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GEOTHERMAL ELECTRIC ENERGY AND ITS IMPACTS ON THE ENVIRONMENT

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by

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ABSTRACT

An overview of various geothermal systems and their possible utilization is first provided.

This is followed by a detailed summary from the available literature of the various environmental impacts of geothermal electric energy projects.

The pollution potential to water, air and soil is described as well as the possibility of thermal and noise pollution. Other environmental concerns discussed include land subsidence, induced seismic activity, land alienation, habitat disturbance and well blowouts.

RÉSUMÉ

Le rapport débute par une revue des différents systèmes géothermiques et de leur utilisation possible.

Suit un résumé détaillé des études portant sur les diverses conséquences que peuvent avoir sur l'environnement les différents projets d'énergie électrique d'origine géothermique.

Le rapport décrit les dangers de pollution de l'eau, de l'air et du sol ainsi que les risques de pollution causés par l'exchès de chaleur et le bruit. Parmi les autres sujets de préoccupation développés dans le rapport, on trouve les affaissements de terrain, les répercussions possibles sur l'activité sismique, le détournement du milieu naturel de ses fins premières, la perturbation de l'habitat et les éruptions géothermiques.

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1 INTRODUCTION

Energy conservation, substitution of renewable resources for nonrenewables and development of domestic alternatives to imported fuels are of increasing interest to scientists and as partial solutions to Canada's energy problem. In this regard, one new resource with promising potential is geothermal electricity. Although much has been made of the renewability of this form of energy in existing fields throughout the world, many questions have been raised over associated environmental concerns. It is the purpose of this report to document in summary fashion the major environmental impacts of geothermal electric energy exploration and development based on a general bibliographic review.

There are three major sources of geothermal electric energy:

(1) Hydrothermal convection systems involving heat transferred to the earth's surface by a circulating fluid (i.e., steam or hot water). This is the most common type of geothermal power source and is found at the Geysers in California, at Lardarello in Italy, at the Wairakei power plant in New Zealand and at other geothermal sites in Japan, Iceland and Mexico (Berman, 1975; Weiss et al., 1979);

(2) Hot igneous systems involving the transfer of heat through the near-surface intrusion of magma (i.e., molten rock) and hot dry rock. In contrast to hydrothermal convection systems, the rock formations in these systems are not sufficiently permeable to trap water. This type of system is not presently commercially viable;

(3) Conduction-dominated systems involving heat transfer to the earth's surface through solid rock by conduction and where the temperature increases proportionately with depth at a constant rate. These systems are currently only in the experimental stage.

1.1 Hydrothermal Convection Systems

These systems may be vapor-dominated (dry stream) or liquid-dominated (wet steam and hot water). The dry steam type is usually defined as one consisting of dry, superheated steam with no associated liquid. Temperatures of dry steam reservoirs range from 220 to 250 degrees Centigrade (428 to 482 degrees Fahrenheit) and have pressures around 35 kg/sq. cm. (500 psi). The condensate from the steam has very low concentrations of chloride (less than 15 ppm) and total dissolved solids. There are usually high concentrations of boron, ammonia, sulfate and magnesium and considerable amounts of non-condensible gases (hydrogen sulfide and carbon dioxide).

Hot water/wet steam systems used to produce electricity have water temperatures greater than 150 degrees Centigrade (302 degrees Fahrenheit) and have a high chloride ion concentration. These reservoirs also have higher concentrations of arsenic, cesium, boron, fluoride, lithium, sodium, rubidium and silica than cooler ground water.

This report discusses the effects of these chemical constituents as sources of water, air and soil pollution. In addition, thermal pollution, land subsidence, induced seismic activity, land alienation, habitat disturbance, noise pollution and well blowouts are discussed.

2 ENVIRONMENTAL CONCERNS

Geothermal power-producing systems normally are designed between the following extremes:

(1) A totally closed system accomplished through fluid reinjection into the reservoir or other aquifer after power conversion. Such a system produces minimal environmental effects, mainly in the form of thermal pollution;

(2) A completely open system where all waste liquids and gases are released untreated after power conversion to surface drainage or the atmosphere. Such a system has the potential for creating substantial environmental pollution. The exact extent of the pollution depends on the amount and nature of chemical constituents and on the rate, volume and methods of disposal.

