Environmental Effects of Geothermal Applications. Case Study: Balçova Geothermal Field

By

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ABSTRACT

Direct application of geothermal energy can involve a wide variety of end uses, such as space heating and cooling, industrial applications, greenhouses, fish farming, and health spas. It uses mostly existing technology and straightforward engineering. The technology, reliability, economics and environmental acceptability of direct use applications of geothermal energy have been demonstrated throughout the world.

The use of geothermal energy is the minimum waste forming type of energy in the world. Geothermal energy is also considered cheap, sustainable and environmentally friendly when compared to the other energy resources.

Turkey has abundant geothermal resources because of its location. In particular, İzmir-Balçova district heating system is one example of the high temperature district heating applications in Turkey exhibiting high geothermal potential.

The objective of the Thesis is threefold, namely: (a) to determine the negative and positive environmental effects of Balçova Geothermal District Heating System, (b) to find out sources of contamination if pollution exists (c) to offer a solution to protect the public health.

Contamination may occur in Balçova Geothermal Field in either water phase or soil phase. Therefore, a sampling program was developed in order to monitor the alterations in water. The sampling points were chosen in a way that Balçova District Heating System production wells, groundwater wells, and the irrigation points could all be monitored.

In order to investigate the contamination of the region, several parameters including physical properties such as temperature, electrical conductivity, total dissolved solids, alkalinity; non-metallic constituents such as ammonia, boron, chloride, silica, sulfate; and metals and semi metals such as calcium, magnesium, sodium, potassium etc. were determined.

The results of this study showed that all of the samples had bicarbonate alkalinity. The concentrations of the parameters were not constant during the monitoring study. This may be because of the nature of geothermal fluid. During the studying period, concentrations of many heavy metals were below the limit of detection of atomic spectrometric techniques used in the study. Wells T and I did not seem to be suitable for drinking and irrigation water, respectively.

In order to determine the effects of Balçova District Heating System on physical environment, noise measurements were conducted. The results of noise measurements have shown higher values than the acceptable limits of Noise Control Regulation.

ÖZ

Jeotermal enerjinin direkt kullanımı, mekanların ısıtılması ve soğutulması, endüstriyel uygulamalar, seralar, balık üretim çiftlikleri ve kaplıcalar gibi bir çok değişik alanı kapsar. Çoğunlukla varolan teknoloji ve basit mühendislik bilgileri kullanılmaktadır. Jeotermal enerjinin direkt kullanımının güvenilirliği, çevre açısından uygunluğu, gerekli olan teknoloji ve bu tür uygulamaların maliyeti dünyanın çeşitli yerlerinde araştırılmış ve örneklendirilmiştir.

Jeotermal enerji, dünyada en az atık üreten enerji türüdür. Diğer enerji kaynaklarıyla karşılaştırıldığında, ucuz, sürdürülebilir ve çevre dostu olduğu göz önünde bulundurulmalıdır.

Türkiye, jeolojik konumundan dolayı, oldukça zengin jeotermal kaynaklara sahiptir. İzmir-Balçova Jeotermal Bölgesel Isıtma Sistemi, Türkiye'deki yüksek sıcaklıklı bölgesel ısıtma uygulamalarına bir örnektir ve yüksek bir jeotermal potansiyele sahiptir.

Bu tez çalışmasının üç temel amacı, sırasıyla: (a) Balçova Jeotermal Bölge Isıtma Sistemi'nin çevreye olumlu ve olumsuz etkilerini belirlemek, (b) kirlilik varsa bunun kaynaklarını ortaya çıkarmak ve (c) halk sağlığını korumak için çözüm önermektir.

Balçova Bölgesel ısıtma sisteminin fiziksel çevreye etkisini belirlemek için gürültü ölçümleri yapılmıştır. Gürültü ölçümü sonuçları, Gürültü Kontrolü Yönetmeliği'nde belirtilen sınır değerden daha yüksektir.

Balçova Jeotermal Sahası'nda kirlilik su ve toprak fazlarında görülebilir. Bu yüzden, sudaki değişiklikleri gözlemlemek amacıyla bir örnekleme programı geliştirilmiştir. Örnek alınacak noktalar, Balçova Bölgesel Isıtma Sistemi üretim kuyuları, yeraltı suyu kuyuları ve sulama noktalarının tümünü kapsayacak şekilde seçilmiştir.

Bölgedeki kirliliği araştırmak amacıyla, sıcaklık, iletkenlik, toplam çözünmüş katı miktarı, alkalinite gibi fiziksel özellikler; amonyak, bor, klorür, silis gibi ametaller ile kalsiyum, magnezyum, sodyum, potasyum vb gibi metal ve yarımetaller tayin edilmiştir.

Bu çalışmanın sonuçları, tüm örneklerde bikarbonat alkalinitesi bulunduğunu ortaya koymuştur. Araştırma süresince, belirtilen parametrelerin konsantrasyon değerleri değişkenlik göstermiştir. Bunun nedeni, jeotermal sıvının yapısı olabilir. Çalışma süresince, birçok ağır metalin derişimlerin tayininde kullanılan atomik spektrometri tekniklerinin belirleme sınırının altında olduğu saptanmıştır. T kuyusu içme, I kuyusu ise sulama amaçlı kullanıma uygun değildir.

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CHAPTER I

INTRODUCTION

The principal energy produced in the world today is obtained from fossil fuels, i.e. coal, petroleum and natural gas, hydropower and nuclear energy. The world needs alternative energy sources in order to meet the increasing demand and, thus, improve the productivity of natural resources under the view of technical, economical, social, political and environment aspects. These are all renewable primary energy resources such as geothermal, hydrothermal, solar and wind energy; and geothermal energy is undoubtedly a major resource among them (Çelik and Sabah, 2002)**.** Geothermal energy is also considered cheap, renewable, and environmentally friendly.

The environmental aspects of geothermal development are receiving increasing attention with the shift in attitudes towards the world's natural resources. Not only there is a greater awareness of the effect of geothermal development on the surrounding ecosystems and landscape, but also a growing appreciation of the need for efficient and wise use of all natural resources.

During 1960's, when our environment was in a healthier state than it is at the present and we were less aware of the threat to our globe, geothermal energy was considered as a 'clean energy'. There is actually no way of producing or transforming energy into a form that can be utilized by man without making some direct or indirect impact on the environment. In other words, utilization of any energy resource affects the environment. However, the negative effects of the geothermal energy are less than the other energy resources (Dickson and Fanelli, 1995).

Excessive withdrawal of geothermal fluid, but less putting the fluid back which is known reinjection, pollution and mismanagement can deprive future generations from using the resource.

Balçova Geothermal Field is one of the well-known and must studied fields in Turkey and contains various direct use applications such as district heating, greenhouse heating, hotel, hospital, university and swimming pool heating and greenhouses and lawn irrigation. While all the other application use the geothermal fluid as a heat carrier medium and transfer its heat to clean water by heat exchangers, irrigation application uses the geothermal fluid directly. Since the toxic chemicals possibly present in the geothermal fluid, they may alter the chemical composition of crops and human health could be affected through the food chain. The other applications which uses the geothermal fluid indirectly, chemical composition of the fluid may lead to corrosion and scaling in the transmission lines, thus it should be monitored regularly.

In order to observe the changes in chemical composition and to investigate the contamination in Balçova Geothermal Field, samples were collected from five different locations for water within a total area of about 3.5 km^2.

Moreover, in order to determine effects of geothermal energy on physical environment, noise was measured from drilling area and heating center.

The main objective in doing the present study is (a) to determine the negative and positive environmental effects of Balçova Geothermal District Heating System, (b) to find out sources of contamination if pollution exists (c) to offer a solution to protect the public health.

The Thesis contains eight chapters. Chapter I is Introduction. In Chapter II, general information on geothermal energy is given. Environmental effects of geothermal applications are described in Chapter III. Chapter IV explains the state of geothermal law and regulations in Turkey and in the World. Balçova Geothermal Field and District Heating System is introduced in Chapter V. The sampling programme and analysis methods of the geothermal fluid constituents are also given in the same Chapter. The results of the analytical methods are tabulated and plotted in Chapter VI. Conclusions and some recommendations on the protection of the field are given in Chapter VII.

CHAPTER II

GEOTHERMAL ENERGY

Geothermal energy is heat (thermal) derived from the earth (geo) and a type of energy, which is accumulated in the earth's crust at various depths as hot water, steam or gas under pressure or in hot dry rocks. Geothermal energy is a renewable energy resource which has advantages and disadvantages comparing with other energy sources:

Advantages:

- Does not require fuel burning to produce heat or electricity,
- Limitless source of energy, if it is used in a sustainable way,
- Less risk than nuclear power plants,
- Environmentally friendly,
- Lower CO_2 emissions than fossil fuels,
- Fairly cheap, comparable price to that of fossil-fuel power stations,
- Require very little land for geothermal power plant.

Disadvantages:

- Contains noncondensable gases, (CO_2, H_2S, CH_4 etc.)
- Noise and odor.

2.1. Geothermal Systems

Geothermal systems can be described as "convecting water in the upper crust of the Earth, which, in a confined space, transfers heat from a heat source to a heat sink, usually the free surface" (Hoschstein, 1990). A geothermal system consists of three main elements: *a heat source, a reservoir and fluid*, which is the carrier that transfers the heat. The heat source can be either very high temperature (>600^{o}C) magmatic intrusion that has reached relatively shallow depths (5-10 km) or, as in certain low temperature systems, the Earth's normal temperature, which, increases with depth. The fluids are essentially rainwater that has penetrated into the Earth's crust from the recharge areas, has been heated on contact with the hot rocks, and has accumulated in reservoir, occasionally at high pressures and temperatures. The reservoirs are covered with impermeable rocks that prevent that hot fluids from easily reaching the surface and keep the under pressure. These fluids are in the liquid or vapor phase, depending on temperature and pressure and carry with their chemicals (Ca, Mg, As, B, Si etc.) and gases (CO_2, H_2S, CH_4 etc). Figure 2.1. is a simple representation of an ideal geothermal system.

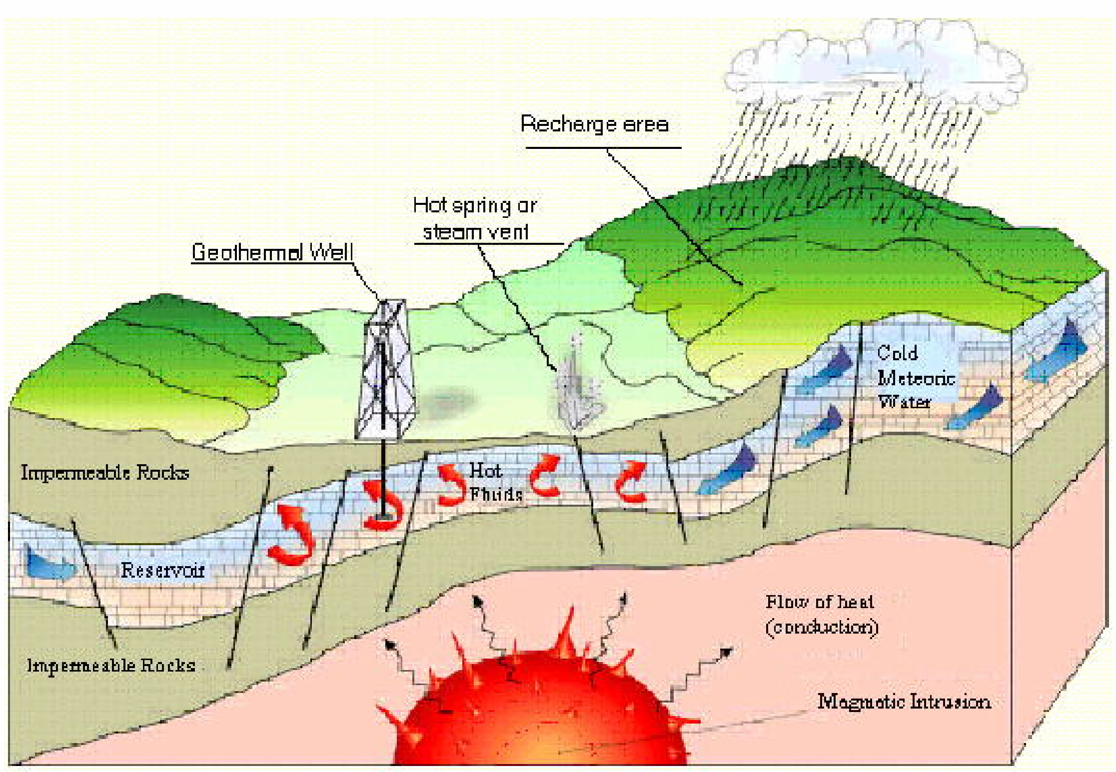

Figure 2.1.Schematic representation of an ideal geothermal system (Dickson and Fanelli, 1995).

Geothermal resources can be classified as low temperature (<90^{o}C), moderate temperature (90-150^{o}C), and high temperature (>150^{o}C) resources. The uses to which these resources are applied are also influenced by temperature. Electricity generation is the most important form of utilization of high-temperature geothermal resources (>150°C). The medium-to-low temperature resources (<150°C) are suited to many different types of application. Figure 2.2. gives the classical Lindal diagram (Lindal, 1973), which shows the possible uses of geothermal fluids at different temperatures.

Direct use, as the name implies, involves using the heat in the fluid directly without a heat pump or power plant. Geothermal direct use dates back thousand years to when early civilizations used hot springs for bathing, cooking and loosening feathers. Today, geothermal hot water is used for building and greenhouse heating, aquaculture (growing of fish), ice-melting, milk pasteurizing, food dehydrating, mushroom growing and heating leaching solutions at gold mines. Direct use projects generally use resource temperatures between 38 and 149°C. Typically, the agricultural and aquacultural uses require the lowest temperatures, with values from 25 to 90°C. The amounts and types of chemicals such as arsenic and boron I”n geothermal fluids are the major problems with flora and fauna; thus, heat exchangers are often necessary. Space heating requires temperatures in the range of 50 to 100°C, with 40°C useful in some marginal cases and ground-source heat pumps extending the range down to 4°C which the heat pump transfers heat from the soil to the house in winter and from the house to the soil in summer. Cooling and industrial processing normally require temperatures over 100°C (Dickson and Fanelli, 1995)

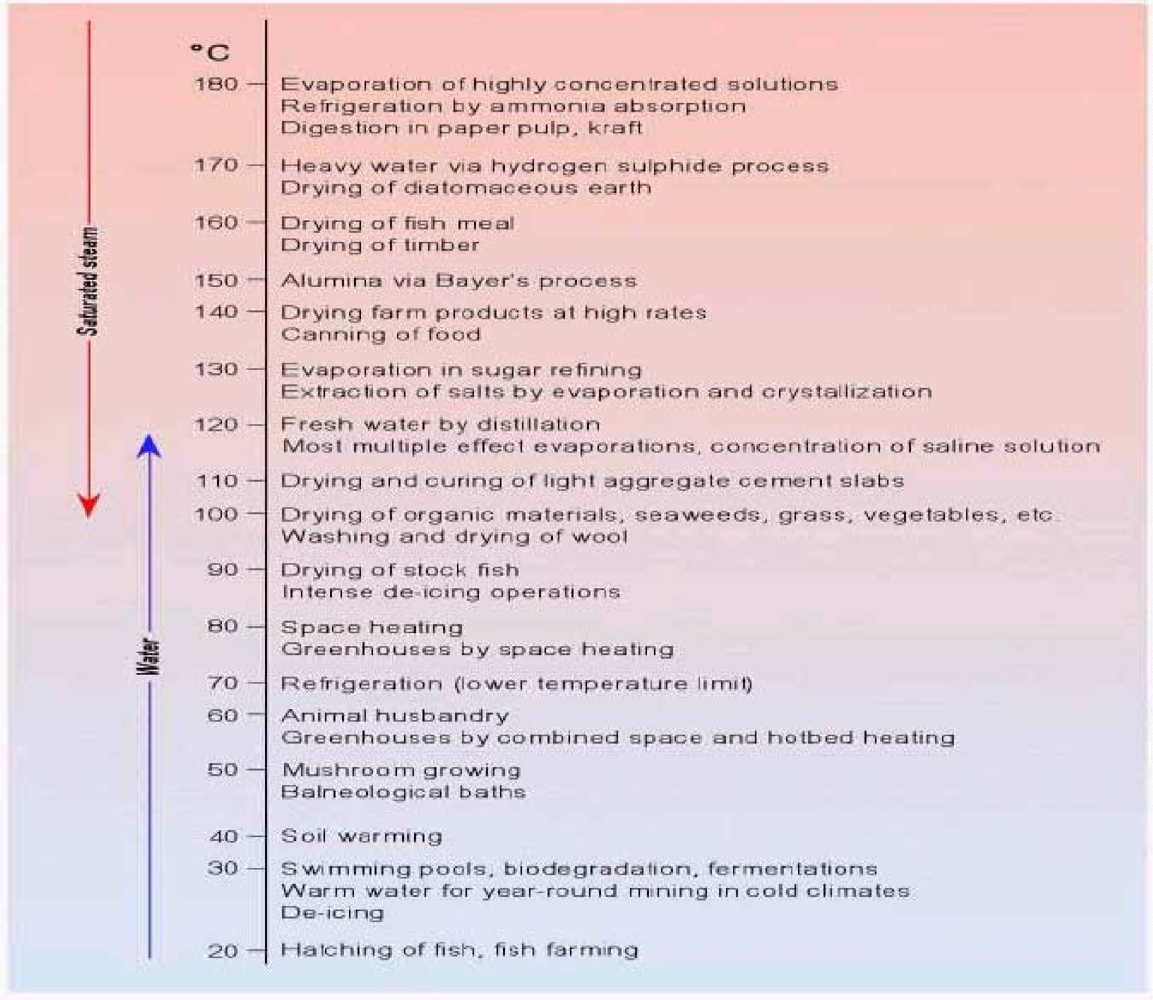

Figure 2.2. Lindal Diagram (Lindal, 1973).

2.2. Chemistry of Geothermal Fluid

The content of geothermal fluids can be separated into two groups: gas phase and liquid phase.

