The United Nations University

GEOTHERMAL TRAINING PROGRAMME
Orkustofnun, Grensásvegur 9,
IS-108 Reykjavík, Iceland

IGC2003 - Short Course
September 2003

Environmental monitoring

Einar Gunnlaugsson

Orkuveita Reykjavikur, Bæjarháls 1, IS-110 Reykjavik, Iceland

Abstract

Although geothermal energy is a clean and sustainable energy source, its development has some impact on the environment. The main effects are related to surface disturbances, physical effects due to fluid withdrawal, noise, thermal effects and discharge of chemicals.

1 Introduction

For thousands of years, mankind has been an integral part of the environment, and has had similar impact as other animal species. By increasing technology, especially during the last century, this has changed.

Although geothermal energy is generally accepted as being an environmentally benign energy source, especially when compared to fossil fuel energy sources, all geothermal development has some impact on the environment. It is minimal during the early exploration phase before drilling, but when drilling commences there are often more serious impacts on the physical environment. The effects on the reservoir during development and production have specific impacts on the environment, which often result in a decline of natural features. But other changes also occur during development and production such as subsidence, thermal pollution, seismicity, the possibility of hydrothermal eruptions, chemical impact from discharges, and noise from the operational phase. These can also affect vegetation and animal life, and all this needs to be considered and monitored.

The importance of collecting baseline data for all environments likely to be affected by geothermal development cannot be overemphasized. The objective of baseline data collection is to outline the existing environment, and to understand the changes that may occur as a result of development. Good baseline data may also provide information for protection against false accusations of environmental damages. Sufficient samples have to be collected and analysed to ensure that results are representative of the whole field, and of seasonal variations. The baseline data may include data collection from seismicity, subsidence, hydrology, geothermal resources, vegetation, wildlife, air quality and noise.

In this lecture, the environmental effects of geothermal utilization will be discussed and examples shown.

2 Benefits of geothermal development

Although this lecture is dealing with environmental effects of geothermal utilization, it should be kept in mind that this energy source is one of the cleanest energy sources available and also has potential economic benefits. Geothermal energy is, in all cases, domestic energy and is used locally. This reduces, in many cases, import of other energy sources such as fossil fuels, and is therefore of economic benefit to the community. The amounts of greenhouse gas emissions from geothermal energy are also lower than most other types of electricity generation methods. Emissions from geothermal utilization are not an addition on a long time-scale, since this is a natural emission emitting from the geothermal fields anyway.

3 Environmental impacts

The impacts of utilization of geothermal energy are mainly associated with the exploitation of high-temperature geothermal systems. The main environmental concerns associated with geothermal development are:

- Surface disturbance
- Effects of mass withdrawal
  - Changes in surface manifestations
  - Subsidence
  - Induced seismicity
- Disposal of fluid
  - Gas
  - Water
- Thermal effects
- Noise
- Biological effects

3.1 Surface disturbance

The construction of roads in geothermal fields to drilling sites may involve destruction of vegetation, forests and untouched lava fields. The area of activity is relatively small. A drill site is usually 200-2,500 m^2, and directional drilling where more than one well is drilled from the same site reduces the overall impact. The energy is usually utilized near the drill site, reducing length of pipelines.

3.2 Effects of mass withdrawal

3.2.1 Changes in surface manifestations

Natural surface features such as hot springs, mud pools, geysers, fumaroles and steaming ground are associated with most geothermal systems. Geothermal development that draws from the same reservoir has the potential to affect these features.

At the low-temperature geothermal fields utilized for the district heating in Reykjavik, geothermal activity has disappeared both in Reykjavik (Laugarnes area) and at Reykir. The name of the capital Reykjavik is derived from steam emitting from hot springs, which now have disappeared. At the Reykir field, natural flow was around 200 l/s before utilization of deep well pumps started. All thermal manifestations have disappeared.

In water-dominated, high-temperature geothermal systems, features that rely on the flow of deep geothermal water have shown a tendency to decline with exploitation of the deep reservoir. These fields are often recognised by the presence of silica sinter and a significant chloride content. An example of this is at Wairakei, New Zealand, where the water level dropped by 200 m during initial exploitation, and geysers and chloride springs within the thermal area have disappeared. Monitoring of the chemistry during the early exploitation showed that the chloride content of the springs dropped almost immediately during the test discharge period due to mixing of near surface groundwater containing low chloride content (Figure 1).