All phases of a geothermal project including exploration, development and production/utilization have the potential for environmental degradation. During exploration and development, drilling can produce waterborne silts, mud solids, drill cuttings, soil disturbance, possible accidental spills and well blowouts. During production and utilization, the main source of pollution is the geothermal fluid which can chemically react with other materials and can contain waste heat, dissolved and suspended solids, and dissolved and entrained gases.

2.1 Water Pollution

The chemical characteristics of geothermal fluids vary considerably both in number of chemical constituents and in concentration (Table 1 and Figure 1); geothermal waters can range from potable to highly saline and corrosive. Pollution problems associated with dry and wet steam systems are generally less than those associated with hot water systems, because the vapour from geothermal steam is usually lower in pollutants.

Table 2 presents a grouping of chemical constituents according to their relative abundance. Aquatic life criteria for some of these chemical constituents are listed in Table 3. Several elements (aluminum, bromine,

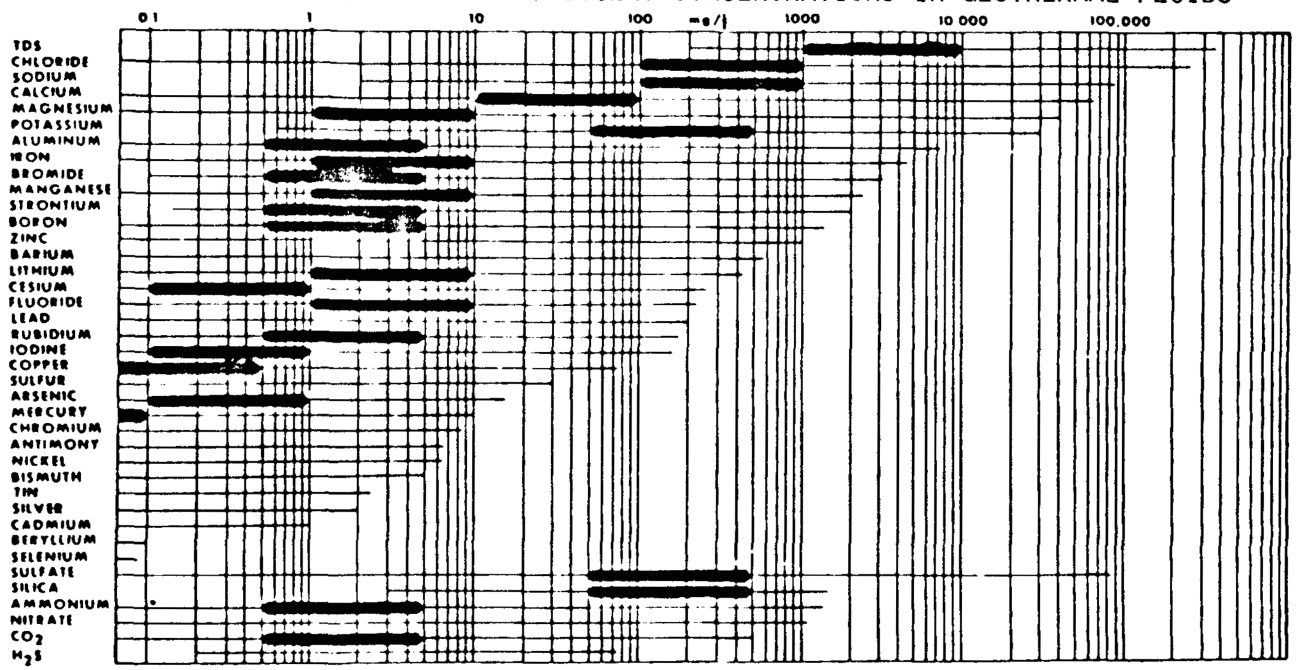
TABLE 1: CHEMICAL COMPOSITION OF GEOTHERMAL WATERS WORLDWIDE

Constituent	Concentration in ppm	Comments
Aluminum (Al)	0 - 7,140	
Ammonium (NH_4)	0 - 1,400	
Arsenic (As)	0 - 12	Health hazard
Barium (Ba)	0 - 250	Human death if >550 mg dosage
Boron (B)	0 - 1,200	Deleterious to plants
(HBO_2)	13.6 - 4,800	
Bromide (Br)	0.1 - 3,030	
Cadmium (Cd)	0 - 1	Toxic to fish if >0.2 ppm
Calcium (Ca)	0 - 62,900	Clogging scale
Carbon Dioxide (CO_2)	0 - 490	Clogging scale
(HCO_3)	0 - 10,150	pH control
(CO_3)	0 - 1,653	
(HCO_3 + CO_3)	20 - 1,000	
(CO_2 + HCO_3 + CO_3)	15 - 7,100	
Cesium (Cs)	0.002 - 22	
Chloride (Cl)	0 - 241,000	Major corrosion constituent
Cobalt (Co)	0.014 - 0.018	Toxic to life in large amounts
Copper (Cu)	0 - 10	Health hazard if >1 ppm
Fluoride (F)	0 - 35	Healthful if <1.5 ppm
Germanium (Ge)	0.037 - 0.068	pH control, corrosion-scale agent
Hydrogen Sulfide (H_2S, total)	0.2 - 74	
Iodide (I)	0 - 105	
Iron (Fe)	0 - 4,200	May precipitate on oxidation
Lanthanum (La)	20	
Lead (Pb)	0 - 200	Cumulative poison

Constituent	Concentration in ppm	Comments