2.2.1 Gas Phase

Gas composition of geothermal fluids differs from field to field even from well to well in the same field. Examples of gas composition from different fields are given in Table 2.1. For high-temperature systems carbon dioxide (CO_2) with lesser amounts of hydrogen sulfide (H_2S) are the main gases, together often representing over 90% of the gas content. Minor and variable amounts of other gases including ammonia (NH_3), hydrogen (H_2), methane (CH_4), and nitrogen (N) may also be present together with trace quantities of oxygen (O_2), the noble gases, hydrocarbons (HC) and volatile species of boron (B), fluorine (F), arsenic (As), and mercury (Hg). These gases are also found in low-temperature systems; however the relative proportions of the gases can be different from that shown in high-temperature fields: N and CH_4, for example, may be the principal gases rather than CO_2 and H_2S. Fumaroles, the steam discharges produced by boiling of subsurface waters, over magmatic systems show a very different chemistry and are characterized by the presence of significant amounts of hydrogen chloride (HCl), hydrogen fluoride (HF) and H_2S, together with variable amounts of the geothermal gases (Nicholson, 1993).

2.2.2. Liquid Phase

The chemicals dissolved in geothermal fluid depend on the geochemistry of the reservoir. Fluids from high-temperature reservoirs can include a range of ions (e.g. chlorides (Cl), sodium (Na), potassium (K), calcium (Ca), fluoride (F), magnesium (Mg), silicate (Si), iodine (I), antimony (Sb), strontium (Sr), bicarbonates (HCO_3) and, of most concern, several toxic chemicals boron (B), lithium (Li), arsenic (As), hydrogen sulfide (H_2S), mercury (Hg), rubidium (Rb) and ammonia (NH_3). Fluids from low-temperature reservoirs generally have a much lower concentration of dissolved chemicals than fluids from high-temperature reservoirs. Examples of the composition of the different water types are given Table 2.2 (Nicholson, 1993).

Table 2.1. Geothermal gas discharge chemistry (milimoles/mole total gases) (Nicholson, 1993)

Field/Feature	**CO_2**	**H_2S**	**CH_4**	**H_2**	**N_2**	**NH_3**
Wells: liquid dominated system						
Wairakei, NZ (average)	917	44	9	8	15	6
Cerro Prieto, Mexico (well 19A)	822	79.1	39.8	28.6	5.1	23.1
Tongonan, Philippines (well 103)	932	55	4.1	3.6	1.2	4.3
Reykjanes, Iceland (well 9)	962	29	1	2	6	-
Wells: vapor dominated systems						
The Geysers, USA (average)	550	48	95	150	30	125
Larderello, Italy (average)	941	16	12	23	8	8
Fumaroles						
Wairakei, NZ (Karapiti)	946	23	7.4	10	11	2.6
Larderello, Italy (average)	923	20.6	14	26	10.7	-

Table 2.2. Representative analyses of geothermal fluid (ppm) (Nicholson, 1993).

Sample	**Temp.**	**pH**	**SiO_2**	**Ca**	**Mg**	**Na**	**K**	**Li**	**HCO_3**	**SO_4**	**Cl**	**F**	**B**	**As**
1	108	-	52	257	17	570	-	0.5	-	932	625	2.8	2.6	-
2	192	7.9	293	5	0.8	653	71	0.7	305	-	885	1.8	4.9	2.7
3	437	8.4	690	17	0.03	1320	255	14.2	-	36	2.26	1.3	-	4.8
4	<500	-	563	8	<2	2320	461	25.3	232	72	3.86	6.8	-	4.3
5	558	-	705	592	0.6	6382	1,551	14.5	28	<3.5	11,92	-	13.4	-
6	600	-	400	28	54	50.4	17.5	215	7.15	5	155	16	390	12
7	99	7.8	268	6	1.2	1172	117	-	2502	778	112	-	25.6	-

Sample Descriptions

1. Hot Springs, Monroa, UT.
2. Hot Springs, Steamboat, NV
3. Well 44, Wairakei, NZ
4. Brine discharge from Wee 54-3, Roosevelt Hot Springs, UT
5. Analyses calculated from flased brine, Well M-26, Cierro Prieto, Mexico
6. Brine discharge from Well 11d, Salton Sea Geothermal Field, CA
7. Brine discharge from Well 14 (surface), Kizildere Geothermal Power Plant, Turkey

2.3. Geothermal Energy Use in the World and Turkey

2.3.1. In the World

Historically, the first applications of geothermal energy were space heating, cooking and medicinal uses. The earliest record of space heating dates back to 1300 in Iceland. In the early 1800's, geothermal energy was used to recover boric acid. The first attempt to produce electricity took place at Lorderello in 1904 with an electric generator that powered four light bulbs. The first district heating system in the world was constructed in 1890 in Boise-Idaho (USA), which feeds 200 houses and 12 business centers, and still in operation. The first large scale municipal district heating service started in Iceland in 1930.

Geothermal energy has been produced commercially for over 80 years, and for four decades on the scale of hundreds of MW both for electricity generation and direct use. The utilization has increased rapidly during the last three decades. In 2000, geothermal resources have been identified in over 80 countries and there are quantified records of geothermal utilization in 58 countries in the world. The worldwide use of geothermal energy amounts to about 49 TWh/a of electricity and 53 TWh/a for direct use. Continental distribution of electric generation and direct use of geothermal energy is given Table 2.3 (Fridleifsson, 2001).

Table 2.3. Electricity generation and direct use of geothermal energy in 2000 by continents (Huttrer, 2001), (Lund and Freeston, 2001).

	Electricity generation			**Direct use**		
	Installed Capacity (MW_e)	**Total production (GWh/a)**	**(%)**	**Installed Capacity (MW_t)**	**Total production (GWh/a)**	**(%)**
Africa	54	397	1	125	504	1
America	3390	23342	47	4355	7270	14
Asia	3095	17510	35	4608	24,235	46
Europe	998	5745	12	5714	18,905	35
Oceania	437	2269	5	342	2065	4
Total	7974	49,263	100	15,144	52,979	100

2.3.1.1. Electricity Generation

Electricity is generated from geothermal steam in 21 countries spread over all continents (Table 2.3). The top ten in 2000 were: The USA (2228 MW_e), The Philippines (1909 MW_e), Italy (785 MW_e), Indonesia (590 MW_e), Japan (547 MW_e), New Zealand (437 MW_e), Iceland (170 MW_e), El Salvador (161 MW_e), and Costa Rica (143 MW_e). Table2.4 (Huttrer, 2001) shows the installed capacity, electrical capacity and energy production of the 21 countries respectively in the year of 2000 (Fridleifsson, 2001).

Table 2.4. Installed geothermal generating capacities (Huttrer, 2001).

Country	**Installed Capacity (MW_e)**	**Electricity Generation (GWh)**	**National Capacity (%)**	**National Energy (%)**
Australia	0.17	0.9	n/a	n/a
China	29.17	100	n/a	n/a
Costa Rica	142.5	592	7.77	10.21
El Salvador	161	800	15.39	20
Ethiopia	8.52	30.05	1.93	1.85
France	4.2	24.6	n/a	2
Guatemala	33.4	215.9	3.68	3.69
Iceland	170	1138	13.04	14.73
Indonesia	589.5	4575	3.04	5.12
Italy	785	4403	1.03	1.68
Japan	546.9	3532	0.23	0.36
Kenya	45	366.47	5.29	8.41
Mexico	755	5681	2.11	3.16
New Zealand	437	2268	5.11	6.08
Nicaragua	70	583	16.99	17.22
Philippines	1909	9181	n/a	21.52
Portugal	16	94	0.21	n/a
Russia	23	85	0.01	0.01
Thailand	0.3	1.8	n/a	n/a
Turkey	20.4	119.73	n/a	n/a
USA	2228	15.470	0.25	0.4
Totals	7974.06	49,261.45		

2.3.1.2. Direct Use

Direct applications of geothermal energy can involve a wide variety of end uses, such as space heating and cooling, industry, greenhouses, fish farming, and health spas.

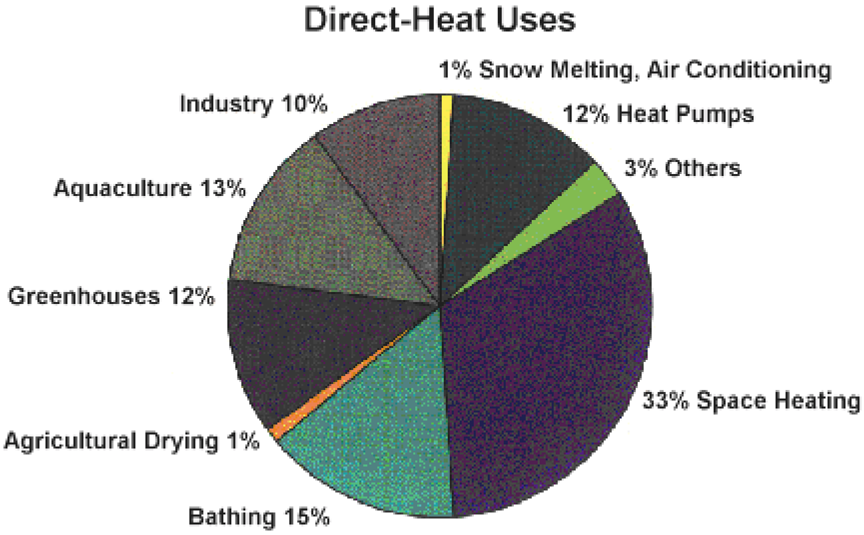

Figure 2.3. Summary of world wide energy use of direct heat (Lund and Freeston, 2000)

Figure 2.3 shows distribution of annual energy utilization in the world by sectors. Bathing here refers mainly to swimming in thermal mineral pools and pools heated by geothermal fluids. Snow melting and air conditioning (1%) have been put together. Space heating which includes both district heating and supply of domestic hot water is the largest use of geothermal fluids with some big district heating systems in operation. Heat pumps utilize 12% of the total, the major countries being Switzerland and USA. Industrial uses represent 10% of the total, with New Zealand and Iceland being the major countries utilizing geothermal fluids in this way. Fish and the other animal farming account for 13% with China and USA having the major energy utilization.

Table 2.5 shows the installed capacity and produced energy in the top fifteen direct use countries (Lund and Freeston, 2001). The direct utilization is expanding at a rate of about 10% per year, mainly in the space heating (replacing coal), bathing, and fish farming sectors.

Table 2.5. World's top countries using geothermal energy in direct uses 2000 (Fridleifsson, 2001).

Country	**Installed Capacity (MW_t)**	**Electricity Generation GWh/a**
China	2282	10531
Japan	1167	7482
USA	3766	5640
Iceland	1469	5603
Turkey	992	4377
New Zealand	308	1967
Georgia	250	1752
Russia	308	1707
France	326	1360
Sweden	377	1147
Hungary	473	1135
Mexico	164	1089
Italy	326	1048
Romania	152	797
Switzerland	547	663

2.3.2. In Turkey

Turkey is located in the Alpine-Himalayan Orogenic Belt, which constitutes major factor in having high geothermal potential. There are 170 known geothermal fields, at low (<90°C), medium (90-150°C) and high (>150°C) temperatures (Mertoğlu, 2000). Most of the development is achieved in geothermal direct use applications by 61,000 residences equivalence geothermal heating (665MW_t) including district heating, thermal facilities and 35,727 ha geothermal greenhouse heating. 195 spas are used for balneological reasons (327MW_t) (TJD, 2003).

Geothermal direct use and electricity generation installed capacities of Turkey is 992 MW_t and 20.4 MW_e, respectively. A liquid carbon dioxide and dry ice production plant is integrated to the power plant. Table 2.6 gives the geothermal utilization and the capacities in the country.

Table 2.6. Categories in geothermal utilization in Turkey (TJD, 2003)

Geothermal Utilization Categories	Capacity
District Heating	665 MW_t
Balneological Utilization	327 MW_t
Total Direct Use (Residences+thermal facilities+greenhouse)	992 MW_t
Power Production	20.4 MW_e
Carbon dioxide Production	120,000 tons/yr

The estimated geothermal power and direct use potential are about 2000 MW_e and 31,500 MW_t, respectively. However, only 3% of this potential has so far been utilized (TJD, 2003).

2.3.2.1. Electricity Generation

In Turkey, high temperature geothermal fields suitable for conventional electricity generation are as follows: Denizli-Kızıldere (200-242^{o}C), Aydın-Germencik (232^{o}C), Aydın-Salavatlı (171^{o}C), Çanakkale-Tuzla (173^{o}C), Kütahya-Simav (162^{o}C) and İzmir-Seferihisar (150^{o}C). The only operating geothermal power plant of Turkey is the Denizli-Kızıldere geothermal power plant with a capacity of 20.4 MW_e (Gokcen *et. al.*, In Press).

2.3.2.2. Direct Use

Turkey is among the first five countries in geothermal direct use applications. Table 2.7 lists geothermal district heating systems installed in Turkey. According to the table, geothermal district heating applications have started in 1987 with the heating of 600 residences in Balıkesir-Gönen and reached 52,000 residences (665 MW_t), recently (Hepbaşlı and Çanakçi, 2002).

Table 2.7. City based geothermal district heating systems installed in Turkey (Hepbaşlı and Çanakçi, 2002).

Location	**Province**	**Capacity (MW_t)**	**Geothermal Fluid Temperatures (^oC)**	**Year Commissioned**	**Installed capacity (residence)/ number of dwellings heated**
Gönen	Balıkesir	32	80	June 1987	4500/3400
Simav	Kütahya	25	120	October 1991	6500/3200
Kırşehir	Kırşehir	18	54-57	March 1994	1800/1800
Kızılcahamam	Ankara	25	80	November 1995	2500/2500
Balçova (Narlıdere)	İzmir	72	115	October 1996	20,000/6849 (728)
Kozaklı	Nevşehir	11.2	90	1996	1250/1000
Afyon	Afyon	40	95	October 1996	10,000/4000
Sandıklı	Afyon	45	70	March 1998	5000/1700
Diyadin	Ağri	42	78	September 1998	2000/1037
Salihli	Manisa	142	94		20,000

CHAPTER III

ENVIRONMENTAL EFFECTS OF GEOTHERMAL ENERGY

There is no way of producing or transforming energy into a form that can be utilized by man without making some direct or indirect impact on environment. Nevertheless, geothermal energy production generally has a well-deserved image of an environmentally friendly energy source when compared with fossil fuels and nuclear energy.

The extent and nature of environmental impacts of geothermal development are determined by the nature and the characteristic of geothermal fluid described in Table 3.1.

Table 3.1. Characteristics of geothermal resource and the effects on development and environment (Brown, 1995; Freeston, 1993; Dickson and Fanelli, 1995)

Resource Characteristic	**Effects**
Temperature	Determines the type of technology used; the type of technology (direct use, flash or binary power plant) determines whether there are emissions to the atmosphere.
Chemical Composition	Determines the nature of air emissions (if any), and the nature of the fluids that may be discharged.
Depth	Determines size of the drilling rigs required to extract the resource. Larger drill rigs are used to reach deeper reservoirs; the larger rigs require greater surface disturbance for larger drilling pads.
Reservoir rock formation	Determines the duration of drilling. Difficult subsurface conditions can extend the drilling time and the associated effects of drilling.
Areal extent	Determines how many power plants may be developed, with the accompanying impacts and surface disturbance.

Environmental effects differ depending on the type of the geothermal field and the application. In general, geothermal development will have an impact on the physical, chemical and biological environment through liquid and gas discharges. Geothermal development will also have socio-economic effects.

3.1. Impacts on Physical Environment

Exploration, development and utilization of a geothermal field can have a significant impact on physical environment surrounding the resource.

3.1.1. The Landscape

In general, the area required for geothermal development is a function of the power output of development, the type of countryside and the properties of the reservoir. Land is required for drill pads, access roads, steam lines, power plant and transmission lines. The actual area of land covered by the total development can be significantly higher than the area required for these components. Estimates range from 10% to 50% with 20% of the total area being the average.

Road construction in steep environments normally involves extensive intrusion into the landscape and can often cause slumping or landslides with consequent loss of vegetation cover. The lack of vegetation then allows greatly accelerated erosion with the possibility of further slumping and landslides and increased suspended sediments in the surrounding watershed. The impact of this erosion can be minimized by careful planning to reduce the number of steeply-sloping exposed banks, and remedial action such as planting fast-growing trees which bind the soil.

The pipelines that will transport the geothermal fluids and construction of the utilization plants, will also affect animal and plant life and the surface morphology. Pipeline corridors are typically 5 m in width and depending on the pipe size, may need access roads for construction and maintaining. Pipelines are often painted to blend into the landscape. Transmission lines require corridor free overlying vegetation, and access roads are required for construction of large steel pylons.

Most studies do not consider visual impact and aesthetic to be a problem, since the structures are low in profile and can be blended into the natural surroundings. The impact of permanent features like pipelines can be minimized by painting and avoiding changes of form and line such as the use of horizontal rather than vertical expansion loops (Brown, 1995).

3.1.2. Noise

Noise is one of the most ubiquitous disturbances to the environment from exploration drilling, construction and production phases. Table 3.2 gives typical noise for equal subjective "loudness" for particular noise intensity at different frequencies (Freeston, 1993).

The potential impact of noise depends not only on its level but also on the proximity of receptors (people, animals, etc.) to the site and nature of the noise. Noise is attenuated with distance (by about 6dB every time the distance is doubled), although lower frequencies (e.g. noise from drill rigs) are attenuated less than higher frequencies (e.g. steam discharge noises).

On the site itself, workers can be protected by wearing ear mufflers during drilling and discharge tests. The impacts from noise during drilling and construction can be reduced by the use of best practice. During normal operation, it should be possible to keep noise levels down to below 65dBA, at one kilometer; the noise should be practically indistinguishable from other background noises (Armannsson and Kristmannsdottir, 1992).

3.1.3. Degradation of Thermal Features

Natural features associated with high temperature geothermal systems are geysers, fumaroles, hot springs, hot pools, mud pools, and 'thermal' ground with special plant species. These features may be important either for their cultural or ecological significance or tourist attractions. Exploitation of a system leads to a decline in the reservoir pressure, which can result in a decline of such features (in size/or vigor), or even their death.

In some cases, thermal features of particular interest or cultural value may be specially protected (e.g. through designation as National Parks), and be off limits to development. At other sites the only way to prevent or minimize the decline of thermal features is to minimize the reduction in reservoir pressures during exploitation but there are currently no viable techniques apart from those which would severely reduce production. The only possible technique would be to alter the way in which the energy is used, such as by not removing the fluid but instead only transferring the heat using heat exchangers. However, with current technology, this would involve a large reduction in the amount of energy that could be extracted, and necessitate drilling more wells (Brown, 1995).

Table 3.2. Typical noise levels (Freeston, 1993).