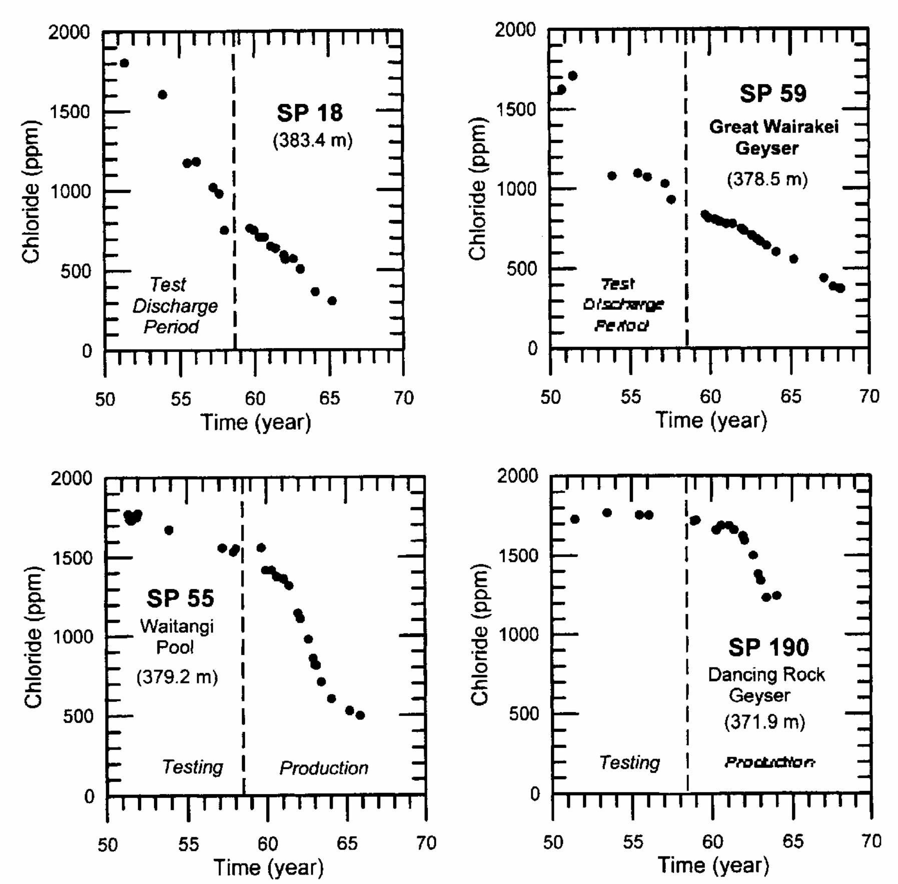

Figure 1: Changes with time in chloride content of water in thermal features at Wairakei geothermal field, as a result of development (Hunt, 2001).

In water-dominated geothermal systems that rely on the flow of steam and are characterized by steaming ground, acid sulphate springs and fumarole activity tends to increase and perhaps migrate initially on exploitation. Decreasing pressure in the reservoir causes an increase in steam flow, which has a high mobility through the earth. As reservoir steam zone pressures decline with continuing exploitation, the amount of steam reaching the surface or near-surface aquifers declines, and the natural steam features also slowly decline.

When the steam pressure in the near-surface aquifers becomes greater than the overlying lithostatic pressure, hydrothermal explosions can occur resulting in the formation of large craters, which have killed numbers of people.

In vapour-dominated geothermal systems, a reduction in the reservoir pressure leads directly to a reduction in the surface discharges. Monitoring of thermal manifestations, occurrences and flow rate is important. It is often difficult to measure the flow rate from fumaroles and steam vents, especially at higher flow rates. Photographs of the area taken at different times can give valuable information on changes in thermal activity. A relatively new technique using airborne infrared technology and comparison of images from different times may be useful to monitor changes in thermal activity.

3.2.2 Subsidence

Withdrawal of fluid from underground reservoirs can result in a reduction of pressure in pore spaces, which can lead to ground subsidence. A monitoring programme is required, and prior to exploitation, a baseline levelling survey with installation of a levelling station needs to be undertaken. Prior to exploitation, it is difficult to predict the magnitude and area of subsidence, or the frequency of measurements needed.

At Nesjavellir, in the Hengill area, a monitoring program using a levelling survey has been undertaken over the last 10 to 15 years. It started in an area relatively close to the exploitation, but has been expanded to all the Hengill area. The area has been measured in two to five year intervals depending on changes. For the period prior to 1994, some subsidence could be seen although close to detection limits of the method. During the last few years, the levelling surveys have shown an increase in land elevation following increased seismic activity in the area on a regional scale.