Lithium (Li)	0 - 300	
Magnesium (Mg)	0 - 39,200	Clogging scale
Manganese (Mn)	0 - 2,000	May precipitate on oxidation
Mercury (Hg)	0 - 10	
Molybdenum (Mo)	0.029- 0.074	
Nickel (Ni)	0.005 - 2	
Nitrate (NO_3)	0 - 35	Drinking standard, 45 ppm
Nitrite (NO_2)	0 - 1	Organic pollutant
Oxygen (O_2, dissolved)	0 - 10	Corrosion-related
Phosphate (PO_4)	0 - 0.3	Eutrophication agent
(HPO_4)	0.75 - 2.05	
(H_2PO_4)	0.02 - 0.22	
Potassium (K)	0.6 - 29,900	Scale-corrosion accelerator
Rubidium (Rb)	0 - 169	
Silica (SiO_2, total)	3 - 1,441	Major scale constituent, corrosion inhibitor
Silver (Ag)	0 - 2	Mandatory limit, 0.05 ppm
Sodium (Na)	2 - 79,800	Scale-corrosion accelerator
Strontium (Sr)	0.133 - 2,000	
Sulfate (SO_4)	0 - 84,000	Clogging scale
Sulfur (S)	0 - 30	
Total Dissolved Salts	47 - 387,500	
Zinc (Zn)	0.004 - 970	Toxic to fish if >0.3 ppm
Zirconium (Zr)	24	

SOURCE: Geonomics, Inc., 1978, p.14 - 17

FIGURE 1: RANGES OF CHEMICAL CONSTITUENT CONCENTRATIONS IN GEOTHERMAL FLUIDS



Ranges of chemical constituent concentrations in geothermal fluids - mg/l. Narrow bars show measured ranges. Wide bars show ranges within which the majority of measurements will probably fall. Where no wide bar is shown, data are insufficient to make a judgment.

Source: Hartley, 1978, p. 24

TABLE 2: RELATIVE ABUNDANCE OF MAXIMUM REPORTED CONCENTRATIONS OF CHEMICAL COMPOSITION IN GEOTHERMAL WATERS WORLDWIDE

Major Constituents (maximum >100,000 ppm)	Secondary Constituents (maximum 1,000–10,000 ppm)	Minor Constituents (maximum 1-1,000 ppm)	Trace Constituents (maximum <0.01 ppm)	
Chloride	Aluminum	Arsenic	Antimony	Platinum
Sulfate	Iron	Barium	Beryllium	Praseodymium
Sodium	Bromide	Cadmium	Bismuth	Rhenium
Calcium	Manganese	Cesium	Cerium	Rhodium
Magnesium	Strontium	Copper	Dysprosium	Ruthenium
Potassium	Carbonate	Fluoride	Erbium	Samarium
Bicarbonate	Silica (total)	Hydrogen Sulfide(total)	Europium	Scandium
	Ammonium	Iodide	Gadolinium	Selenium
	Boron	Lanthanum	Gallium	Tantalum
		Lead	Germanium	Tellurium
		Lithium	Gold	Terbium
		Mercury	Hafnium	Thallium
		Nickel	Holmium	Thorium
		Nitrate	Indium	Thulium
		Phosphate(total)	Iridium	Titanium
		Rubidium	Lutetium	Tungsten
		Silver	Molybdenum	Uranium
		Zinc	Neodymium	Vanadium
		Zirconium	Niobium	Ytterbium
			Osmium	Yttrium
			Palladium	