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

3.1.4. Hydrothermal Eruptions

Although rare, hydrothermal eruptions constitute a potential environmental hazard with high temperature, liquid-dominated fields. They occur when steam pressure in aquifers near the surface builds up to a pressure at which it ejects the ground over it, creating a crater 5 m to 500 m in diameter and up to 500 m in depth (although most are less than 10m deep).

3.1.5. Ground Subsidence

In the early stages of a geothermal development, geothermal fluids are withdrawn from a reservoir at a rate grater than the natural inflow into the reservoir. This net outflow results in the rock formations at the site becoming compacted (particularly in the case of clays and sediments), leading to subsidence at the surface. Key factors causing subsidence include:

- A pressure drop in the reservoir as a result of fluid withdrawal,
- The presence of fluid above or in the upper part of a shallow reservoir of a geological rock formation, which has a high compressibility,
- The presence of high permeability paths between the reservoir and the formation (and through to the ground surface).

If all of these conditions are present then ground subsidence is likely to occur. In general, subsidence is greater in liquid-dominated fields due to the geological characteristics typically associated with each type of field. Ground subsidence can have serious consequences for the stability of pipelines, drains, and well casings at a geothermal field. If the field is close to a populated area, the subsidence could lead to instability in dwellings and other buildings, in other areas, the local surface watershed systems may be affected.

3.1.6. Induced Seismicity

Most high-temperature geothermal systems lie in tectonically active regions where there are high levels of stress in the upper parts of the crust; this stress is manifested by active faulting and numerous advantages. Studies in many high temperature fields have shown that the reinjection of fluids into the field during exploitation of the reserves can result in an increase in the number of small magnitude earthquakes (microearthquakes) within the field. Detailed studies show that the induced microearthquakes cluster (in space) around and below the bottom of the reinjection wells and so the effects at the surface are generally confined to the field. To date, such microearthquakes have not caused any serious damage. Impacts can be limited by reducing re-injection pressures to a minimum and ensuring that buildings on the site are earthquake resistant.

3.1.7. Thermal Effluents

Geothermal power plants utilize relatively low source temperatures than conventional power plants to provide the primary energy for conversion to power production. The efficiencies are much lower in geothermal plants than other types of power plant, but the waste heat per MW of electricity generated is much larger. Typical amounts of waste heat produced by various energy sources are given Table 3.3 (Geothermal Energy Recent Developments, 1978)

Table 3.3. Typical amounts of waste heat produced by various energy sources (Geothermal Energy Recent Developments, 1978)

Energy Source	**Waste Heat (×10^{10}kWh/year)**
Nuclear	1.886
Coal	1.20
Fuel oil	1.20
Natural gas	1.20
Vapor dominated geothermal	4.50
Water dominated geothermal	9.70

In water dominated systems, the waste heat is divided between that due to heat contained in the waste water and that contained in the steam.

Most geothermal developments dispose of waste geothermal water by deep reinjection, where the environmental impact due to the heat is negligible. A few geothermal developments still dispose of their waste geothermal water into local waterway, such as Wairakei Geothermal Power Plant in New Zealand and Kızıldere Geothermal Power Plant in Turkey. In these cases there is increasing realization of the need to protect the environment from the heat input.

The heat contained in the steam is the principal heat used to generate electricity. The waste heat from steam is usually in the form of condenser outflows condensing turbines or atmospheric discharges in atmospheric exhaust turbines. When a cooling tower is used, the heat contained in the condenser outflow is vented to the atmosphere. Discharge to surface waterways will more likely affect the local biota.

3.2. Chemical Impacts of Geothermal Development

The possible chemical contamination of land, air and water can have some undisered effects on human health, domestic animals and wildlife during geothermal development. Geothermal power generation is often considered as a “clean” alternative to fossil fuel and nuclear power stations. Although chemical contamination of the environment may occur through gas, steam and waste water discharge, impacts can be minimized or even eliminated by careful management (Brown, 1995). Generally, chemical content of geothermal fluid and their average concentrations s are given Figure 3.1 (Serpen, 1999).

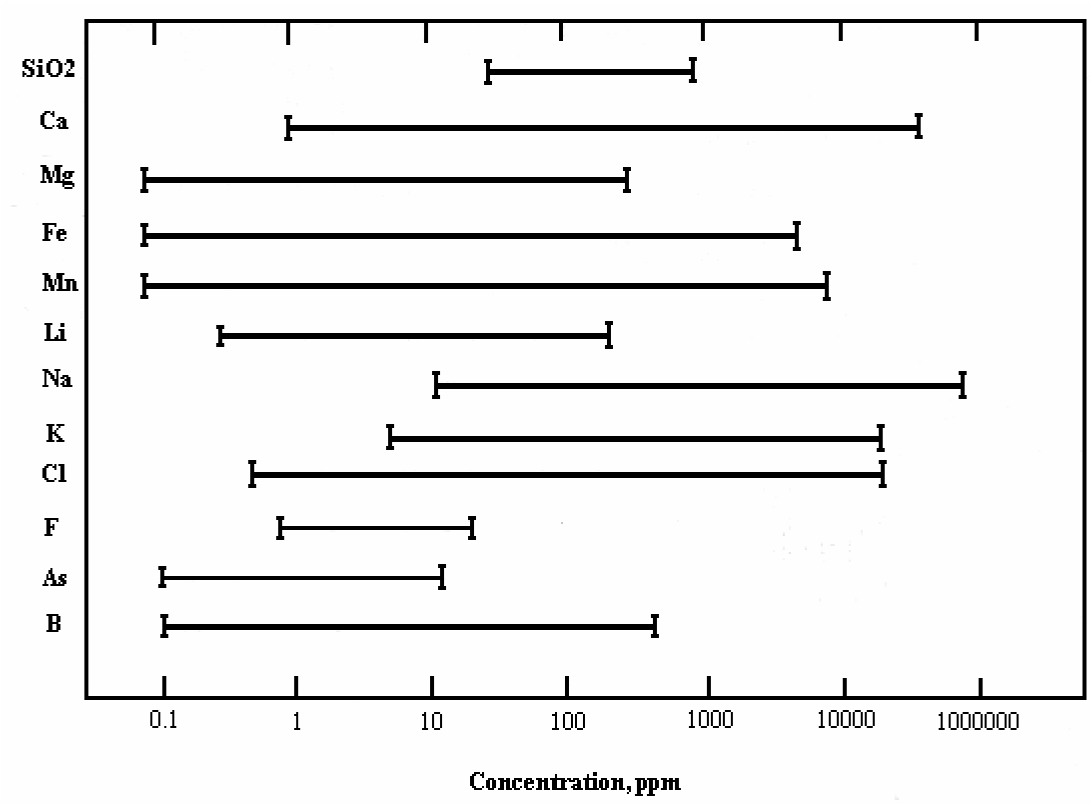

Figure 3.1. Chemical content of geothermal fluid and their average concentrations

3.2.1. Air Pollution

Geothermal power generation using a standard steam-cycle plant will result in the release of non-condensable gases, and fine solid particles into the atmosphere (Figure 3.2). The most significant ongoing gas emission will be from the gas exhausters of the power station, often discharged through a cooling tower. Although gas and particles discharge will also occur during well drilling, bleeding, cleanouts and testing as well as from line valves and waste water degassing, this is usually insignificant by comparison (Brown, 1995).

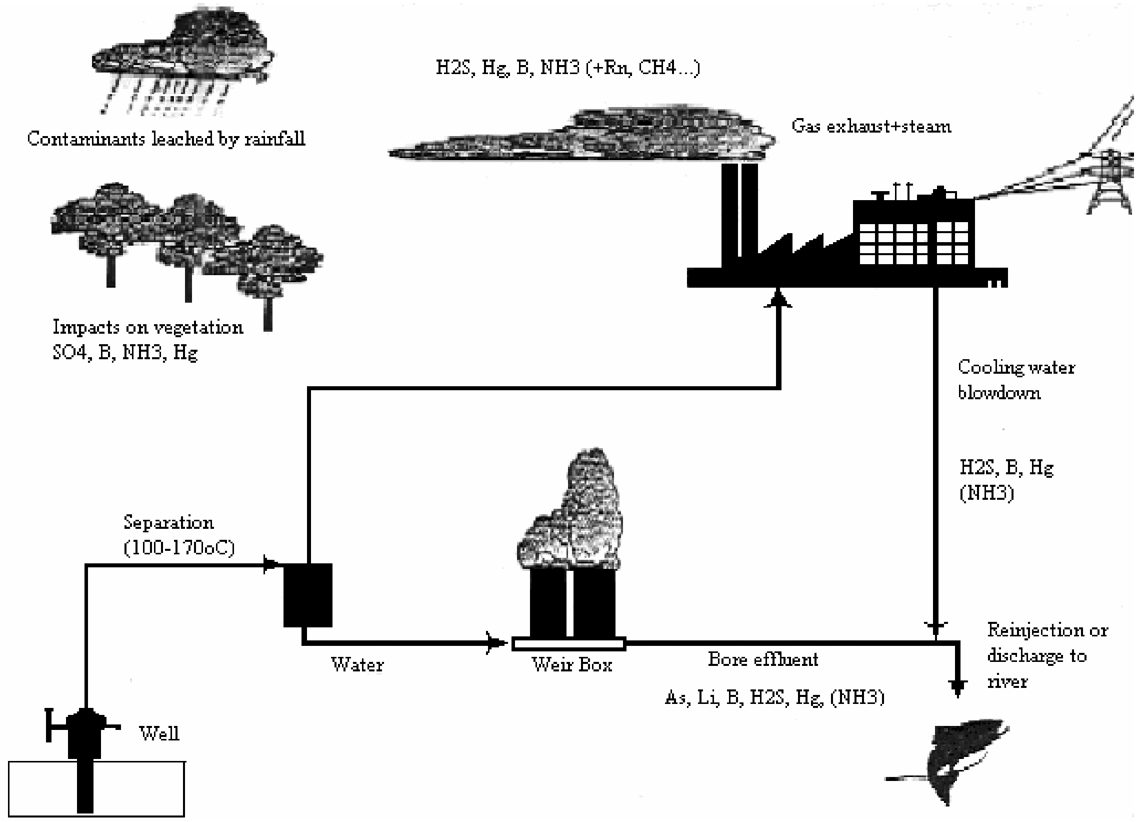

Figure 3.2. A summary of the discharges and main chemical contaminants from steam-cycle geothermal power plant on a water dominated geothermal field (Brown,1995).

The non-condensable gases in geothermal steam may be released into the atmosphere depending on which type of generating plant is used. Noncondansable gases mainly carbon dioxide (CO_2) and hydrogen sulphide (H_2S). As with CO_2 emissions, H_2S emissions can very significantly from field to field, depending on the amount of H_2S from contained in the geothermal fluid and the type of plant used to exploit the reservoir.

Although mainly CO_2, the geothermal gases can include very high concentrations of H_2S as shown Table 3.4 (Brown, 1995). The impacts of H_2S discharge will depend on local topography, wind patterns, and land use. On the other hand, it includes an unpleasant odor, equipment corrosion, eye irritation and respiratory damage in human. H_2S releases to the atmosphere and is oxidized to sulphur dioxide (SO_2), and then to sulfuric acid (H_2SO_4) which cause acid rain resulting in corrosion to plant equipment.

Geothermal gases in steam may also contain ammonia (NH_3), traces of mercury (Hg), boron vapors (B), hydrocarbons such as methane (CH_4) and radon (Rn). B, NH_3, and to a lesser extent mercury, are leached from the atmosphere by rain, leading to soil and vegetation contamination. B, in particular, can have serious impact on vegetation contamination. These contaminants can also affect surface waters and impact aquatic life. Radon (Rn), a gaseous radioactive isotope naturally present in Earth crust, is contained in the steam and discharged into the atmosphere. Although Rn levels should be monitored, there is little evidence that Rn concentrations are raised above background level by geothermal emissions (Barbier, 2001).

Table 3.4. Contaminant concentrations (ppm) in selected geothermal fluids and gases and in a world average freshwater (Brown, 1995).

	B	**Hg**	**H_2S**	**NH_3**
Fresh water	0.01	0.00004	<dl	0.04
Deep well waters				
Salton Sea (US)	390	0.006	16	386
Cerro Prieto (Mex)	19	0.00005	0.16	127
Wairakei (NZ)	30	0.0002	1.7	0.20
Steam (s) or non-condensable gases (ncg)				
Geysers (US)(s)	16	0.005	540	700
Geysers (US) (ncg)	-	-	222	52
Cerro Pieto (s)	-	0.04	-	-
Cerro Pieto (ncg)	-	-	350	190
Waikarei (s)	0.23	0.002	52	4
Waikarei (ncg)	0.052	-	400	7.5

3.2.2. Water Pollution

Pollution of rivers and lakes is a potential hazard in power production and the management of spent geothermal fluids. Once heat has been extracted from geothermal fluids, they are either discharged (into waterways or evaporation ponds) or reinjected deep into the ground. In the case of surface disposal pollution problems may occur due to:

- The large volumes of fluid involved,
- The relatively high temperature of the fluid,
- The toxicity of the waste fluid.

In vapor dominated reservoirs, most of the pollutants are found in the vapor state, and the pollution of water bodies is more easily controlled than in water-dominated reservoir (Barbier, 2001). Discharges of the temperature depend on the original temperature of the reservoir fluid and type of plant used. As an example, at the 156MW$_e$ Wairakei Geothermal Power Plant in New Zealand (which is a liquid-dominated high temperature reservoir), 6500 tone/h of water are discharged every hour at a temperature of 60-80^{o}C (Nicholson, 1992) and 20.4 MW$_t$ Kızıldere Geothermal Power Plant in Turkey, 1000 tone/h of water discharged at a temperature of 147^{o}C.

Discharge of waste water is also an important source of chemical pollutions. The chemicals dissolved in the waste water depend on the geochemistry of the reservoir and the power plant operating conditions and may vary widely between fields (Hunt and Brown, 1996). Fluids from high temperature reservoirs can include a range of ions (e.g. chlorides, sodium, potassium, calcium, fluoride, magnesium, silicate, iodine, antimony, strontium, bicarbonates) and, of most concern, several toxic chemicals: boron, lithium, arsenic, hydrogen sulphide, mercury, rubidium, and ammonia. However, the low-to-moderate temperature geothermal fluids used in most direct-use applications generally contain low levels of chemicals and the discharge of spent geothermal fluids is seldom a major problem.

Most of the chemicals are present as solute and will remain in solution and be carried on from the point of discharge. However, some will be taken up into river or lake sediments, where they may accumulate to high levels. Indeed, concentrations in the sediments may become higher than the soluble concentrations of the species in the water, so that any remobilization of the species in the sediment could lead to a potentially toxic flush of the species into the environment. Chemicals which remain in solution may be taken up by aquatic vegetation and fish (Nicholson, 1992), and some can also move further up to the food chain into birds and animal residing near the river. For example, in New Zealand, annual geothermal discharges into the Waikato River contain 50kg mercury. This is regarded as partly responsible for the high concentrations of mercury (often greater than 0.5mg/kg of wet flesh) in trout from the river and high (greater than 200µg/kg) sediment mercury levels.

In addition to pollution effects, the discharge of large volumes of waste water may increase erosion in water ways and may also lead to the precipitation of minerals such as silica near the outlet.

Allowing the effluent water to form ponds (ponding) reduces the temperature of water and encourages the minerals to sediment out. It can help to reduce contaminants in the waste water but can also lead to environmental impacts (e.g. contamination of groundwater if the pond lining is not impermeable). The impacts of waste water disposal can be minimized if waste water and condensate are collected and reinjected via deep wells at the edge of the field.

3.3. Biological Impacts of Geothermal Development

Geothermal energy developments can not, obviously, be located in land of environmental significance and pose threat to native flora and fauna. The biological impacts of geothermal development include impacts on animal and human health, and vegetation as shown Figure 3.3. To control these impacts, criteria are set to provide an upper limit for contaminant concentrations in the environment. Above these recommended levels, adverse effects on biological life can be expected; below these limits, there should be no long or short-term effects. Different criteria have been developed for different purposes; for air, for drinking water, for aquatic life production, for crop irrigation and stock watering, and to protect the aesthetic quality of the environment (Brown, 1995). Some chemicals which have biological impacts on environment are given in the following paragraphs.

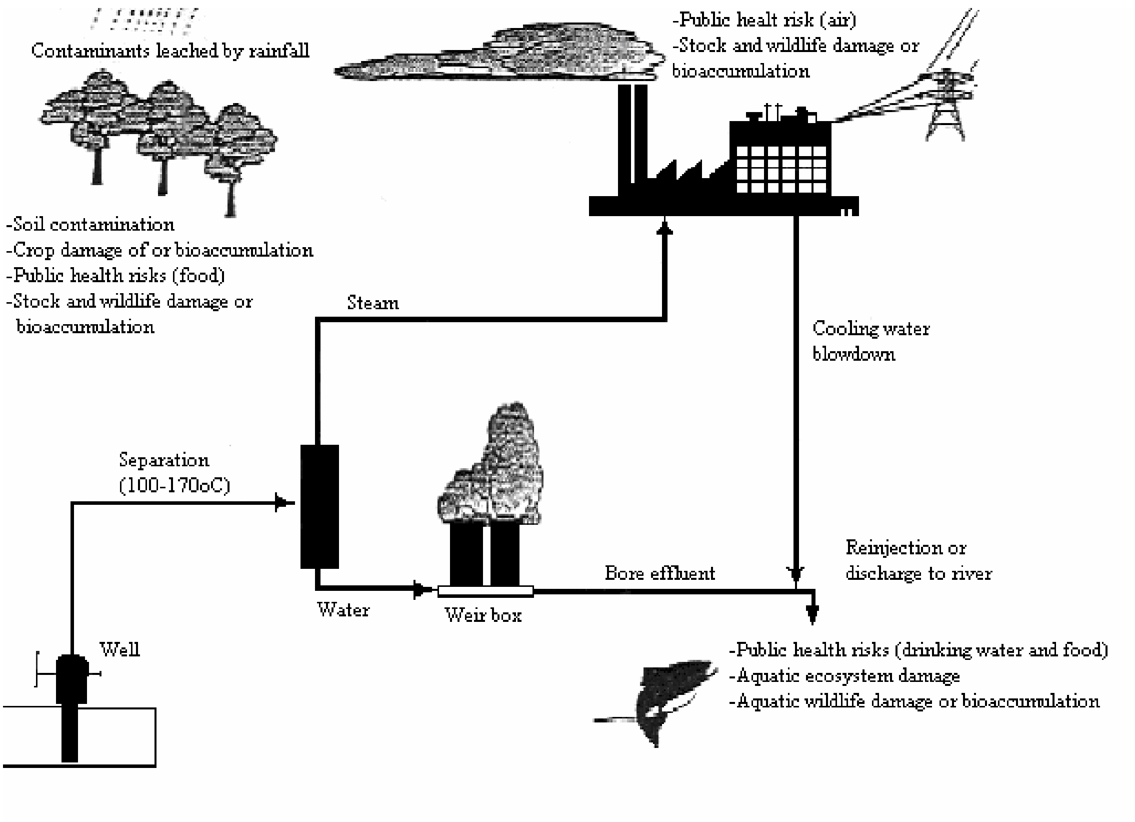

Figure 3.3. Potential biological impacts of geothermal development (Brown, 1995)

3.3.1. Lithium (Li)

Lithium does not appear to have an adverse affect on human health or aquatic life. However, Li may affect some plants, crops, citrus trees etc. for example, citrus trees are very sensitive to Li, with severe toxicity symptoms occurring at concentrations of 0.1-0.25 mg/L.