The largest recorded subsidence in connection with exploitation has been recorded at Wairakei in New Zealand (Allis, 1990). There, the subsidence was first detected in 1956. It has occurred over most of the production field with its centre about 500 m east of the Eastern bore field (Figure 2). The subsidence is predicted to increase to about 20 m by the year 2050.

A pond up to 6 m deep has formed in the area of maximum subsidence. Trees that have been flooded have died. The subsidence has also caused damage in well casings, on pipelines and a section of a nearby highway has had to be rebuilt and resurfaced.

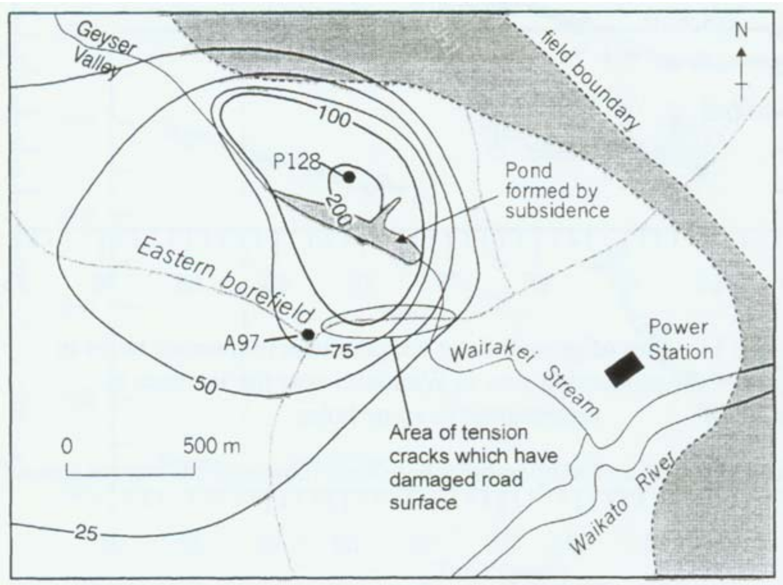

Figure 2: Subsidence rates in the main subsidence bowl at Wairakei. Rates are in mm/yr for the 1990s (Hunt, 2001).

3.2.3 Induced seismicity

Seismic activity seems to be present in geothermal systems and is thought to be related to the flow of water through subsurface channels. Increased flow during exploitation can therefore increase seismic activity. Injection of fluids into deep formations has also been recognized as a cause of seismicity. Evaluation of earthquakes and monitoring of seismicity can give valuable information regarding location of fractures and faults, and therefore locations of geothermal activity and the flow pattern of geothermal fluids.

3.3 Disposal of fluid

Over the past 25 years, people have become more anxious about the possible chemical contamination of the land, air and water. The main effects during geothermal development are from chemicals in liquid and vapour discharges. Before a geothermal field is developed, the effects of chemistry of gases and water on the environment have to be assessed and baseline data collected. The influence of the chemistry of air and water discharges depends on the nature of the field, the surrounding environment and on the operating procedures used during power generation. The chemical constraints on development are often set from international standards, and are determined by the sensitivity to humans and the biota.

3.3.1 Gas

The main geothermal gases are carbon dioxide (CO_2) and hydrogen sulphide (H_2S). Relative amounts of greenhouse gas emissions from various types of electricity generation methods are shown in Figure 3. The total amount of geothermal energy produced in the world is equivalent to saving 12.5 million tonnes of fuel oil per year; and the total direct use of geothermal energy in the world is equivalent to about 13.1 million tonnes. Lund (2000) has estimated that this fuel oil saving per year corresponds to a reduction of about 82 million tonnes of CO_2 emissions annually.