Source: Geonomics, Inc., 1978, p. 17

TABLE 3: AQUATIC LIFE CRITERIA FOR CONSTITUENTS IN GEOTHERMAL FLUID

Constituent	Criteria for Fresh water	Criteria for Marine water	Remarks
Ammonia (un-ionized)	0.02 mg/l		Toxicity pH dependent
Arsenic			Daphnia impaired by 4.3 mg/l
Barium			Toxicity level >50 mg/l
Beryllium	0.11 mg/l - soft water 1.1 mg/l - hard water		Toxicity hardness - dependent
Boron			Toxic to minnows at 19,000 mg/l
Cadmium	.004-.0004 mg/l - soft water .012-.0012 mg/l - hard water	0.005 mg/l	Toxic at <0.5 mg/l all tests
Chromium	0.1 mg/l		Toxicity varies with pH and oxidation state
Copper	0.1 96 hr LC_{50}	0.1 96 hr LC_{50}	Toxicity alkalinity - dependent
Iron	1.0 mg/l		Toxicity variable
Lead	0.01 96 hr LC_{50} (sol. lead)		Salmonids most sensitive fish
Manganese		0.1 mg/l	Not a problem in fresh water
Mercury	0.0005 mg/l	0.0001 mg/l	High bio-accumulation and thus affects human food
Nitrates			Toxicity to fish >900 mg/l
Phosphorus		0.0001 mg/l P	Eutrophication factor
Selenium	0.01 96 hr LC_{50}	0.01 96 hr LC_{50}	Toxic at >2.5 mg/l
Silver	0.01 96 hr LC_{50}	0.01 96 hr LC_{50}	Toxicity dependent on compound
H_2S	0.0002 mg/l	0.0002 mg/l	Toxic at very low levels
Zinc	0.01 96 hr LC_{50}		Toxicity dependent on temperature, DO, hardness
Total Dissolved Solids (TDS)			Osmotic effects - variable

Source: Hartley, 1978, p. 34

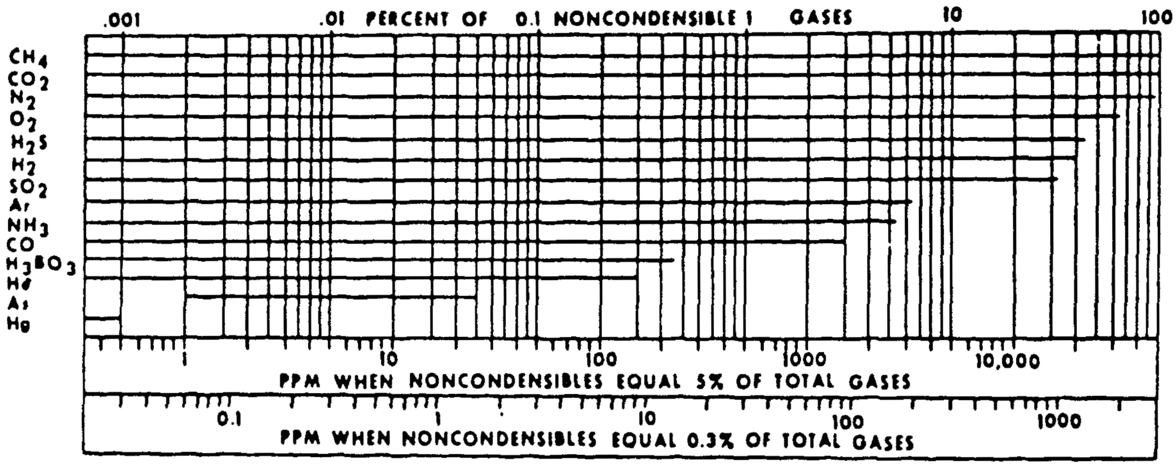
strontium, lithium, cesium, fluorine, rubidium, antimony, nickel and boron) which are known to be toxic to humans are not included in this table. These elements may also have toxic effects on aquatic life.