3.3.2. Arsenic (As)

Arsenic, a naturally occurring element, is found throughout the environment; for most people, food is the major source of exposure. Acute (short-term) high-level inhalation exposure to arsenic dust or fumes has resulted in gastrointestinal effects (nausea, diarrhea, abdominal pain); central and peripheral nervous system disorders have occurred in workers acutely exposed to inorganic arsenic (EPA, 2003). Chronic (long-term) inhalation exposure to inorganic arsenic in humans is associated with irritation of the skin. Lung cancer has also been lined to long-term inhalation of particulate As.

Very high concentrations of arsenite (As in a +3 oxidation) can lead to chronic or even acute poisoning.

Criteria for stock watering and aquatic life are set to prevent chronic toxicity to livestock and aquatic biota.

3.3.3. Boron (B)

Long term exposure to B leads to mild gastro–intestinal irritations in human as B is rapidly and almost completely adsorbed by the intestinal tract. For human, this normally occurs through food intake, rather than through drinking water. High concentrations of B in drinking water can cause weight loss in stock, but does not appear to affect aquatic life.

B is essential to the normal growth of all plants, but can be toxic when present in excess of the concentrations required. B limits are recommended for irrigation waters, although crop tolerance can vary depending on the type of soil (Brown, 1995).

3.3.4. Mercury (Hg)

The fundamental problem with Hg is its tendency to accumulate through the food chain: processes know as “bioaccumulation”. Most of the mercury in water, soil, sediments, or plants and animals is in the form of inorganic mercury salts and organic forms of mercury such as methylmercury, which is the most toxic form. Methyl mercury affects the central nervous system, while inorganic Hg attacks the kidneys. Human ingestion of Hg occurs mainly through food, although the WHO (1993) drinking water criteria are based on a 10% intake through drinking water.

Animals are more sensitive than plants to both inorganic Hg and to methyl mercury. Nearly all of the mercury that accumulates in fish tissue is methylmercury. Inorganic mercury, which is less efficiently absorbed and more readily eliminated from the body than methylmercury, does not tend to bioaccumulate (EPA, 2003).

3.3.5. Hydrogen Sulphide (H_2S)

At low concentrations it has an obnoxious odor similar to rotten eggs. Chronic and subchronic exposure to low concentrations of H_2S does cause long-term health problems in humans. Normally, H_2S is found by humans at 8 ppb. At low concentrations, it is primarily a nuisance, but as concentrations increase, it may irritate and injure the eye (10 ppm), the membranes of the upper respiratory tract (50-100 ppm), and lead to loss of smell (150 ppm). H_2S is acutely toxic to humans when at sufficient concentration and exposure to concentrations of >150 – 200 ppm for 48 hours or more can result in death.

Any criteria of drinking water is proposed by WHO (1993), other than a limit set to avoid taste and odor.

H_2S is caused acidic rain and this may potentially have a detrimental effect on vegetation in long-term. Separately, H_2S is very toxic to fish.

3.3.6. Ammonia (NH_3)

NH_3 in drinking water does not directly affect human health. It can, however, compromise disinfection efficiency during drinking water treatment, and cause taste and odor (aesthetic) problems. Nor is NH_3 a major consideration in either stock or irrigation water. NH_3 is, however, acutely toxic to freshwater organism, particularly fish. Acute toxicity in fish is indicated by equilibrium loss, increased oxygen uptake, coma and death.

NH_3 in a freshwater is predominantly present as the non – toxic ammonium ion ($NH4^+$), so criteria are normally given in terms of total $NH_3 + NH_4^+$, and vary as a function of temperature and pH.

3.3.7. Existing Criteria and Guidelines

Many countries have developed or adapted criteria to protect their own environment. The criteria may be designed to protect native species or ecosystem from those of another country with a similar biological diversity.

The WHO (1987) air quality criteria are for the protection of occupational health and public health. For organisms other than human, evidence of adverse effects of atmospheric contamination is difficult to identify and to quantify. Air quality guidelines are given in Table 3.5 (Brown, 1995).

Plants are generally more seriously affected by low concentrations of H_2S than animals or humans. Moreover, criteria for Hg vapor concentrations do not take account of bioaccumulation of Hg in plants or animals, or of higher than average Hg ingestion. Arsenic may be present in the atmosphere as particulates, although particulate As inhalation is likely to be an occupational health risk, rather than public health problem.

Table 3.5. Guidelines for air quality (mg/m^3) to protect public health (WHO)

Contaminant	**Average over:** **30 min**	**24 hrs**	**12 months**
H_2S	0.008-0.08	0.15	-
Hg	-	-	0.001 (indoor)
As	-	-	<0.001

Crops and stock also need to be protected if contaminated water is to be used for irrigation. Limits for irrigation water are given in Table 3.6. Like the human health criteria, guidelines for irrigation contaminant concentrations are relatively transferable between countries.

Drinking water guidelines have formed the basis for the drinking water criteria of many countries, and are often adopted with few, if any alterations which are given in Table 3.7. These criteria are set to avoid odor and taste problems with drinking water supply. WHO lowered their criteria for As from 0.05 to 0.01 ppm following the identification of As as a probable carcinogen. However, Hg ranges from 0.002 mg/L in EPA to 0.01 mg/L in WHO and TS.

Table 3.6. Criteria for irrigation waters (mg/L)

Parameters	**TS**[1]	**WRC**[2]	**USEPA**[3]	**CCREM**[4]
As	0.1	0.40	0.10	0.10
B	0.33-1.25[5]	-	0.75	0.5
Li	2.5	2.5	2.5	2.5
Hg	-	0.001	-	-

[1] TS: Turkish Standard

[2] WRC: The water Research Council's "United Kingdom Water Quality Standards Arising from European Community Directives

[3] USEPA: The US Environmental Protection Agency's "quality Criteria for Water"

[4] CCREM: The Canadian Council of Resource and Environment Ministers "Water Quality Guidelines"

[5] Value of different crops

Table 3.7. The maximum concentration of the parameters in mg/L which were regulated by Environmental Protection Agency (EPA), Turkish Standard (TS) and the World Health Organizations (WHO)

Contaminant	**TS**	**EPA**	**WHO**
As	0.01	0.05	0.01
B	0.3	-	0.3
Cl	250	250	250
Hg	0.001	0.002	0.001
H_2S	0,04	-	0.05
NH_3	0,05	-	1.5

3.4. Socio–Economic Impacts of Geothermal Development

A socio–economic study aims to determine the changes in the conditions within the geothermal project which have evolved as direct and indirect impacts of the project. The study provides a guide on how the geothermal project can be kept in consequence with the socio–cultural and economic situations in the area. These standard sources of information for socio – economic analyses consisting of a combination of the following:

- Secondary data or records utilizing usually a 10–year period trend,
- Surveys in the form of personal interviews, telephone interviews or mailed forms,
- Consultations through dialogues, focused group discussions, and multisectoral assemblies.

3.4.1. Parameters for Analysis

The socio–economic parameters may vary depending on the magnitude of the project. Generally, the following parameters or indicators are measured as bases for the assessment of the impacts:

- Demography (population densities and characteristics, morbidity and mortality rates, productivity levels, and inventory of directly affected households),
- Community lifestyle, needs and problems,
- Housing and community facilities (housing supply, status of adequacy of facilities for water, power, sewerage, and drainage systems),
- Basic services available (water supply, sanitation, road, education etc.),
- Income and employment (status, job availability, income levels, spending patterns, and loan and credit facilities),
- Socio–political organization (local government structure and leadership, institutional capabilities, and linkages, political affiliations, non–governmental people's organizations),
- Socio–cultural problems (settlement patterns, property compensation, cultural heritage, alteration of archeological, scenic, and aesthetic resources),
- Local indices (prices of goods, land prices, and incomes),
- Landscape,
- Community perception on the project.

Social impacts are the effects of the project to the society in general and to the host community in particular. Impact assessment must specify the potential negative or positive impacts; the degree of effects (high or low, long term or short–term, reversible or irreversible) and the aerial extent of impacts. These impacts can be enhanced (in the case of positive effects) or mitigated or prevented (in the case of negative effects), the social investigator must also discuss the impacts with and without the project. Impacts fall under various categories; physico–chemical sector (public health effects, dislocation, induced development, etc.), economic sector (poverty, employment, traffic, etc.); and institutional sector (cultural, population changes, security, etc.).

The socio–cultural and economic impacts commonly observed in geothermal projects are enumerated below:

I. Physico–chemical changes
   - Dislocation of domicile affecting economic and social systems as transfer of environment may result in incompatible environments leading to lower production, inappropriate skills and destruction of community structure.
   - Landscape alteration and remediation and their effects on hydrology, aesthetic and cultural/historical sites public health affects leading to greater incidence of epidemics.

II. Economic changes
   - Increased employment and secondary trades with corresponding increase in per capital income.
   - Reduction in resource base.
   - Community development fund inflows from geothermal royalties, taxes and other commitments and negotiated benefit packages
   - Increased traffic incidence (for big projects but effects are interim during construction).
   - Change of lifestyle from rural to industrial/economic setting.

III. Institutional changes
   - Cultural adaptation (enables cultural communities to participate in national development).
   - Danger of cultural erosion if process of cultural economic development not properly managed.
   - Population changes in composition and number due to induced development leading to pressure on resource base.
   - Effects on aesthetic and human interest areas (scenic vistas, open space qualities, unique physical features, historical and archeological sites).

The other half of the analysis involves the identification of recommendations such as preventive, mitigating, and contingency measures which may be institutional or compensatory in nature, the formulation of social enhancement programs, and the development of a monitoring programme (Brown, 1995).

3.5. Literature Review

3.5.1. In the World

As the usage of geothermal energy increased in the last century, the resultant environmental problems came into scene. To investigate the effects of geothermal energy use on environment, numerous studies have been conducted throughout the world. Most of the studies in literature are conducted for geothermal power plants where high temperature is used. The parameters investigated are noncondansable gases such as CO_2, Hg and H_2S, total dissolved solids (TDS), conductivity (EC), Cl, SO_4 As, Al, B, Cu, Pb, etc. Some specific studies are summarized below.

A study was conducted in the Mt. Amiata Geothermal Field in Italy. Three areas were selected and samples were analyzed for their As, B and Hg content. The results showed that the geothermal power plants do not represent a macroscopic source of arsenic and boron contamination in the Mt. Amiata area. As far as is concerned, at the Hg mining area of Mt. Amiata concentrations were extremely high both in soil and epiphytic lichens, and anomalous content in these organisms was due to the uptake of elemental mercury originating from soil (Loppi, 1997).

Bargagli *et. al.* (1997) studied the environmental impact of trace element emissions from geothermal power plants in Italy, 67 sites at increasing distances from the five power plants were selected for the sampling of plants. The results showed that trace element in the noncondensable fraction of geothermal vapors affect the environment around the power plants. From the toxicological and environmental points of view, Hg and H_2S emissions are probably those with the highest impact in the geothermal field.

Abbasi *et. al.* (2000) monitored the surface distribution, land subsidence, noise, thermal, air, and water pollution in geothermal region. As a result of this study the land subsidence and noise pollution have showed major affects.

Widagda *et. al.*, (2000) studied the physical and chemical properties of liquid waste of the Tulis River, Italy. The quality parameters to be analyzed were total dissolved solids (TDS), conductivity (EI), sodium absorption ratio (SAR), chloride (Cl), sulphate (SO_4), and boron (B). From the result of various analyses naturally during the dry season proves that its unsuitable to be implemented as irrigation water.

Concentrations of lead, zinc (Pb), copper (Cu), cadmium (Cd), and boron (B) were investigated in geothermal water from wells and cooling tower discharge, as well as in soils, and plants that are in contact with geothermal waters of the Olkaria field in Kenya. The study has shown that concentrations of Pb, Cu, Cd, and B are higher at the Olkaria geothermal power station than in Lake Naiwasha waters. Waste steam is highly acidic, and contains high amounts of zinc. According to the study, Lake Naivasha sediments have anomously high concentrations of boron. (Simiyu and Tole, 2000)

Kaltschmitt (2000) conducted a study to compare heat provision from geothermal energy with the provision of heat from other renewable energy and fossil fuel energy sources. In particular, a comparison of the heat provision from the soil and groundwater with heat pumps, hydrothermal resources and deep wells as well as biomass, solar collector and light oil and natural gas was investigated. This investigation showed that the heat provision from geothermal energy could contribute considerably to reduce the environmental impact caused by the use of fossil fuel energy to accomplish the same supply task.

Loppi (2001) investigated mercury and other trace elements (Al, B, Cd, Cu, Fe, Hg, Pb, S, Zn) in the geothermal area of Bagnore (Mt. Amiata, Italy) and four sites were sampled. According to the study, sulphur was the only element found at rather high concentrations at all sites.

3.5.2. In Turkey

Although some studies have been conducted for geothermal fluid monitoring in Turkey, these studies were limited to a small area. Furthermore, very few of these studies had aimed to investigate the environmental effects of the geothermal fluid. Some studies from Turkish fields are listed below.

Aksoy (2001) studied geothermal fluid quality in Balçova-Narlıdere Geothermal Field. The samples were analyzed for components such as chloride, sulfate, fluorite, bicarbonate, magnesium, calcium, sodium, potassium, manganese, iron, aluminum, boron, silica and total dissolved solids (TDS). The study concluded that there is no important difference chemical composition of shallow and deep wells.

Doğdu *et. al.* (2002) studied water and sediment pollution of geothermal origin in the Akarcay Basin in Akcay with nine sampling station. The samples were analyzed for components such as, chloride (Cl), nitrate (SO_2), sulphate (SO_4), bicarbonate (HCO_3), ammonium (NO_4), carbonate (CO_3), nitrite (SO_3), fluoride (F), boron (B), pH, electrical conductivity, dissolved oxygen, lithium (Li), arsenic (As), and iron (Fe). It is concluded that trace elements and heavy metals are increased by geothermal fluid discharge to the river.

Groundwater pollution of geothermal origin in Akarcay Basin in Afyon was studied by Doğdu *et. al.* (2002). In this study, samplings were collected from thirty two thermal and cold water wells. In the region, arsenic, iron, boron, manganese, aluminum, iodine, sodium, potassium, calcium, magnesium, temperature, electrical conductivity, dissolved oxygen, chloride, bicarbonate, carbonate, sulphate, and finally sodium absorption ratio were investigated. Pollution of geothermal origin was determined to cold water wells which are close to the thermal wells.

Tarcan and Gemici (2002) examined the state of boron in the aquifers of the geothermal systems that occur in different geological environments and determined its environment impact in western Anatolia, Turkey. During the study, all earlier and current analyses results were used to assess the water chemistry from Gümüköy, Germencik, Kızıldere, Tekkehamam, Ortakçı, Bayındır, Salihli, Turgutlu, Simav, Saraycık, Gediz, and Gecek fields. The research showed that, the contribution of thermal waters to cold groundwater aquifers caused contamination in aquifers and surface water. In particular, high discharge wastewater disposal from geothermal power plants and district heating systems increased the boron concentration of groundwater and surface water.

CHAPTER IV

ENVIRONMENTAL LAWS AND REGULATIONS

Most countries agree that if pressures being placed on the world's natural resources continue at their current rate than eventually the world will run out of resources and no longer be able to support human life (Luketina, 2000). Because of this reason, most countries have embodied their environmental concerns in legislation. Although the actual legislation varies in detail from country to country, the overall requirements the purpose and the need for the legislation are recognized world-wide (Brown, 1995).

Geothermal is generally regarded as a benign energy source compared with nuclear and fossil fuels, but there are some environmental problems associated with its exploitation. To further the use of geothermal energy, possible environmental effects need to be clearly identified, and countermeasures devised and adopted to avoid or minimize their impact.

Different types of geothermal fields and developments have varying impacts on the environment and legislation needs to cover all possible development scenarios. Many of the regulations are focused more toward power plant than to direct use projects. In general, as development proceeds, the legislative requirements move from environmental impact reports during the pre-development stage, to gaining consents for the development and finally a monitoring role during production.

4.1. In the World

The environmental regulations of different countries are remarkably similar. For example: the United States (U.S.), the Philippines, New Zealand, and Italy. These countries have regulations that require an environmental analysis of a proposed geothermal project, as well as specific regulations that define the quantities of pollutants that may be emitted to the atmosphere or discharged to land water. There is, however, significant variation in the number of agencies involved in the environmental review of a project, and the amount of time required from application through project approval.

The USA regulations are given here as an example. Table 4.1 is summarizes major federal regulations for direct use projects and to applicable areas in the U.S. (Lund, 1998).

Table 4.1. Primary Regulations Governing Geothermal Energy Development (Lund,1998)

Primary Environmental Laws and Regulations	**Air**	**Surface Water**	**Geothermal Fluids**	**Solid Waste**	**Liquid Waste**	**Noise**	**Subsidence/ Seismecity**	**Cultural Resources**	**Biological Resources**
Federal Water Pollution Control Act	-	×	-	-	×	-	-	-	-
Safe Drinking Water Act	-	-	×	-	×	-	-	-	×
Clean Air Act	×	-	-	-	-	-	-	-	-
Resource Conservation and Recovery Act	-	-	-	×	×	-	-	-	-
Toxic Substance Control Act	-	-	-	×	×	-	-	-	-
National Environmental Policy Act	×	×	×	×	×	×	×	×	×
National Historic Preservation Act	-	-	-	-	-	-	-	×	-
Noise Control Act	-	-	-	-	-	×	-	-	-
Geothermal Resource Operational Order #4	×	×	×	×	×	×	×	×	×
Occupational Safety&Health Act	×	-	×	×	×	×	-	-	-
Endangered Species Act	-	-	-	-	-	-	-	-	×

Development of every type of geothermal development in the U.S. is governed by many environmental laws at the federal, state, and local level. The key laws that pertain to the environmental aspects of geothermal development are the:

- National Environmental Policy Act
- Geothermal Resources Operational Orders
- Specific Resource Protection Laws

In addition to the broad requirements of these laws, there are series of federal, state and local regulations that address protection of the environment for specific parameters, such as air quality, water resources, fish and wildlife, vegetation, noise resources, cultural resources, and public health and safety. Specific environmental laws include the:

- **Clean Air Act (1992):** to establish control mechanism toward air pollution and to reduce emissions which requires the application of the best available technology. Geothermal projects have not produced emissions that meet levels that require Prevention of Significant Deterioration (PSD) permitting. For direct use projects, well drilling may require a permit from the local air district.