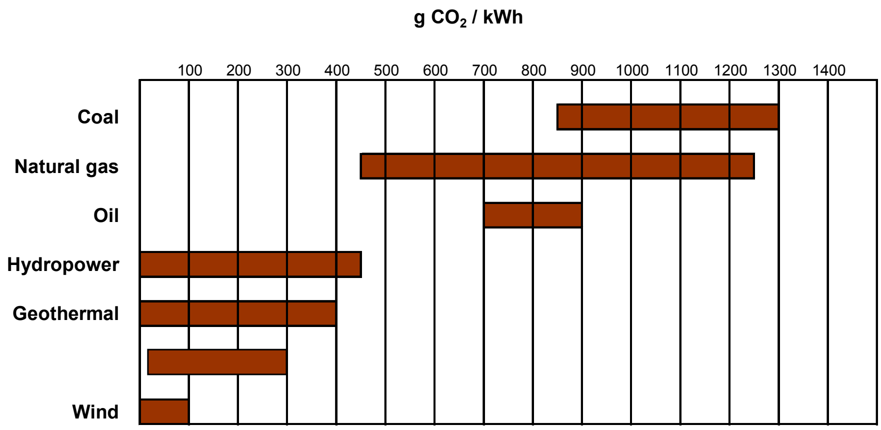

Figure 3: Relative amounts of greenhouse gas emissions from various types of electicity generation methods (Hunt, 2001).

The use of geothermal energy to generate electricity also reduces sulphur gas emissions. The sulphur gases emitted from geothermal power plants are mainly in the form of H_2S compared to SO_2 emissions if burning fossil fuels. The amount of sulphur gases from geothermal power plants is less than 2% of that emitted from an equivalent sized coal- or oil-fired power station.

The impact of H_2S discharge depends on local topography, wind patterns and land use. The smell of H_2S is characteristic for geothermal areas, and this unpleasant smelling gas corrodes copper and copper compounds in equipment, and causes eye irritation and respiratory damage in humans. Table 1 lists the effects on humans.

H_2S dissolves in water and aerosols, such as fog, and it reacts with atmospheric oxygen to form more oxidized sulphur-bearing compounds. Some of these oxidized compounds have been identified as components of "acid rain", but a direct link between H_2S emissions and acid rain has not been established.

The concentrations of H_2S and SO_2 have been measured in Icelandic geothermal areas. The concentration of H_2S in air is closely dependent on weather conditions, and the content of SO_2 is close to background levels. Figure 4 shows the distribution of hydrogen sulphide at the geothermal field Nesjavellir under different weather conditions. The map on the left is based on measurements in calm southerly winds. The highest values are close to the exhaust, and almost equally distributed from there. The map to the right is based on measurements taken in

Table 1: Effects of H_2S on humans. Based on Rolfe (1980); Safety, mining and eng. (1999).

H_2S level in ppm	Effects on humans
0.005	Lower detection limit for odour
0.3 to 1	Detectable by most persons by odour or by sense of taste
3 to 5	Easily detectable - moderate odour
0.7 to 7	Beginning of eye irritation
10	***Permissible exposure level for 8 hrs. working day***
10 to 20	Immediate irritation to the eyes
20 to 30	Strong unplesant odor, but not intolerable. Minimum concentration causing coughing and immediate irritation to the eyes. ***Maximum concentration allowable for short exposure (20 ppm for 10 min)***
50	Pronounced irritation of eyes, throat and lungs, but is possible to breath for several minutes. Symptoms will appear. ***Maximum concentration allowable for ceiling limit.***
100	Coughing, eye irritation, loss of sense of smell after 2 to 5 minutes, may sting eyes and throat.
200	Eye inflammation and respiratiory tract irritation after one hour exposure.
500 to 700	Loss of consciousness and possible death in 30 minutes to an hour. Immediate artificial resuscitation will be necessary.
700 to 1000	Rapid unconsciousness, cessation (stopping or pausing) of respiration and death. **Permanent brain damage may result**, artificial resuscitation and oxygen must be given.
1000 to 2000	Unconsciousness at once, with early cessation of respiration and **DEATH** in a few minutes. Death may occur even if individual is removed to fresh air at once. Brain damage will occur.