At the Wairakei geothermal site in New Zealand, arsenic, mercury, hydrogen sulfide, carbon dioxide and silica have produced adverse effects on the aquatic environment. The Wairakei plant supplies nearly 75 percent of the total arsenic input to the Waikato River, while the concentration factor of arsenic in Largarosiphon major, a weed which dominates the aquatic plant population in Lake Aratiatia, has been recorded at 5300 times normal (Axtmann, 1975a; Aggett and Aspell, 1980). The importance of this accumulation of arsenic by aquatic plants and on up through the food chain is unknown. On the other hand, a rough 1:1 correspondence has been found to exist between concentrations of mercury in lake sediments and in co-existing trout in the Waikato River system. The aqueous hydrogen sulfide in the water effluent of the Wairakei plant has caused sulfur bacteria of the genera Thiothrix and Beggiatoa to grow on plankton in Lake Aratiatia and Lake Ohakuri. Investigations of the effects of dissolved hydrogen sulfide on the eggs and fry of rainbow trout have demonstrated that only concentrations less than 0.006 ppm are safe (Axtmann, 1975a). Dissolved carbon dioxide from the Wairakei plant has been found to increase the growth of L. major to such an extent that in 1968 the accumulation of the weed on the intake screens of the Aratiatia Dam forced a temporary shutdown of the generating station.

2.2 Air Pollution

Air pollution from geothermal plants arises from ejector exhausts, cooling towers, silencers, drains, traps, discharging bores under test and control vent valves (Hartley, 1978). Most of the noncondensible gases or vapours that have been found in geothermal fluids are normal components of the atmosphere (Figure 2 and Table 4), although in varying quantities. Hydrogen sulfide, boron (boric acid) and sulfur dioxide in geothermal gases are currently recognized as potentially damaging to crops (Armstead, 1978).

FIGURE 2: NON-CONDENSIBLE GASES IN GEOTHERMAL FLUIDS



Noncondensible gases in geothermal fluids. Base graph shows individual gases as ranges of percent of total noncondensible gases. Lower scales convert these values to parts per million (ppm) of total (noncondensible plus condensible) gases when noncondensibles equal the specified percentages of total gases.

Source: Hartley, 1978, p.25

TABLE 4: GAS COMPOSITION OF GEOTHERMAL VAPOURS

Constituent	Concentration in volume percent	Remarks
Ammonia (NH_3)	0 - 5,36%	Noxious gas, signifies reducing conditions
Argon (Ar)	0 - 6.3	Minor inert gas
Arsenic (As)	0.002 - 0.05	Health hazard, volatile
Boric Acid (H_3BO_3)	0 - 0.45	Deleterious to plants
Carbon Dioxide (CO_2)	0 - 99	Scale formation
Carbon Monoxide (CO)	0 - 3	Health hazard
Helium (He)	0 - 0.3	Innocuous
Hydrocarbon (C_2 and greater)	0 - 18.3	Potential fuel source, denotes reducing conditions
Hydrogen (H_2)	0 - 39	Provides data on oxidation-reduction environment
Hydrogen Fluoride (HF)	0.00002	Extremely corrosive and reactive
Hydrogen Sulfide (H_2S)	0 - 42	Noxious gas, environmental hazard, corrosion agent
(H_2 + H_2S)	0.2 - 6	
Mercury (Hg)	0.007 - 40.7 (ppb)	Health hazard
Methane (CH_4)	0 - 99.8	Potential fuel source
Nitrogen (N_2)	0 - 97.1	Major inert gas
(N_2 + Ar)	0.6 - 96.2	
Oxygen (O_2)	0 - 64	Important for oxidation-reduction reactions, can be corrosive
Sulfide Oxides (SO_2)	0 - 31	Corrosion agent, harmful to environment

Source: Geonomics, Inc., 1978, p.20

With respect to other vegetation, hydrogen sulfide is of major concern because it is heavier than air and tends to settle towards the ground. Controlled greenhouse studies have shown that Douglas fir (Pseudotsuga menziesii) after a continuous six week exposure to hydrogen sulfide fumes at 3000 ppb developed a progressive tip burn; defoliation occurred after ten weeks of exposure. An eight week exposure at 300 ppb hydrogen sulfide also produced tip burn on the trees. Sulfur accumulation in the needles was low owing to slow growth rate (Thompson and Kats, 1978).