- **Federal Water Pollution Act (1977):** to provide protection of surface waters through a permitting process. This act established the National Pollutant Discharge Elimination System (NPDES) and effluent guidelines. Under NPDES system, discharge quantities, rates, pollutants concentrations, and fluid discharge temperature are regulated by permits issued by either EPA or states with EPA-approved programs.

- **Safe drinking Water Act:** to design safing guard the primary and secondary safe drinking water supplies of the nation. The main regulation that directly affects geothermal energy recovery are those for underground injection control (UIC) designed to protect groundwater aquifers. The UIC regulations establish five disposal well categories based on well construction, practices, and fluids to be injected. Geothermal injection wells were placed in Class V.

- **Endangered Species Act (1973):** to protect in danger of threatened any species.

- **Resource Conversation and Recovery Act (1976):** to assistance safe disposal of discharged materials for technical and financial, and to regulate hazardous waste. Solids wastes that are not hazardous wastes are currently exempt from the hazardous waste regulation under the act.

- **Toxic Substance and Control Act:** to regulate commerce and protect human health in the environment by requiring testing and to use restrictions on certain chemical substances. The main impact of this act on geothermal energy development affects the sale for commercial use of by-products recovered from either liquid or solid waste streams.

- **National Historic Preservation Act (1980):** to preserve and convere the intangible elements of our cultural heritage such as arts, skills, folklike, and folkways.

- **Noise Control Act (1971):** to control noise in the state and local governments and o produce low-level noise by construction equipment, transportation equipment, any motor or engine, and electrical or electronic equipment. Primary controls of noise from geothermal energy development fall under the Occupational Safety and Health Act (OSHA) and Geothermal Resource's Operational Order (GROs) No.4.

- **Occupational Safety & Health Act (1970):** to develop specific operating requirements for the geothermal developers on federal lands. The act deals specifically with toxic materials and other harmful agents.

- **Geothermal Resource Operational Orders (GRO's):** to define specific operating requirements for the geothermal developers on federal lands. The GRO's were based on geothermal operating experience at the Geysers and at the geothermal locations on federal lands.

- **National Environmental Policy Act (1970):** to encourage harmony between people and the environment, to promote efforts to prevent or eliminate damage to the environment and the biosphere, and to enrich the understanding of ecological systems and natural resources important to the country (U.S., Department of Energy, 2003)

National Environmental Policy Act (NEPA) is one of the primary U.S. laws for the protection of the environment. NEPA requires that the agency include a program for monitoring and enforcement for each mitigation measure adopted.

When project or action may have a significant effect on the environment, NEPA requires that federal agencies prepare an Environmental Impact Assessment (EIA). Environmental impact assessment (or assessment of environmental effects) is a process for assessing the environmental implications of a decision to enact legislation, to implement policies and plans, or initiate development projects. The main aims of the process of EIA are to:

- to encourage and provide opportunities for public participation in environmental aspects of proposals before decisions are taken;
- to ensure that proponents of proposals take primary responsibility for protection of the environment relating to their proposals;
- to facilitate environmentally sound proposals by minimizing adverse aspects and maximizing benefits to the environment;
- to provide a basis for ongoing environmental management including through the results of monitoring; and
- to promote awareness and education in environmental values.

An EIS must provide a complete discussion of significant environmental effects and inform the public and decision makers of reasonable alternatives that would avoid or minimized adverse environmental affects. The EIA process can be applied to the assessment of all development likely to have environmental effects.

For projects that will not have a significant effect on the environment, an Environmental Assessment (EA) must be prepared. EA is a process which identifies and analyses environmental change over time in an area or region. It begins with the identification of critical issues and environments and includes the effects of monitoring to assist decision-making on plans, projects, and activities.

4.2. In Turkey

Although no specific guidelines or standards have been established for geothermal development, some regulations have been developed to protect environment. The Environment Law (coded 2872) which came into force in 1983 initiates from the principle of the “the polluter pays" and handles the environmental issue on a very broad scope. The aim of the Law is twofold, namely (a) to consider the environment as a whole, to prevent and eliminate pollution, (b) to allow the management of the natural and historical values and the land in such a way as utilizing and preserving such richness to concern for the future generations as well. The measures to be taken and the arrangements to be made should be compatible with the economic and development targets. According to the basic principles that govern the application of the Environment Law and as stated in constitution, citizens as well as the state bear responsibility for the protection of the environment. The principle in economic activities for determining the implementation of production methods to minimize and solve environmental problems is one of the basic of the Environment Law. The Environmental Impact Assessment Regulation (EIAR) was put into force on 7th of February, 1993. The purpose of Turkish EIAR is to regulate the administrative and technical principles which will be obeyed during the process of environmental impact assessment to be realized with a view to identify and to evaluate all possible impacts on environment of investment decisions of all public or private organizations, institutions and agencies whose proposed activities may cause environmental problems; to prevent or mitigate the adverse impacts which may cause any harm to the environment and to asses the alternatives of the activities (World Energy Council, 2003).

According to Turkish Constitutional Law, the natural resources such as water, oil, minerals and geothermal belong to the state. Concessions for developing these natural resources are granted by the state within the framework of separate water, mining and oil codes. Unfortunately, there is no legislation for geothermal resources that are regulated by a set of several old and complex laws and regulations.

One of the most used codes in geothermal cases was issued as far back as in 1926 and regulates the utilization of hot springs as health spa. Another regulation enacted by the Ministry of Culture and Tourism regulates the geothermal resources involved in tourism activities. In early 1980's geothermal resources were briefly taken under the Mining Code. A few years later this was abolished, apparently with the intention of issuing a new geothermal law, yet this has never materialized. Therefore, in order to develop a geothermal project, one must follow very tortuous and cumbersome bureaucratic routes that involve more than one ministries and governmental agencies (Serpen and Toksoy, 2001).

Research and investigations are conducted by The Governorship of İzmir in order to constitute regulations as draft law about geothermal energy for both present geothermal sources and any possible sources to be discovered in the forthcoming years. The aim of these draft law is to provide environmentally friendly and sustainable means of managing geothermal facilities. However, draft law is not already in use as official legislation.

CHAPTER V

BALÇOVA GEOTHERMAL FIELD AND INVESTIGATION OF GEOTHERMAL FLUID CHEMISTRY

Balçova Geothermal Field (BGF) is located in the vicinity of Balçova town which is approximately 7 km away from the Centrum of İzmir province in the western tip of Turkey, and is endowed with considerably rich geothermal resources. The Balçova Geothermal Field covers a total area of about 3.5 km^2 as shown Figure 5.1.

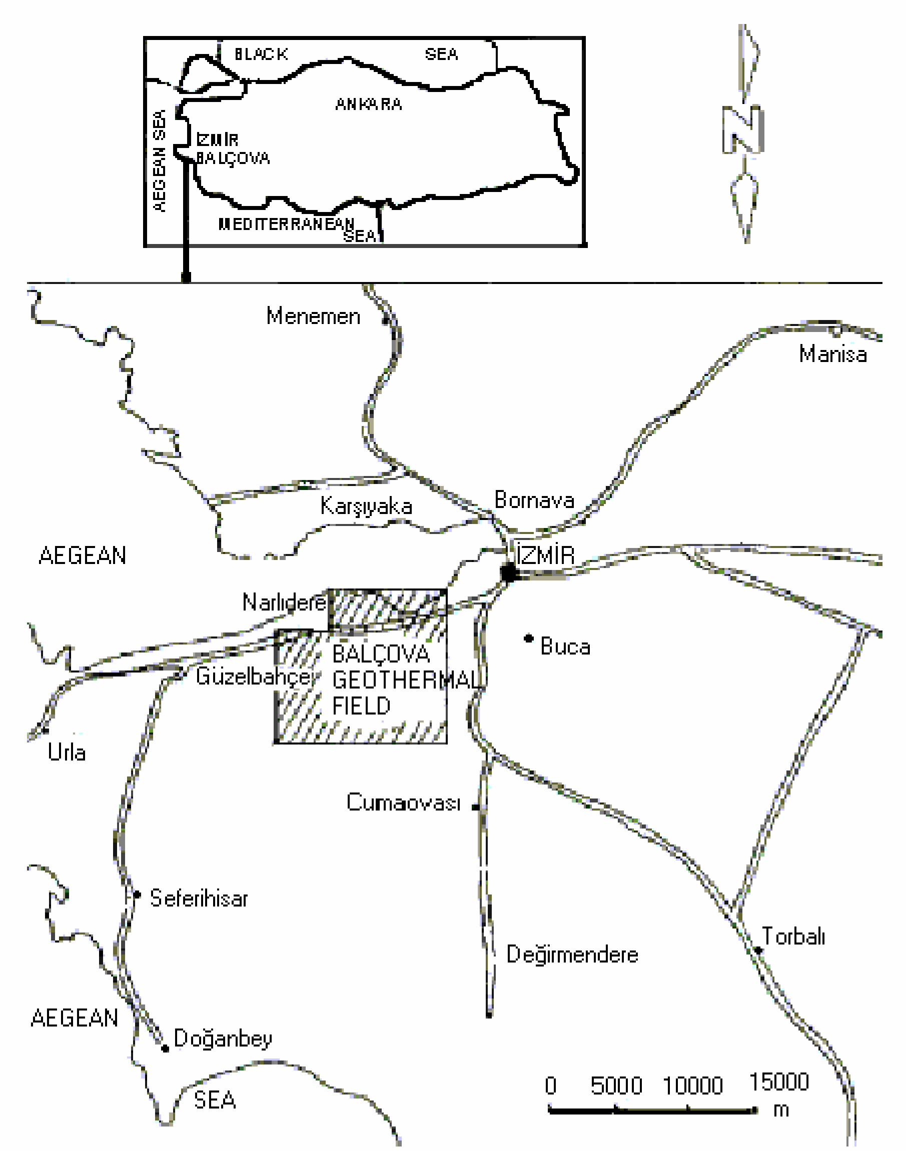

Figure 5.1. Map of Balçova Geothermal Field (Hepbaşlı and Çanakçı, 2002)

5.1. Historical Background of Balçova Geothermal Field

The famous Agamemnon Spas were located in Balçova. Agamemnon was known in antiquity for the therapeutic qualities of the water. According to a legend, Agememnon was advised by an oracle to bring soldiers who had been wounded during the campaign against Troy to the sulfur–rich waters of these natural hot springs. The periods that Ionians passed to Aegean Coasts a part of Alexander the Great's Army's wounded were cured in these hot springs. It had a wide usage in that period, constructions were brought and progressed. Today, the ancient ruins are not seen in the area. Only information about the springs can be obtained from the historical sources in 1763. After the period, Agamemnon Spas are reconstructed by a Frenchman called Elfont Meil with adding the staying units and they endured to our century. Today there is a modern Spa complex with a total capacity of 1000 person/day providing hot spring pools and baths, therapy pool, sauna, underwater massage, physical exercise, electro – therapy and physical – therapy (Gökçen, 2001).

5.2. Geochemistry of Balçova Geothermal Field

Balçova Geothermal Field is one of the most important geothermal fields in Turkey with a 140^{o}C reservoir temperature. The formation of the geothermal system is completed with circulation of meteoric waters, which leak into porous and reservoir rocks around a heat block (Aksoy and Filiz, 2001). Na-HCO_3-Cl-type thermal waters are used for balneology, swimming and heating. Some measurement and chemical analysis data from the field is given in Table 5.1. Several parameters including physical properties such as temperature, EC, TDS, alkalinity, B, Si, As and some metallic ions such as Ca, Mg, Na, Fe etc. were analyzed. Table indicates a temperature range of 90-140 ^{o}C and conductivity of 1830-2080 µS/cm.

The results of cation analyses show that thermal waters with 8-14 mg/l boron concentrations create significant problems in groundwater that is used for agricultural purposes (Gemici and Tarcan, 2002).

Table 5.1. Analyses of hot water well in BGF (Aksoy, 2000)

No	**Well**	**Date**	**T (^{o}C)**	**pH**	**EC µS/cm**	**Li^+ mg/l**	**Na^+ mg/l**	**K^+ mg/l**	**Mg^{2+} mg/l**	**Ca^{2+} mg/l**	**Mn^{2+} mg/l**	**Fe^{3+} mg/l**	**Al^{3+} mg/l**	**NH_4^4 mg/l**	**B mg/l**	**SiO_2 mg/l**	**HCO_3^- mg/l**	**SO_4^{2-} mg/l**	**F^- mg/l**	**Cl^- mg/l**	**TDS mg/l**
1	B-4	Nov-00	96	7. 38	1914	1.5	371	31	13	28	0.11	0.21	0.13	1.15	8.7	148	634	180	3.85	206	1627
1A	B-4	Mar-01	94	6. 92	1888		407	36	14	35						117	727	172		186	1694
2	B-10	Nov-00	99	6.92	1966	1.6	379	32	14	35	0.16	0.18	0.11	0.85	8.8	149	630	164	5.05	190	1610
2A	B-10	Mar-01	93	6. 34	1953		425	39	12	38						116	783	171		193	1777
3	B-11	Nov-00	100	7.48	1897	1.5	367	30	24	31	0.05	0.15	0.15	1.81	9.2	124	623	161	3.75	208	1583
3A	B-11	Mar-01	93	7.22	1919		411	34	13	36						112	761	170		194	1730
4	BTF-3	Nov-00	103	7.30	1836	1.5	364	31	21	34	0.11	0.28	0.12	0.66	9.5	138	615	167	3.75	198	1584
4A	BTF-3	Mar-01	96	8.02	1851		403	36	16	32					6.4	107	708	173		198	1679
5	BD-3	Nov-00	127	7.34	1926	1.5	401	35	17	19	0.10	1.35	0.12	0,.8	7.5	215	605	179	2.80	211	1696
5A	BD-3	Feb-01	127	8.00	2010	nm	439	38	18	20	nm	nm	nm	0.64	7.5	177	620	188	nm	216	1723
5B	BD-3	Mar-01	130	8,.5	1866		431	39	10	19					7.2	166	640	175		232	1716
6	BD-4	Nov-00	136	7.19	1947	1.6	388	34	16	22	0.07	0.14	0.13	1.21	8.8	210	610	175	4.15	205	1676
6A	BD-4	Feb-01	136	8.00	2060	nm	415	35	18	32	nm	nm	nm	0.46	8.2	192	590	191	nm	218	1700
6B	BD-4	Mar-01	138	8.08	1922		438	42	9	30					7.2	167	693	181		212	1778
7	BD-6	Nov-00	132	6.97	1947	1.6	395	35	17	19	0.09	0.77	0.1	0.88	9.3	213	571	180	4.25	231	1677
7A	BD-6	Feb-01	135	7.88	2080	nm	400	36	18	23	nm	nm	nm	0.43	7.7	195	590	187	nm	228	1686
7B	BD-6	Mar-01	136	8.10	1979		453	40	9	26					7.5	185	690	173	nm	223	1807
8	BD-7	Dec-00	119	7.45	1792	1.4	391	30	12	28	0.05	0.56	0.13	1.51	8.3	165	595	171	6.37	205	1616
8A	BD-7	Feb-01	121	7.85	1704	nm	390	31	18	38	nm	nm	nm	0.68	7.9	150	670	174	nm	203	1683
8B	BD-7	Mar-01	118	8.10	1582	nm	352	35	13	20	nm	nm	nm		6.3	152	670	168	nm	159	1576

5.3. Development of Balçova Geothermal Field

Exploration studies started in BGF started in 1963. At the beginning three wells were drilled, including the first geothermal exploratory well in Turkey. The first well produced a mixture of hot water and steam at 124°C at a depth of 40 m. The survey revealed a fault zone delineated by low resistively and huge temperature closures under 30-50 m thick alluvium. Because of high carbonate content and rapid scaling geothermal utilization could not been started until 1981-82. From 1981 to 1983, 7 thermal gradients and 9 production wells (100-150 m) were drilled.

Table 5.2 gives a chronological development of BGF between 1963 and 2003 (Updated from Hepbaşlı and Çanakçı, 2002). According to the table, the first geothermal heating application of Turkey was applied at Balçova Thermal Facilities using downhole heat exchanger to increase the thermal output, in 1983. In 1992, downhole heat exchanger application is abandoned. Geothermal fluid is taken to the surface and is transferred its heat to a secondary fluid by plate type heat exchangers. Balçova District Heating System (BGDHS) was adjudicated in 1995 with a capacity of 2500 dwellings heating and 500 dwellings air-conditioning (Mertoğlu, 1995). As of April 2001, in the BGF, the number of geothermal district heating system subscribers has reached 7607 dwelling equivalence of which about 17% are for hotels and official buildings.

5.3.1. District Heating System

The total capacity of Balçova district heating system was determined as 7500 dwellings heating and 1500 dwellings air-conditioning. Then air-conditioning part is canceled and the capacity is used only for heating because of economical reason. The outdoor and indoor design temperatures for the system are 0 and 22^{o}C, respectively. Figure 5.2 illustrates a schematic diagram of the Balçova Geothermal District Heating System.

The wellhead temperatures of the production wells vary from 95 to 140^{o}C. Geothermal fluid, collected from seven production wells at an average wellhead temperature of 118^{o}C, is then pumped to a mixing chamber, where it is mixed with the reinjection fluid at an average temperature of 60-62^{o}C, cooling the mixture to 98-99^{o}C. This geothermal fluid is then sent to two primary plate type heat exchangers and is cooled to about 60-

62^{o}C, as its heat is transferred to the secondary fluid which is city water. The geothermal fluid whose heat is taken at the heat exchanger is injected back into the reinjection wells. Secondary fluid is heated up to 80^{o}C is circulated through the city circulation lines and gives up its heat to the building loop at the secondary heat exchangers under each building (Hepbaşlı and Çanakçı, 2002).

