic hazards to motor vehicle, bicyclists or pedestrians?			√		√				√
14. Public services. Will the proposal have an effect upon, or result in any of the following areas:									
a. Fire protection?			√			√			√
b. Police protection?			√			√			√
c. Schools?			√			√			√
d. Parks or other recreational facilities?			√			√			√
e. Maintenance of public facilities, including roads?	√			√			√		
f. Other governmental services?			√			√		√	
15. Energy. Will the proposal result in:									
a. Use of substantial amounts of fuel or energy?			√		√		√		
b. Substantially increased demand upon existing sources of energy, or require the development of new sources of energy?			√			√			√
16. Utilities. Will the proposal result in a need for new systems, or substantial alterations to the following utilities:									
a. Power or natural gas?			√		√		√		
b. Communications systems?		√			√		√		
c. Water?	√			√			√		
d. Sewer or septic tanks?		√			√		√		
e. Solid waste and disposal?	√			√			√		
17. Human health. Will the proposal result in:									
a. Creation of any health hazard or potential health hazard (excluding mental health)		√			√			√	
b. Exposure of people to potential health hazards?		√			√			√	
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 public view?		√		√			√		
19. Recreation. Will the proposal result in an impact upon the quality or quantity recreational opportunities?	√			√			√		

20. Cultural resources.									
a. Will the proposal results in the alteration of or the destruction of a prehistoric or historic archaeological site?			√			√			√
b. Will the proposal result in adverse physical or aesthetic effects to a prehistoric, or historic building structure, or object?			√			√			√
c. Does the proposal have the potential to cause a physical change, which would affect unique ethnic cultural values?			√			√			√
d. Will the proposal restrict existing religious or sacred use within the potential impact area?			√			√			√
21. Mandatory finding of significance.									
a. Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a 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 rate or endangered plant or animal or eliminate important examples of the major periods of history or prehistory?			√			√			√
b. Does the project have the potential to achieve short-term, to the disadvantage of long-term, environmental goals? (A short-term impact on the environment is one, which occurs in a relatively brief, definitive period of time while long-term impacts will endure well into the future.)			√			√			√
c. Does the project have impacts, which are individually limited, but cumulatively considerable? (A project may impact on each resource is relatively small, but where the effect of the total of those impacts on the environmental effect of the total of those impacts on the environment is significant.)			√			√			√
d. Does the project have environmental effects, which will cause substantial adverse effects on human beings, either directly or indirectly?			√			√			√