In contrast, big leaf maple (Acer macrophylum) and to a lesser extent native oaks (Quercus sp.) in the Geysers area have exhibited symptoms (marginal and tip dieback) attributed to boron accumulation (Osterling, 1976). Chemical analysis of leaf and needle tissues showed abnormally high concentrations of boron.

The acidity of rainwater may also increase as a result of development of geothermal sites. This can be caused by oxidation of hydrogen sulfide or sulfur dioxide and the formation of hydrogen and sulfate ions. Such reactions can occur at considerable distances from an effluent source (Weber and Lee, 1976). Although conclusive evidence is not available on the effects of acid rain on vegetation (particularly forests), indications are that trees grown in areas affected by acidification may be depressed by 0.3 to 1 percent per year (Weber and Lee, 1976).

Gases such as mercury vapour, radon and argon are sometimes present in trace amounts (Axtmann, 1975a,b). Smaller quantities of particulate matter including silica and heavy metals such as lead and silver are also likely to be suspended in geothermal steam. Mercury compounds are soluble in water and thus can be absorbed by living organisms directly from water or indirectly through the food chain. Radon-222, the only radioactive gas, is found in trace amounts in the non-condensible portion of geothermal steam. It is produced by the decay of uranium in the rocks of geothermal reservoirs and can lead to highly toxic residues (U.S. Environmental Protection Agency, 1977).

2.3 Soil Pollution

Emissions associated with geothermal energy may contribute to an increase in the acidity of rainwater and eventually, soils. Hydrogen sulfide and sulfur dioxide may be oxidized to H^+ and SO_4^{-2} and ammonia may be converted to nitric acid ($H^+NO_3^-$). An increase in acidic soil conditions could inhibit the growth of bacterial populations and enhance the development of fungi. This could hinder plants which utilize root nodules formed by nitrogen-fixing bacteria (Hartley, 1978).

Acid precipitation is likely to have a chronic effect on ecosystem processes. Disruptions within an ecosystem could involve: (1) increased leaching of nutrients from plant foliage and soil; (2) interference with decomposition processes; and (3) disruption of processes such as nitrification and nutrient uptake. Direct effects could result from soil pollution such as loss of forest productivity. These modifications could also influence wildlife utilization of an area through habitat disturbance.

2.4 Thermal Pollution

Where cooling towers are used, thermal pollution is caused by surplus condensate, although this can be minimized through reinjection. With direct river cooling, waste heat simply raises the temperature of the receiving water body. In Wairakei, this is by far the most serious type of thermal pollution. Large amounts of hot water, at or near the boiling point, can damage fisheries and encourage the growth of unwanted weeds (Axtmann, 1975b). Fish reproduction can also be halted by surplus heat (Hartley, 1978; Nilsen et al., 1974).

Observations of organisms in hot springs and other geothermal habitats have led to a set of general principles (Brock, 1975). There are distinct upper temperature limits for different groups of organisms: fish and other aquatic vertebrates (38 degrees Centigrade); insects (45 - 50 degrees Centigrade); protozoa (50 degrees Centigrade); vascular plants (45 degrees Centigrade); mosses (50 degrees Centigrade); eucaryotic algae (56 degrees Centigrade); fungi (60 degrees Centigrade); blue-green algae

(70 - 73 degrees Centigrade); and bacteria (above 99 degrees Centigrade). Increases in temperature can lead to a greatly simplified ecosystem structure. Even at temperatures below the upper limit for a group of organisms, species diversity for the group may be severely restricted (Brock, 1975). A summary of temperature-induced aquatic effects is presented in "Quality Criteria for Water" (U.S. Environmental Protection Agency, 1976). Increases in water temperature also have a direct effect on water quality through changes in water solubilities.

Thermal pollution from cooling towers has less of an impact on the environment. Effects include slight heating of the local atmosphere, an increase in humidity and occasional fogging (Axtmann, 1975b; Armstead, 1978; Willis, 1978).