Table 5.2. A list of the chronological development of Balçova Geothermal Field during the years 1963-2003 (Hepbaşlı and Çanakçı, 2002).

Year	**Description**
1963	Drilling the first geothermal well
1983	Heating the Balçova Thermal Facilities by using a downhole heat exchanger system
1983	Heating the Dokuz Eylul University by using a downhole heat exchanger system
1992	Heating the Balçova Thermal Facilities by using plate heat exchanger system
1994	Heating the Balçova Thermal Princess Hotel
1995	Adjudication of the first stage, 2500 dwellings heating and 500 dwellings air-conditioning
1996	Increasing the capacities from 2500 to 5000 dwellings for heating and from 500 to 1000 dwellings for air-conditioning
1996	Commissioning the BGDHS
1996	Realizing reinjection works
1997	Increasing the capacity to 7680 dwellings
1998	Commissioning the Narlıdere Geothermal District Heating System (NGDHS) with 1500 dwellings
2000	Starting the temporary (initial) approval works of BGDHS
2001	Completing the installations of the Dokuz Eylul University and Economic University
2001	Heating of Cağlayan Housing Development by reinjection fluid
2002	Binding of Balçova Thermal Hotel to Central Heating System
2002	Studying increase the capacity of Faculty of (DEU), music school, and Narlıdere
2003	Commissioning Art School of DEU, Crown Plaza Hotel and hostels

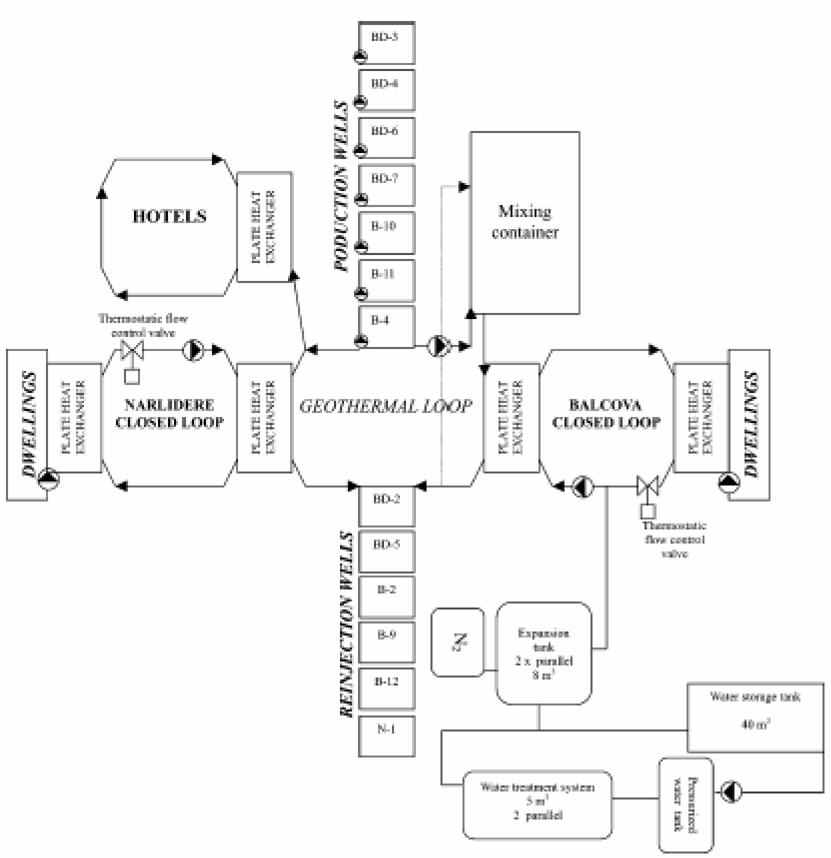

Figure 5.2. A schematic of Balçova Geothermal District Heating System

When the system started to operate in 1995, the production wells were artesian that produce two-phase fluid at 140°C which contains H_2S, CO_2, and other noncondensable gases. The fluid then is sent to a direct contact condenser, where the noncondensable gases were separated and exhausted to the atmosphere while steam phase was condensed before it was sent to the heat exchanger. Inlet temperature of the geothermal fluid to the condenser was 130°C, outlet temperature was 98°C.

Since 2000 downhole pumps are employed to extract fluid which is only liquid, thus there is no need to a condenser. The benefits of downhole pumps are better generating capacity and no reduction in production flowrate due to scaling, increased production temperature from each well by lowering the water level, higher production temperature with no loss to the atmosphere and surface, and better energy recovery.

As the end of 2001, there are 14 wells ranging depth from 48 to 140 m in the BGF. Of these, seven wells are used as production and six wells are used as reinjection wells, while one well is out of operation, which are given Table 5.3 (Hepbaşlı and Çanakçı, 2002).

Table 5.3. Some details about geothermal wells in BGF (Hepbaşlı and Çanakçı, 2002)

Well name	**Date**	**Depth (m)**	**Temperature (^oC)**	**Flow rate (m^3/h)**	**Current Use**
BD-1	1994	564	120-125	-	Out of operation
BD-2	1995	677	135-140	-	Reinjection
BD-3	1996	750	130-140	100-110	Production
BD-4	1998	624	135-140	140-150	Production
BD-5	1999	1100	125-130	-	Reinjection
BD-6	1999	605	135-140	100-110	Production
BD-7	1999	1100	125-130	100-110	Production
B-2	1989	-	95-105	-	Reinjection
B-4	1983	125	95-105	70-80	Production
B-9	1983	48	95-105	-	Reinjection
B-10	1989	125	95-105	70-80	Production
B-11	1989	125	102-105	30-40	Production
B-12	1998	160	95-105	-	Reinjection
N-1	1997	150	100	-	Reinjection

Reinjection is the best method to increase the production of geothermal areas; this maintains the pressure of reservoirs and eliminates the used geothermal waters, which contain large amount of produced chemicals in an environmentally way. After geothermal fluid transfers its heat to the city water by heat exchangers, is collected by a reinjection line and distributed back to reinjection well. BGDHS has six reinjection wells with a temperature range of 95-130^{o}C.

5.4. Existing and Potential Environmental Impacts of BDHS

Balçova District Heating System has some adverse effects as well as its contribution to the environment and the economy. These effects started to be observed first during the investigation of the geothermal area and became more significant as the operating period continues. For example, during the drilling stage, top soil layer and vegetation were altered. At the same time, the total amount of drilled sludge was disposed directly to the area without taking any precautions, which lead to contamination of the area at that early stage. In addition to these, the pumps and machines used for both drilling and operation purposes cause irritating noises. On the other hand, geothermal fluid is reused by reinjection instead of discharging to the area. In this way, both the geothermal source is fed and environmental pollution is minimized. But time to time, some of the reinjection wells overflow due to the excess amount of water pumped to these wells. This excess amount then flows into rivers and ultimately gets mixed up with sea water.

Contamination could be present in the field in either water phase or soil phase. Because of downhole pump application, very little gaseous emissions can occur at well head or during well tests. Therefore, a sampling program was developed in order to monitor the alterations and unusual ties in water phases. For all of these reasons, water analyses and noise measurements were performed in order to observe the environmental effects of BDHS.

Noise is one of the most ubiquitous disturbances to the environment from exploration drilling, construction and production phases. In order to determine effects of BDGS on physical environment, noise was conducted from drilling site and heat center.

5.5. Selection of Sampling Points

The sampling points were chosen in a way that BGDHS production wells, groundwater wells, and the irrigation points. Water sampling points are shown in Figure 5.3. In respect to the sampling program, the sampling points were decided as the following. Water samples were collected from five different points,

- **Two production wells** were chosen in order to monitor the alterations in the composition of the geothermal fluid. One is B10 well which operates throughout the year, thus it is considered to be a good observation well. Furthermore, B10 gives high Mg content which is a property of surface water which shows a possible mixing of geothermal fluid with surface water. The second well is BD4 which has the highest temperature (135-140°C) in the field.
- **The reinjection line (R)** was chosen prior to the fluid distribution to reinjection wells. To determine the characteristics of reinjection fluid, R was chosen as an observation point.
- **Groundwater well (T)** was chosen as a sampling point in order to monitor the interactions between the groundwater and the geothermal fluid
- **Well (İzmirspor –I)** was chosen as another sampling point, which is used for irrigation.

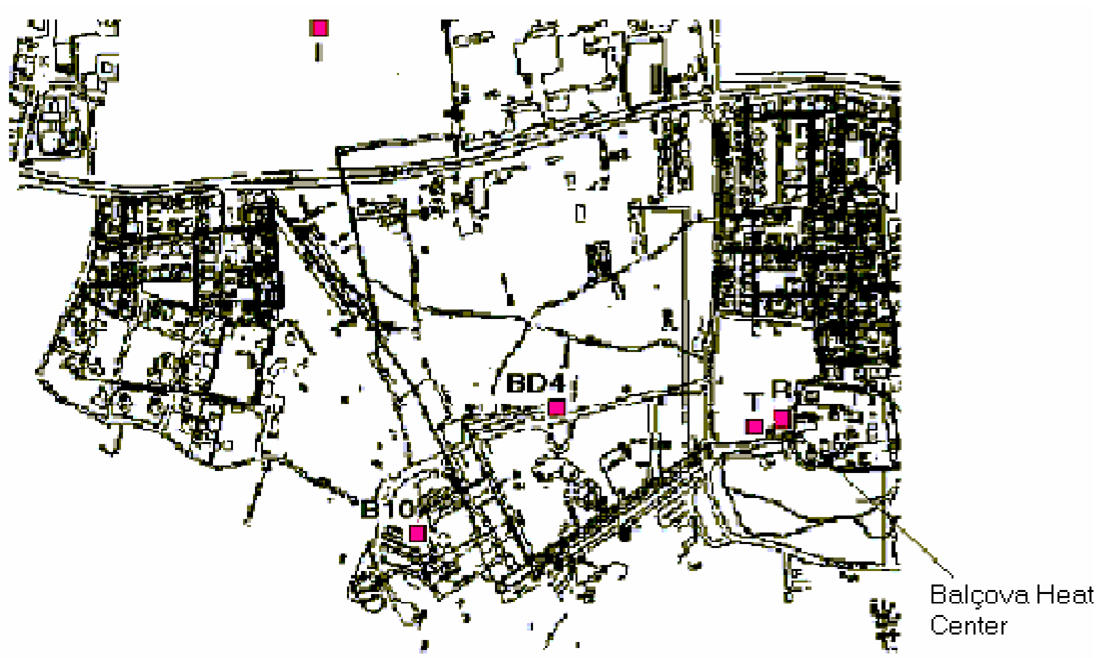

Figure 5.3. Location of sampling points in BGF

5.6. Materials and Methods

5.6.1. Sampling Program

According to the procedure, collecting of geothermal fluid sample involves the following steps:

- Flowing the well,
- Sample withdrawal,
- In-stu or field analysis and,
- Sample preservation and handling.

Preserving samples retards biodegradation reactions, hydrolysis reactions, precipitation reactions and sorption reactions. For this reason, storage conditions are very important. Water sample storage was applied by adding an acid or base as preservative to adjust pH. Analyses were performed as quickly as possible on arrival at the laboratory. If immediate analysis is not possible, storage in a dark environment at 4^oC is recommended for most samples. Preservatives were added to the container immediately after collecting the samples. All samples should be placed to prevent contamination and to preserve the details on the label which may otherwise rub off on transportation. The geothermal fluid samples were collected using 1 L polyethylene bottles.

Water sample containers may require special cleaning before use. The purpose of cleaning is to remove traces of previous samples, to leach any contaminants from the vessel walls and, for trace analysis, to help adsorption prevention of species onto the bottle walls. For collecting cation samples such as ammonia (NH_3), chloride (Cl), bicarbonate (HCO_3), the sample container thoroughly were washed with HNO_3 (1+5) solution, and then rinsed with deionized waters. Each sample container was rinsed at least three times with geothermal fluid during the sampling study. Each well was flowed for 5-10 minutes to prevent contamination during sampling through the pipes.

5.6.2 Experimental Methods for Analyses

Samples were collected and stored in a precleaned polyethylene bottles for laboratory experiments whereas temperature and pH were determined in-situ. Electrical conductivity was determined immediately in laboratory. The remaining major chemical constituents were analyzed using standard methods described in AWWA (1995). Bicarbonate was determined with neutralization titration and chloride with precipitation method. Gravimetry was applied in the determination of sulphate and total dissolved solids. Ion-selective electrodes were used in the determination of F^-. Finally, major cations and Cu, Cr, Cd, Pb, Zn, B, Si were determined with inductively coupled plasma-atomic emission spectroscopy (ICP-AES).

5.6.2.1. Determination of Ammonium Nitrogen

The salicylate method was used for the determination of ammonia. To preserve the sample, pH was adjusted to 2 or less with concentrated sulfuric acid (about 2 mL per liter). Samples preserved in this manner can be stored up to 28 days at 4°C or less. But, most reliable results are obtained when samples were analyzed as soon as possible after collection. "Ammonia Nitrogen Reagent Set" was used for the analysis as spectrophotometer reagents. The reagents included sodium tartrate, sodium citrate, sodium salicate, sodium nitroferricyanide, lithium hydroxideanhydrous, and sodium dichloroisocyanurate. In this method, monochloromine reacts with salicylate to form 5-aminosalicylate. The 5-aminosalicylate is oxidized in the presence of a sodium nitroprusside catalyst to form a blue-colored compound. The blue color is masked by the yellow color from the excess reagent present to give a final green-colored solution. Absorbances of the sample solutions prepared this way were measured using HACH DR/2010 spectrophotometer at 655 nm.

5.6.2.2. Determination of Alkalinity

Alkalinity can be determined by titration of water sample with a strong mineral acid. The samples were analyzed right after the collection. Sulfuric acid (0.02 N) was employed as the titrant and methyl orange and phenolphthalein solutions were used as indicators. Firstly, phenolphthalein indicator solution was added to the volume of 100 mL samples. The color of the sample did not change with the addition of phenolphthalein, but if color of the sample changed, titration was carried out until the color disappears. Then methyl orange indicator solution was added to the sample. Methyl orange indicator gives yellow color to the solution. Titration was continued until red color was seen. The volume of the sulfuric acid which is used during the titration was recorded. Bicarbonate and calcium carbonate ($CaCO_3$) concentrations were calculated using equation 5.1 and 5.2, respectively.

$$\text{mg } HCO_3^-/\text{L} = T \times 24.4 \tag{5.1}$$

$$\text{mg/ } CaCO_3\text{L} = T \times 20 \tag{5.2}$$

where; T = volume of sulfuric acid used (mL)

5.6.2.3. Determination of Chloride

Chloride may be determined argentometric method by titration with silver nitrate ($AgNO_3$) using potassium chromate (K_2CrMnO_4) as indicator. Hydrogen peroxide (30%) was used to prevent interference of $AgNO_3$ (0.01 N) as titrant. Chloride is precipitated as silver chloride, and the excess silver ions form silver chromate to yield a permanent red-colored end-point. The samples were analyzed within a week after collection.

The volume of $AgNO_3$ solution recorded and the concentration of chloride was calculated by equation 5.3.

$$\text{mg } Cl^-/\text{L} = \frac{(A - B) \times N \times 35450}{100 mlsample} \tag{5.3}$$

where; A= mL titrant for sample

B= mL titrant for blank

N= Normality of $AgNO_3$

5.6.2.4. Determination of Sulphate

Gravimetric method with ignition of residue was used for determination of sulfate. These samples were analyzed within a week after collection. In this method, sulfate is precipitated in a hydrogen chloride (HCl) solution as barium sulfate ($BaSO_4$) by the addition of barium chloride ($BaCl_2$). HCl and $BaCl_2$ were used as reagents for the analysis. The precipitation is carried out near the boiling temperature, and after a period of digestion the precipitate is filtered, washed with tepid deionize water until free of Cl^-, ignited or dried, and weighed as $BaSO_4$. The mass of sulfate was calculated by equation 5.4.

$$\text{mg } SO_4^{2-}/\text{L} = \frac{mgBaSO_4 \times 411.6}{100mlsample} \tag{5.4}$$

5.6.2.5. Determination of Total Dissolved Solids

Total dissolved solids (TDS) were determined by gravimetric method. The samples were analyzed within a week after collection. This gives an indication of salinity of the solution. The quantity of dissolved solids can also be calculated by summing the concentrations of the solutes. This method is based on the evaporation of solution to dryness and weighing the dried residue. In this method, samples were placed in crucible and put in an oven at 110°C. Dry weight of the sample was recorded as TDS. The mass of total dissolved solid was calculated by equation 5.5.

$$\text{mg TDS/L} = \frac{(A-B) \times 1000 \times 1000}{50mlsample} \tag{5.5}$$

where, A= mg crucible with sample

B= mg crucible of tare

5.6.2.6. Determination of Fluoride

The fluoride was determined using ion-selective electrode. The samples were analyzed within a week after collection. Various F^- standard solutions were prepared in total ionic strength adjustment buffer solution (TISAB). TISAB is used to adjust all samples and standards to establish the same ionic strength. The buffer contains sodium chloride, glacial acetic acid, CDTA and ammonium citrate. The stock standards solution of F^- was prepared using solid sodium fluoride (NaF). The lower concentrations of standards were prepared daily.

10 mL portion of the sample were transferred were into a beaker and diluted with 10 mL of TISAB solution. The mixture is stirred for 3-4 minutes and the potential is recorded. The same procedure was applied also for the standards and remaining samples.

5.6.2.7. Determination Major Cations and Heavy Metals

Ca, Mg, Na, K, Li, Mn, Fe, Al, B, Si were determined by using inductively coupled plasma atomic emission spectrometry (Varian, ICP). The samples were acidified with HNO_3 to adjust pH less than 2. The samples, prepared by this way, were stored at 4^oC for six months. Quantitative method was applied for this determination. If necessary, samples were filtered. Samples were prepared with HNO_3 (1 mL per 100 mL sample). Multielement standard solution (1000ppm) which contains 23 elements was used. Standard solutions and blank were prepared by this way. The operating conditions of the analysis are given in Table 5.4. Appropriate wavelength was chosen for each element from among many wavelengths.