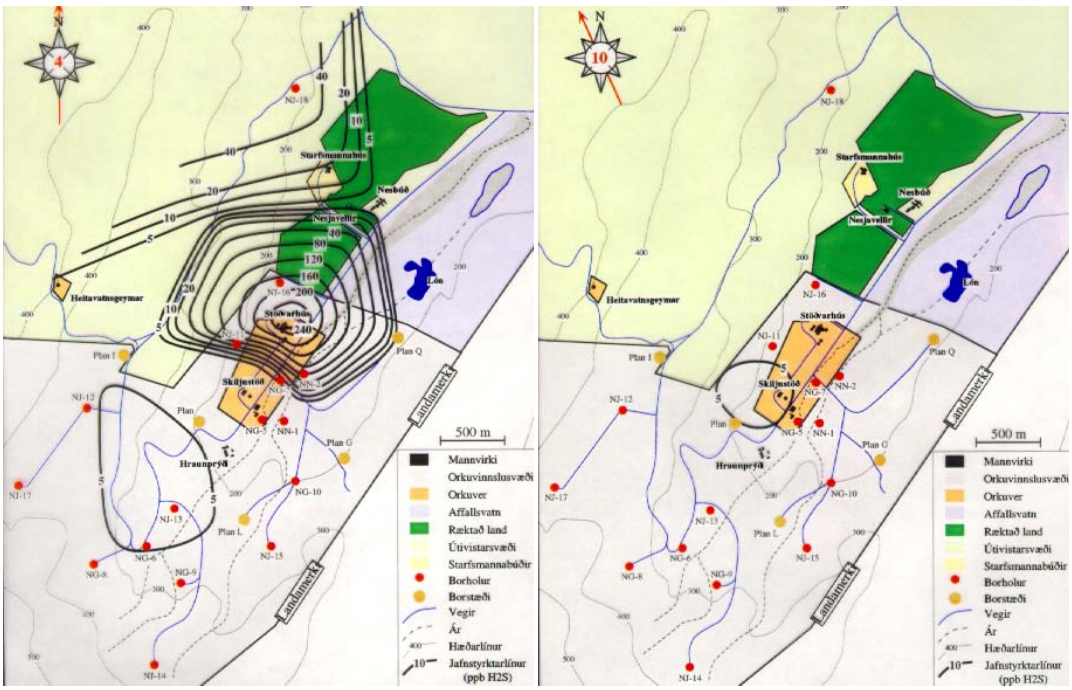

Figure 4: Distribution of hydrogen sulphide at the Nesjavellir field, Iceland under different weather conditions. The map on the left is based on measurements in calm southerly winds. The highest values are close to the exhaust, and almost equally distributed from there. The map to the right is based on measurements taken in strong south-easterly winds and heavy rain.

strong south-easterly winds and heavy rain. Hydrogen sulphide was hardly detected in the area; it had all dissolved in the rain. The gas emissions from the plant were similar in both cases. These maps show that the concentration of hydrogen sulphide in the air is strongly dependent on the weather conditions.

Carbon dioxide (CO_2) is the main gas component in geothermal steam. Like hydrogen sulphide, it is a heavy gas, which accumulates in pits and low depressions. It is also present naturally in air in low concentrations. It is not as highly toxic as hydrogen sulphide, but larger concentrations will alter the blood pH. Carbon dioxide and methane (CH_4), also present in geothermal steam, are the "greenhouse gases". Geothermal steam may also contain ammonia gas (NH_3), and trace amounts of mercury (Hg).

In many utilized high-temperature geothermal fields, gas emissions follow strong environmental requirements and therefore have to be monitored.

3.3.2 Water

Geothermal water, especially some high-temperature water, often contains high concentrations of contaminates such as lithium (Li), boron (B), arsenic (As), hydrogen sulphide (H_2S), mercury (Hg), and sometimes ammonia (NH_3). If water containing these contaminates is released into rivers or lakes, it can potentially damage aquatic life and terrestrial plants. In such cases, the water composition of rivers and lakes has to be monitored to ensure that the composition is within acceptable limits.

Geothermal water from the power plant at Nesjavellir is recharged to the groundwater through shallow drillholes, faults and fissures. This water does not contain contaminates except hydrogen sulphide in condensed steam. The H_2S oxidizes to form elemental sulphur or, ultimately sulphate (SO_4) depending on pH according to equation (1):

$$H_2S + 0.5\ O_2 = S_{(c)} + H_2O \qquad (1)$$

In waterways, yellow sulphur can be found, and in the groundwater sulphate content has increased (Figure 5).

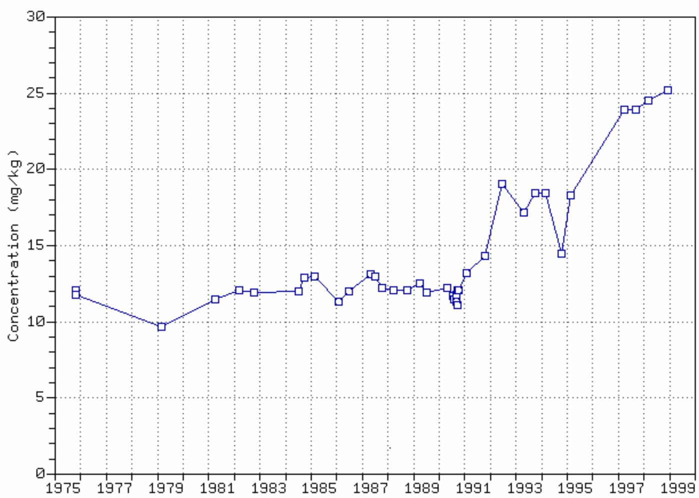

Figure 5: Concentration of sulphate in groundwater near Nesjavellir power plant, Iceland.