2.5 Land Subsidence

Land subsidence has occurred in the development of some geothermal fields. Whenever subsurface fluids are removed, there is a reduction in the fluid pressure supporting the overlying rock that can result in a vertical drop or horizontal movement of the land. At Wairakei where geothermal fluids are not reinjected, there has been a total vertical movement exceeding 3.7 meters (12 feet) since 1956 affecting an area of over 65 square kilometers (25 square miles); smaller horizontal movement was first recorded in 1965 (Axtmann, 1975b). In the Mexican Cerro Prieto hot water field (no reinjection), subsidence was recorded even before extensive production began (Dutcher et al., 1972). In contrast, the dry steam fields at the Geysers and Lardarello have experienced no land subsidence (Bowen, 1973). Land subsidence is thought to be a concern with respect to future geothermal development of the Imperial Valley in California and geopressured resources along the Gulf Coast of Texas (Dutcher et al., 1972; Wilson et al., 1977).

2.6 Induced Seismic Activity (Earthquakes)

It is possible that seismic activity at geothermal sites can be induced by withdrawal or reinjection of geothermal waters from or into underground reservoirs. To date there is no evidence that construction of a geothermal plant has increased seismicity. No anomalous earthquakes have occurred near the wells of the Okate, Japan, wet steam geothermal power site (Kubota and Aosaki, 1975), the dry steam field at Lardarello (Cameli and Carabelli, 1975), the Geysers (Geonomics, Inc., 1978) or the Wairakei field (Axtmann, 1975b). Hazardous elements associated with any induced seismic activity could range from limited rock vibrations and ground motion to large ground motion including faulting, liquefication, landsliding, differential settlement and lurch cracking (Geonomics, Inc., 1978).

2.7 Land Alienation and Habitat Disturbance

Geothermal electric systems, by their very nature and development methods, usually cause less land disruption than pipelines, fuel storage areas, aboveground waste disposal or energy processing facilities. The severity of land disturbance is also much less than many conventional energy source operations such as open pit coal mining. Nonetheless, there are significant land use impacts which can accompany the development of a geothermal field. These relate to acreage requirements, compatibility with adjacent land uses and the protection of sensitive areas.

The land required for development of a geothermal field is primarily a function of the electrical capability of the generating plant, the number and density of wells and the topography of the site. For example, the larger the generating plant, the more wells must be drilled to achieve the level of production required.

Well spacing is influenced by the locality of the heat reservoir, the rate of steam flow and the constituents of the steam. (The latter could necessitate the development of auxiliary facilities for the reclamation of undesirable chemicals.) Sites under rapid development require the drilling of more wells per acre in a cluster arrangement with short pipelines feeding the steam to generating units. In a slower development, the wells are spaced further apart with longer main supply lines (U.S. Environmental Protection Agency, 1977).

The topography of a site influences acreage requirements; as the slope of the land increases, the required surface area for development also increases (Ecoview Environmental Consultants, 1974). The amount of surface land disturbed in a geothermal development area ranges from 10 to 50 percent with an average of 20 percent (Ecoview Environmental Consultants, 1974). A 1000 MWe facility consisting of ten 100 MWe wells with a spacing of one well per 58 acres would cover 2025 to 3645 hectares (5000 to 9000 acres) or 21 to 40 square kilometers (8 to 14 square miles). Of this amount, 20 percent or 405 to 729 hectares (1000 to 1800 acres) of surface area would be disturbed physically through clearance of vegetation, grading and paving (U.S. Environmental Protection Agency, 1977).

Considerable variability in land requirements exists. The dry steam field at Lardarello, consisting of 13 generating units with a total capacity of 360 MWe from 467 wells, required over 165 square kilometers (65 square miles). At the Wairakei hot water field, 61 wells supplying a 160 MWe power plant were concentrated on a compact well field of less than 2.59 square kilometers (1 square mile). The general land requirements for a 'typical' geothermal development site are shown in Table 5.

2.8 Noise Pollution

High intensity noises of over 100 dBA can be encountered during the development phase of a steam field. Typically, most wells are tested 'open hole' for a number of weeks and some may be left to flow for months as a means of assessing long term production capability. Thus, if some 50 to 100 wells were required, a steam field could be expected to have several sources of about 120 dBA for a period of months or years. Mobile sound attenuation screens can be installed at such test sites, but this was not the practice at Wairakei in the 1950's and 1960's (pers. comm., J. Millen, 1981).

Sound levels from cooling towers representing the combined noise output of fans, fan motors and falling water are believed to generally lie within the range of 80 - 90 dBA (Bush, 1976; U.S. Environmental Protection Agency, 1973). Maximum noise intensity occurs near the base in a forced-draft tower and near the top in an induced-draft tower.