Table 5.4. Wavelengths for the determination of the elements by using ICP-AES

Parameter	**Wavelength (nm)**
Aluminum, Al	396,152
Arsenic, As	188,979
Boron, B	249,773
Barium, Ba	493,409
Chromium, Cr	284,325
Copper, Cu	324,754
Iron, Fe	259,940
Potassium, K	769,896
Magnesium, Mg	285,213
Manganese, Mn	257,610
Sodium, Na	588,995
Nickel, Ni	221,647
Lead, Pb	405,783
Silica, Si	288,158
Zinc, Zn	213,856

CHAPTER VI

RESULTS AND DISCUSSION

Environmental effects of BDHS were investigated in two main groups; effects on physical and chemical effects, respectively. In order to determine the effects of BDHS on physical environment, noise measurements were conducted. Meanwhile, to observe the changes in geothermal fluid composition and to investigate the contamination in BGF, geothermal fluids were analyzed.

6.1. Noise Measurements

Noise, causes a significant impact on physical environment, was measured at drilling site and heat center.

6.1.1. Heat Center

Noise measurements were conducted at 6 different points inside and outside of BDHS Heat Center. Heat Center and measurements points can be viewed in Figure 6.1 and Figure 6.2, respectively. Measurements gave a noise level range of 83.6-90 dB(A) inside the building and 65.4-73.7 Leq outside the building. Although circulation pumps had been working with a capacity of 50% during the measurements, noise level is 90dB(A) (point 1). According to Table 3.2 90 dB(A) is classified as "very noisy", the rest of the measurements are classified as "noisy". It should be noted that, traffic had contribution to the outdoor measurements. Information on measurement points location and noise levels are given Table 6.1.

Figure 6.1. Heat Center of BDHS

Table 6.1. Description of measurement points and noise level

Number	Measurement	Location	Description
1	90 dB(A)[1]	In front of the circulation pumps	Very Noisy
2	83.6 dB(A)	In front of the heat center entrance	Noisy
3	67.4 Leq[2]	Left corner of heat center	Noisy
4	66 Leq	Right corner of heat center	Noisy
5	69.4 Leq	In front of the closest apartment	Noisy
6	73.3 Leq	In front of the B2 Well	Noisy

[1]: Most localities set a dBA (A-weighted decibel) limit at the nearest sensitive receiver. Receivers are residences, office buildings, and even other industrial sites.

[2]: The equivalent continuous sound pressure level, which represents the average of a 24-hour noise history at a location. The Leq is used when it is important to consider variations in noise over time, such as between day and night.

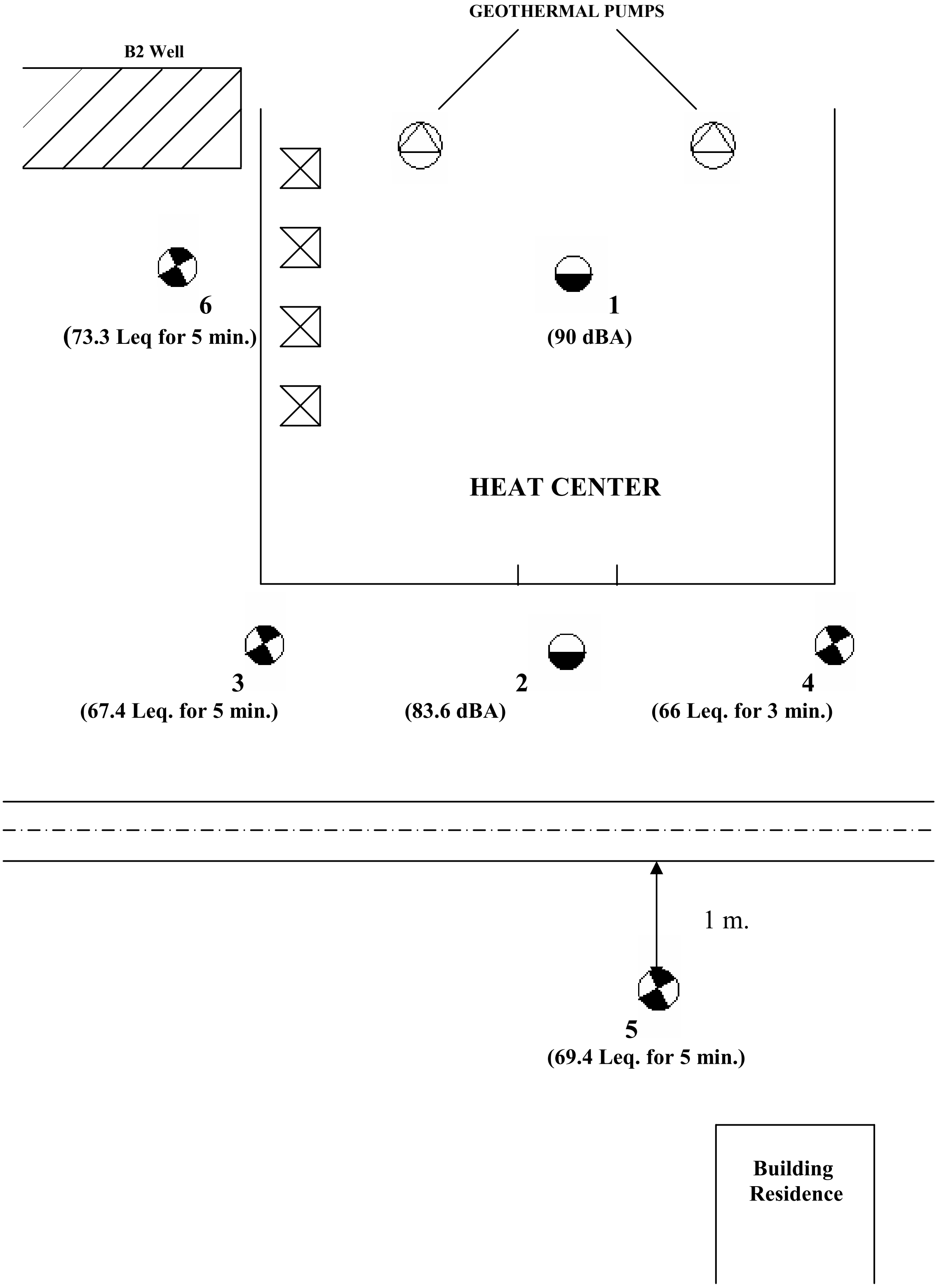

Figure 6.2. Location of the measurement points

6.1.2. Drilling Site

Noise measurements were conducted at drilling site of well BD9**,** which is very close the residential buildings, in BGF at two different operational conditions of drilling activity. Drilling site in BGF showed in Figure 6.3.

- **Only Drilling Engine Active:** According to the noise measurements, the noise level 1m away from the nearest residence at 1 point was recorded as 75 dB(A).

- **Both Drilling Engine and Pump Active:** The noise level 1m away from the nearest residence was found out to be 83.4 dB(A).

Both measurement results exceed the maximum noise limit which is applied to the residential area by Noise Control Regulation which are 65 dB(A) (from 06.$^{\underline{00}}$ to 22.$^{\underline{00}}$) and 55 dB(A) (from 22.$^{\underline{00}}$ to 06.$^{\underline{00}}$) (Noise Control Regulation, 1986).

Figure 6.3. Drilling site in BGF

6.2. Fluid Chemical Analysis

Physical properties such as temperature, electrical conductivity, total dissolved solids, alkalinity; non-metallic constituents such as ammonia, boron, chloride, silica, sulfate; and metals and semi metals such as calcium, magnesium, sodium, potassium etc. were analyzed from September 2002 to June 2003. The samples were collected monthly in well B10 and every two months in R, I and T. Finally one sample was taken from well BD4.

pH and EC values were generally constant during the monitoring period for all samples. pH is influenced by the fluid salinity and temperature and by mineral buffers. The changes in EC values resulted from increasing ion concentrations, especially increasing of bicarbonate and chloride concentration. Measure of the amount of chemical salts dissolved in the waters gives TDS, also called salinity. TDS values range from a few hundred to more than 300,000 mg/l. According to TS 266, pH values must be between 6.5-8.5. Meanwhile, the pH of geothermal resources ranges from moderately alkaline (pH=8.5) to moderately acid (pH=5.5). The pH and TDS of the all samples were within the limits. The İzmirspor (I) well is used for irrigation and T well is a cold water well. Therefore the analysis results of those two wells were compared to the irrigation and drinking water standards, respectively.

At well B10, the pH and EC values were between 6.65-6.95 and 1750-1980 µS/cm, respectively. HCO_3 and Cl concentrations were average 458 mg/l and 174 mg/L. SO_4^{2-} concentrations didn't change during the study and the average value was 154 mg/L. The F^- content of geothermal fluids is usually between 1-10 ppm and well B10 was in the limits. The maximum TDS concentration was 1443 mg/L in January-2003. Ammonia concentrations of the samples ranged between 0.20-0.65 mg/L. The results of the physical properties, NH_4, HCO_3, SO_4 and finally F^- are given in Figure 6.4-Figure 6.10.

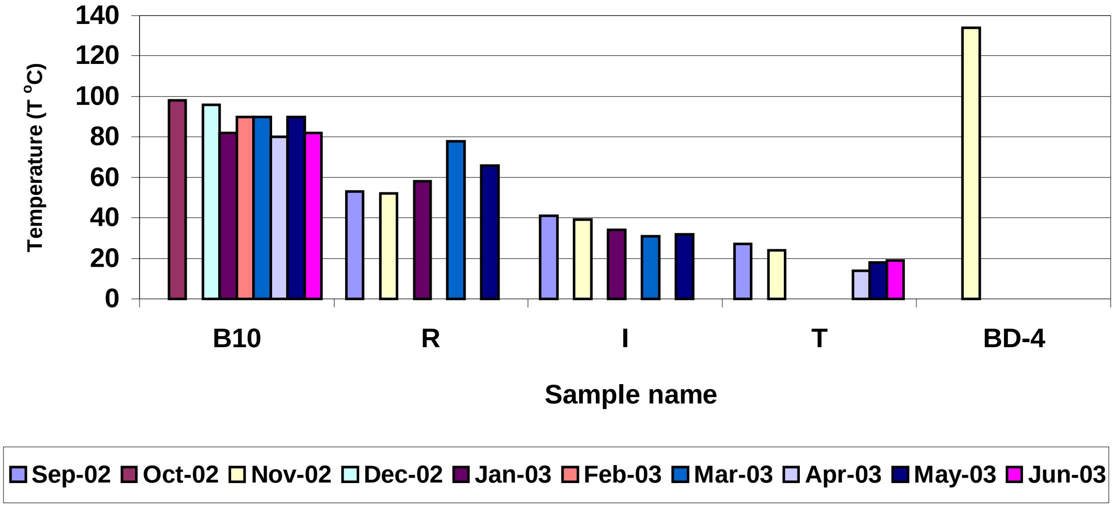

Figure 6.4. The changes of temperature values in each well from September-2002 to June-2003