3.4 Thermal effects

Utilization of geothermal energy both from low- and high-temperature fields may lead to waste of heat through effluent from the utilization. The efficiencies of geothermal power plants are much lower than for most other types of power plants. Thus there is a relatively larger proportion of waste heat from geothermal systems, and this needs to be dissipated in an environmentally acceptable way. In many countries, the maximum change in temperature allowed in any development is only a few degrees.

In vapour-dominated high-temperature geothermal fields, the waste heat can be discharged to the atmosphere in the form of cooling towers or to surface waterways in the form of outflow of cooling water. In water-dominated systems, the waste heat is divided between that due to the heat contained in the wastewater and that contained in the steam. Heat in wastewater is increasingly being used for power generation through binary cycle generation plants and cascading applications.

Discharge to the atmosphere is likely to affect the local climate, whereas discharge to the surface waterways will more likely affect the local biota. Heat in effluent from geothermal applications has to be monitored, and if unacceptable changes are seen, actions have to be taken to minimize the effects.

3.5 Noise

Although noise is not one of the parameters which are regularly monitored, it is mentioned here since it is one of the disturbances to the environment from geothermal development – particularly during the construction and operation phases.

Residents in geothermal areas often find noise as an intrusion into their environment and the behaviour of animals is also affected by noise with reports of changes in size, weight, reproductive activity and behaviour.

Noise is measured in decibels denoted dB(A). Table 2 (Brown, 1995) lists noise from geothermal development in comparison to other familiar sounds.

Following the drilling, there is usually a period where the well is discharged. Vertical discharges are very noisy (up to 120 dBA), but are required to clean the wells and remove drilling debris. After this, there is normally a period of well testing. This can be suitably muffled by the use of silencers, but even here the noise is significant. (70-110 dBA).

3.6 Biology

It is extremely important to collect reliable "baseline biological data" for all environments likely to be affected by geothermal discharges. The impact of gas and water discharges on terrestrial and aquatic life will depend on contaminant dilution, dispersion, chemical speciation in the wider environment and heat. A biological monitoring programme has to ensure that limiting criteria have been correctly set, and that there are no unacceptable biological impacts brought about by geothermal discharges. The monitoring should preferably be performed at the same time of year, and under similar physical and chemical conditions so the result can be compared to those of the previous year or season.

Table 2: Typical noise levels

DB(A)	Familiar Sounds	Average subjective description
130	Jet takeoff at 60 m	Intolerable
125	***Well Discharge***	
120	Threshold of pain at 1000 Hz	
	Free venting well 8 m	
110	***Drilling with air 8 m***	Very noisy
100	Unmuffled diesel truck at 15 m	
95	Loud motorcycle at 15 m	
90	***Construction site***	
	Well vented to rock muffler	
85	Office with typewriter	Noisy
	Bleed line not muffled	
80	Office with geologist	
	Mud drilling	
75	Street corner in large city	
70	Loud radio	
	Outside generator building 8 m	
65	Normal speech at 3 m	
60	Accounting office	Quiet
45	Office with reservoir engineer	
40	Residential area at night	
30		
25	Broadcasting studio	Very quiet
5		
0	Threshold of hearing	

4 References

Allis, R.G. (1990). Subsidence at Wairakei field, New Zealand. *GRC Transactions*, 14, p. 1081-1087.

Brown, K.L. (1995). Impacts on the physical environment. *Pre-Congress Course on environmental aspects of geothermal development. World Geothermal Congress 1995*, p. 39-55.

Hunt, T.M. (2001). Five lectures on environmental effects on geothermal utilization. *United Nations University Geothermal Training Programme 2000-Report 1,* 109 p.

Lund, J.W. (2000). World status of geothermal energy use. Overview 1995-1999. *Proceedings World Geothermal Congress 2000*, p. 4105-4111.

Rolfe, K. A. (1980). Hydrogen sulphide from geothermal developments: Its nature and control. *2nd New Zealand Geothermal Workshop*, p. 119-125.

Safety, mining and eng. (1999). – web: www.instanet.com/~pfc/files/h2s.htm