TABLE 5: LAND USE REQUIREMENTS FOR A TYPICAL GEOTHERMAL DEVELOPMENT SITE

Phase	Surface Area
Exploration and Testing Phase	
Road construction	*3 to 4 miles, graded and compacted*
Drill pads	1 acre each, cleared and compacted
Mud sump	Each one requires an area 100' x 125' x 10' deep to temporarily store up to 1,000,000 gallons of effluent and cuttings.
Full Field Development	
Road construction	Acreage varies. Access roads may be built to drilling pads, mud sumps, buildings for housing equipment and storage. Estimate 30 acres of land cleared for every 15 wells.
Pipelines	Each pipeline is 10" to 30" in diameter, raised on supports rising no more than 12 feet. The area cleared for the pipeline is from 10' to 300' wide, depending on whether access roads are constructed.
Power generation facilities	Roughly 5 acres are required; most of the land must be paved or otherwise made impervious.
—turbine generators & condensors	Each is 150' x 65' x 60' high.
—cooling towers	Each is 360' x 65' x 60' high.
—transformer	Each is 100' x 100' x 55' high.
Transmission lines	Lines consist of towers or poles at a height of 80 to 120 feet, with concrete bases 40 feet apart.

Source: U.S. Environmental Protection Agency, 1977, p. 45

If enclosed within the walls of a pumphouse, recirculating pumps and motors may produce sound levels approaching 100 dBA (Wilson et al., 1977). These sound levels are comparable to a noisy urban area (80 - 90 dBA) or being adjacent to a freeway (90 dBA) (Hartley, 1978). The most intense noise levels in normal geothermal operations result from steam venting if jet gas ejectors are unattenuated (Table 6).

Noise pollution is contaminating only while it is occurring and only in the immediate vicinity of the source; consequences are related to intensity and duration of exposure. A quiet wilderness area has a sound level of 20 - 30 dBA (U.S. Environmental Protection Agency, 1973), considerably lower than a geothermal site. Therefore, habitats in the immediate locale of geothermal activities may be vacated by wildlife until habituation to the noise level takes place. Changes in mating activities, predator-prey relationships and territorial behaviour might also occur with some wildlife species.

2.9 Well Blowouts

Although the probability of a well blowout is low for both hot water and steam geothermal systems, this type of event has occurred. As a well blowout can contain any or all of the constituents of the resident geothermal fluid, such an event can have adverse effect on the environment (Hartley, 1978). Well blowout was experienced during drilling of early production wells at Cerro Prieto and at the Geysers (Berman, 1975; Bacon, 1976) and also in the early development phase at Wairakei (pers. comm., J. Millen, 1981). In 1973, a blowout at the Alfina 1 well in Northern Latium, Italy, released substantial amounts of carbon dioxide and other gases considered to be of risk to the environment (Ferrara and Stefani, 1977).

TABLE 6: NOISE LEVELS OF GEOTHERMAL OPERATIONS DURING DEVELOPMENT PHASE AT THE GEYSERS

Operation	Duration	Noise Level (dB(A))	Distance (ft)
Well Drilling			
Mud Drilling	60 days/well	75-80	50
Air drilling, including	30 days/well		
blow line		120*	25
blow line with air sampler		95*	25
blow line with air sampler and water injection		85	25
Well cleaning; open well	3-6 days	118*	50
Well testing; open well	14 days	118*	50
Rock muffler		89	50
Well bleeding before connection to generator	variable		
open hole		86	5
rock-filled ditch		65	5
blowouts	variable (infrequent)	118*	50
Construction			
Operation of construction machinery (trucks, bulldozers, etc.)	1-2 years	70-90	50
Plant Operation	20-30 years		
Steam line vent (muffled)	intermittent	90	100
Jet gas ejector	continuous		
unattenuated (old design)		117*	5-10
with acoustical insulation		84	5-10
Steam line separator	continuous	80	25
Steam line breaks	brief, infrequent	100*	50
Cooling tower	continuous	80-90	5-10
Turbine-generator building	continuous	70	outside

* Noise level is at or above OSHA standard of 95 dB(A).

Source: U.S. Environmental Protection Agency, 1977, p.65

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