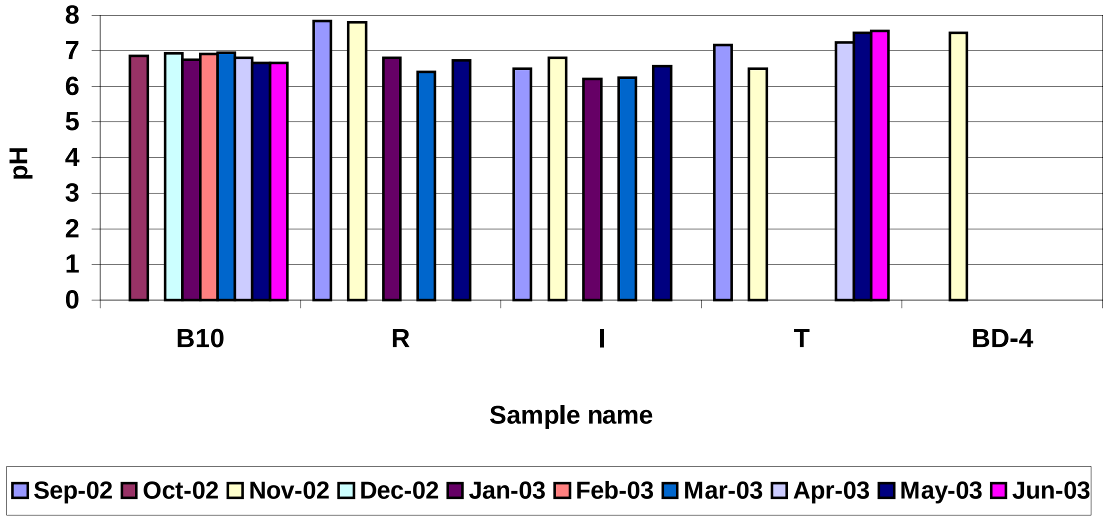

Figure 6.5. The changes of pH in each well from September-2002 to June-2003

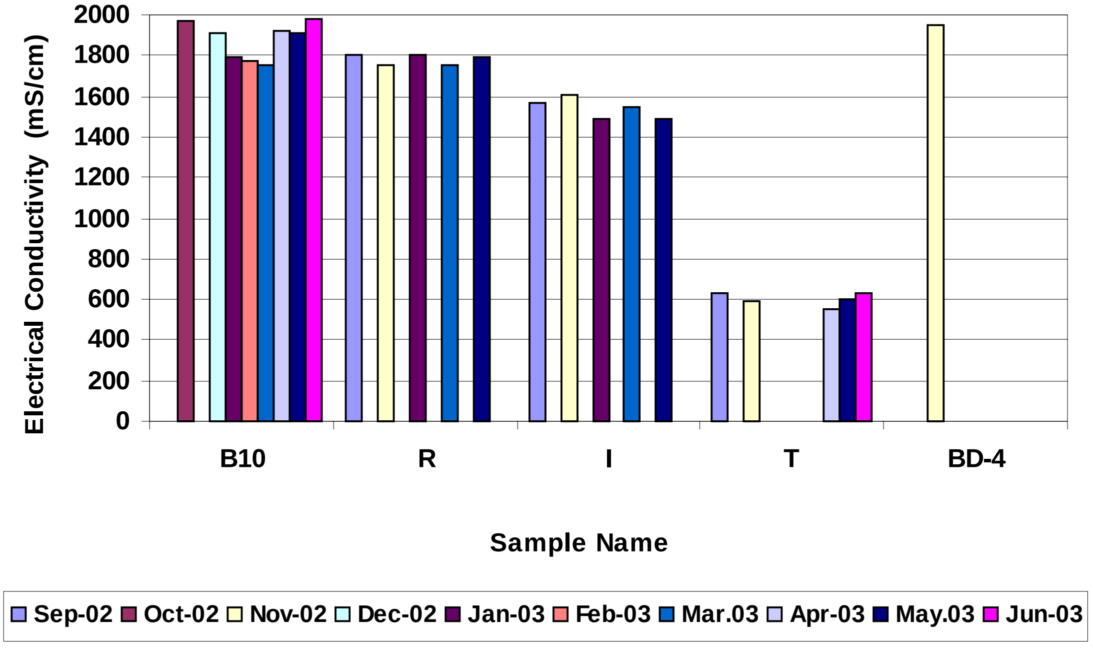

Figure 6.6. Electrical Conductivity values in each well

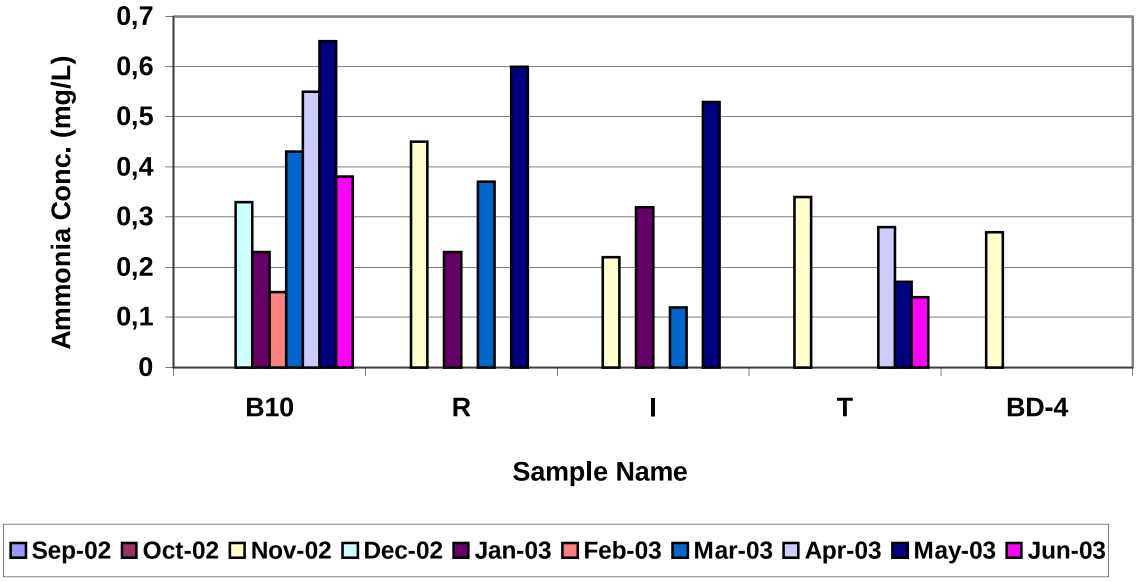

Figure 6.7. The results of the ammonia analysis in each well

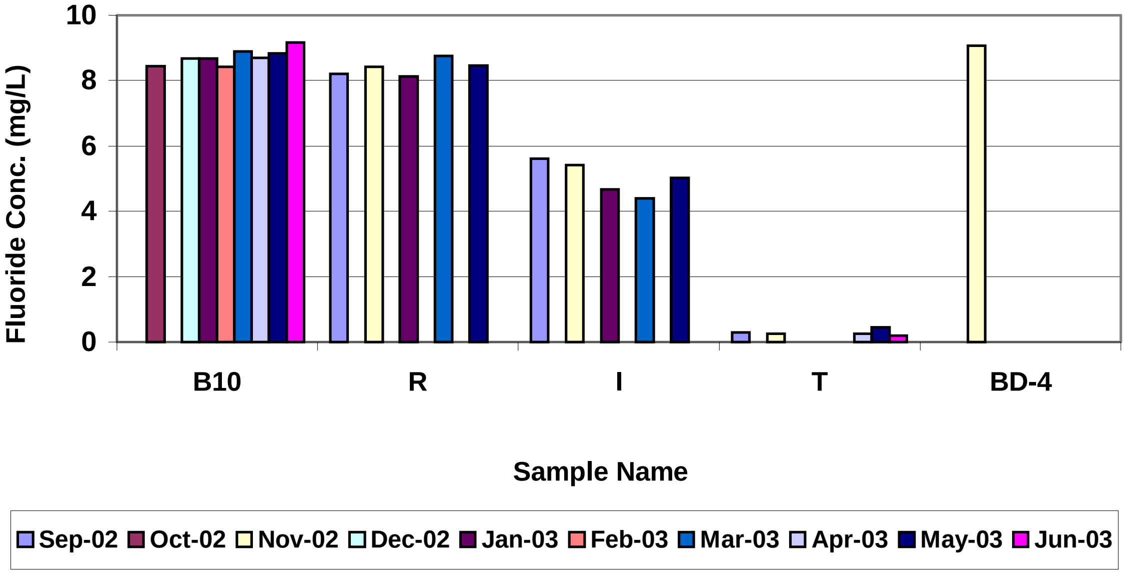

Figure 6.8. The changes of fluoride concentrations in each well

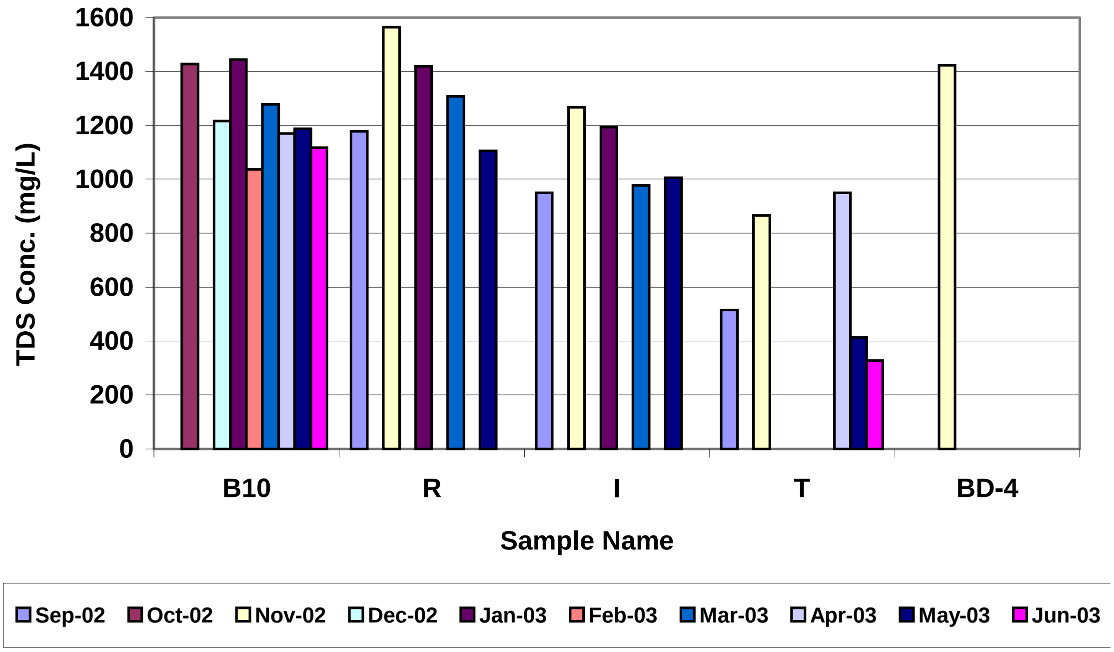

Figure 6.9. Total Dissolved Solids concentrations in each well

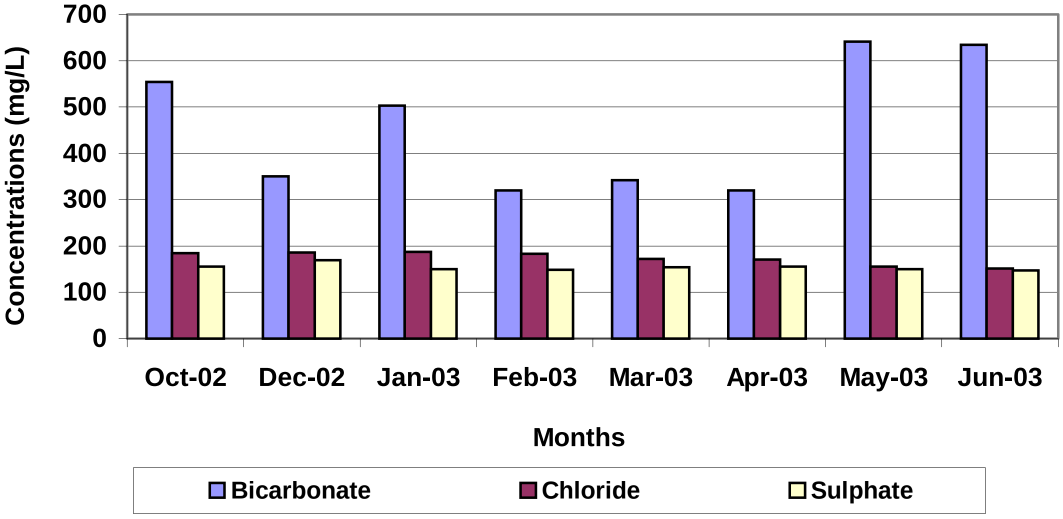

Figure 6.10. The changes of bicarbonate, chloride, and sulphate concentrations in well B10 between October-2002 and June-2003

Calcium concentrations were constant and around 29 mg/L in well B10. Calcium concentrations are controlled by minerals of solubility ($CaCO_3$, $CaSO_4$ etc.). It can be affect the solubility of these minerals will also influence the level of Ca in the geothermal fluid. Potassium and sodium concentrations were about 27 mg/L and 298 mg/L, respectively, which is expected quantity according to Figure 3.1. Magnesium concentrations were constant, it can be explained no leakage from surface or groundwater to geothermal fluid. Aluminum, barium, and manganese concentrations were constant during the study period. Iron concentrations suddenly increased in May-2003. The lowest arsenic concentration was 0.14 mg/L and the maximum arsenic concentration was 0.28 mg/L, which increased in December-2002. Generally, B and SiO_2 concentrations were constant during the study in well B10. The results of the cation, B, SiO_2, and As analysis of well B10 are shown in Figure 6.11 and Figure 6.12. Heavy metal concentrations are given in Table 6.2. During the studying period, some heavy metals such as Cu, Ni and Pb could not be detected. Chromium concentrations were constant in well B10. But, the concentrations of Zn decreased suddenly in December-2002 and February-2003.

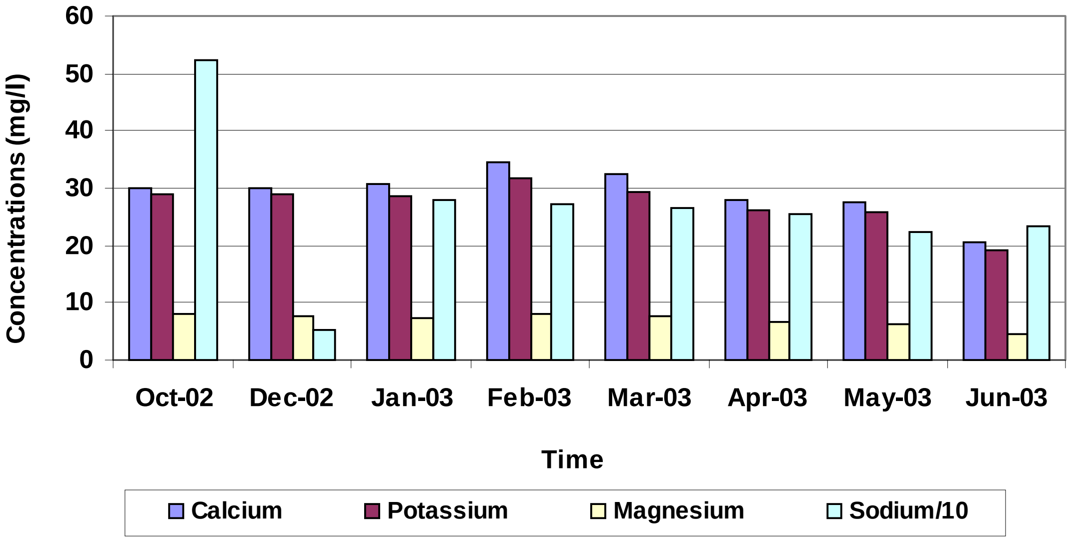

Figure 6.11. Calcium, potassium, magnesium, and sodium concentrations in well B10 between September-2002 and June-2003

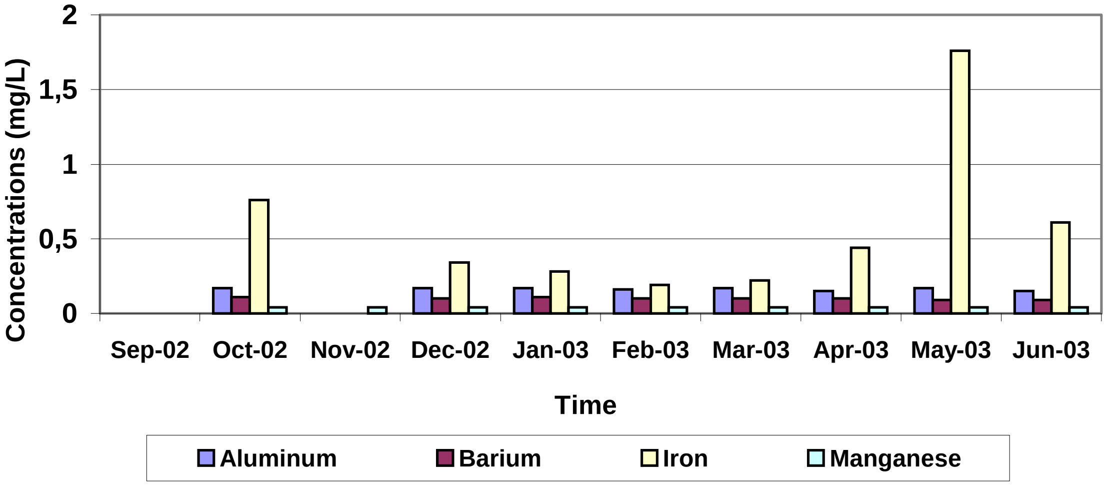

Figure 6.12. Aluminum, barium, chromium, iron, and manganese concentrations in well B10 between September-2002 and June-2003

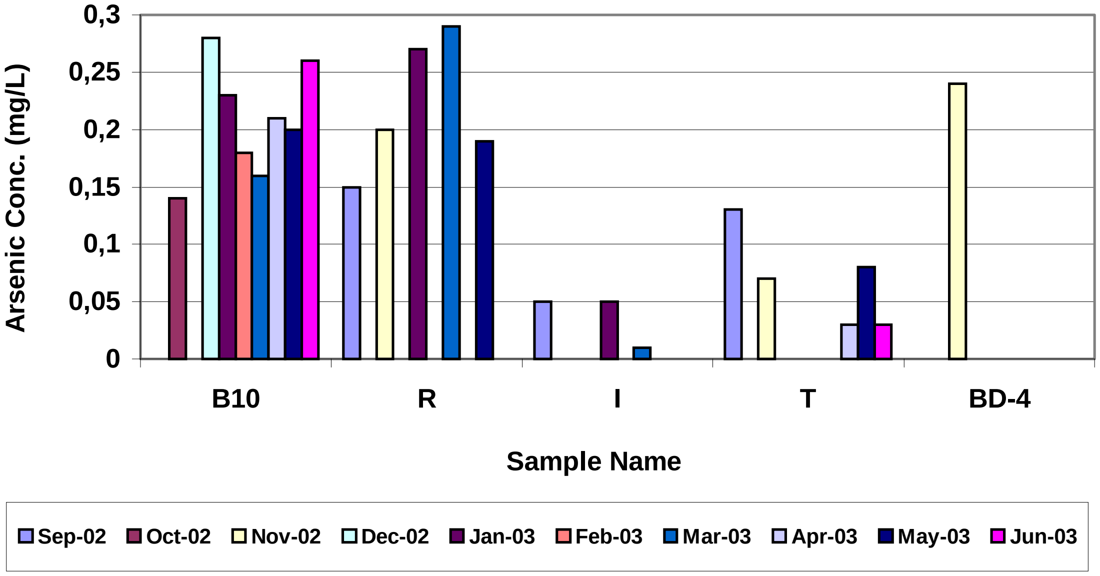

Figure 6.13. Arsenic concentrations in each well from September-2002 to June-2003

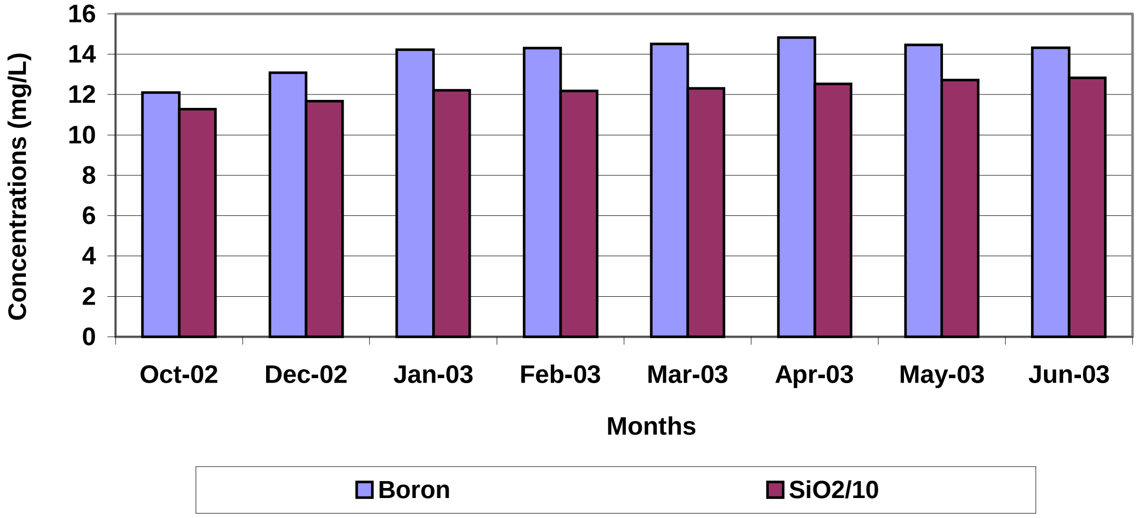

Figure 6.14. Boron and SiO_2 concentrations in well B10 between October-2002 and June-2003

Table 6.2. Heavy metal concentrations in mg/L in well B10

Date	Cr	Zn
Oct-2002	0.11	0.19
Dec-2002	0.10	0.07
Jan-2003	0.11	0.14
Feb-2003	0.11	0.05
Mar-2003	0.11	0.14
Apr-2003	0.11	0.16
May-2003	0.11	0.15
Jun-2003	0.10	0.15

At reinjection line (R), pH values were between the permissible limits and the electrical conductivity values were between 1750-1805 µS/cm. Bicarbonate, chloride and sulphate analysis are shown in Figure 6.15. Bicarbonate concentrations suddenly changed in January and May-2003. Cl concentrations suddenly decreased to 133 mg/L in May-2003. The concentrations of F were about 8.39 mg/L. Sulphate and TDS concentrations were not constant during the monitoring period. The maximum SO_4 was 181 mg/L in November-2002 and the minimum SO_4 concentrations was 141 mg/L in December-

2002. Total Dissolved Solid concentrations increased from 1178 mg/L and 1565 mg/L in November-2002 but decreased from 1307 mg/L to 1106 mg/L in May-2003. The results of the physical properties, NH_4, F and TDS are given in Figure 6.4-Figure 6.9. The results of calcium, potassium, magnesium, and sodium are shown in Figure 6.16. Potassium and sodium concentrations were constant during the study period and were about 25 mg/L and 254 mg/L, respectively. Calcium concentrations were about 28 mg/L. The results of magnesium concentrations were not constant. The concentration of magnesium suddenly decreased to 4.64 mg/l in November-2002. The results of aluminum, barium, iron and manganese are shown in Figure 6.17. Manganese and barium concentrations were constant during the study period. Iron concentrations were about 0.31 mg/l. But the concentration of iron suddenly decreased from 0.70 mg/l to 0.19 mg/l which decreases with decreasing salinity and acidity. Aluminum concentrations were about 0.21 mg/l. But the concentrations of aluminum decreased to 0.17 mg/l in November-2002. Arsenic concentrations were about 0.22 mg/l which are shown in Figure 6.13. Boron concentrations were very high because of associated with organic-rich sedimentary. According to Figure 6.18, silica concentrations were changed between 119.66 to 174.33 mg/L. Heavy metal concentrations in R are tabulated in Table 6.3. After November-2002, copper, nickel, and lead could not be detected. Chromium and zinc concentrations were not constant during the monitoring period. Chromium concentration of R was nearly 0.10 mg/L but decreased in January-2003. Zinc concentration was 0.66 mg/L in September-2002 but exhibited an increase in other months.

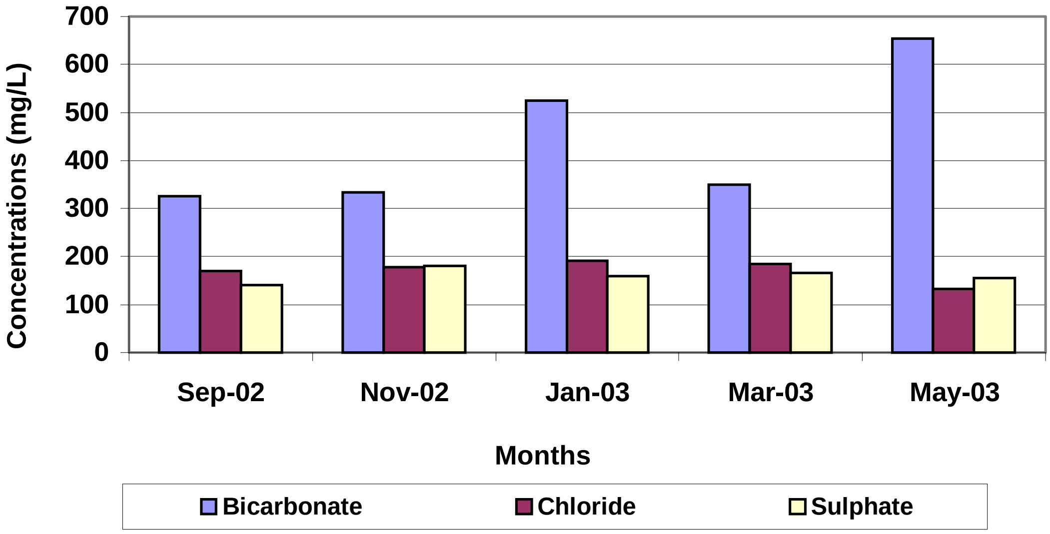

Figure 6.15. Bicarbonate, chloride, and sulphate concentrations in R between September-2002 and May-2003

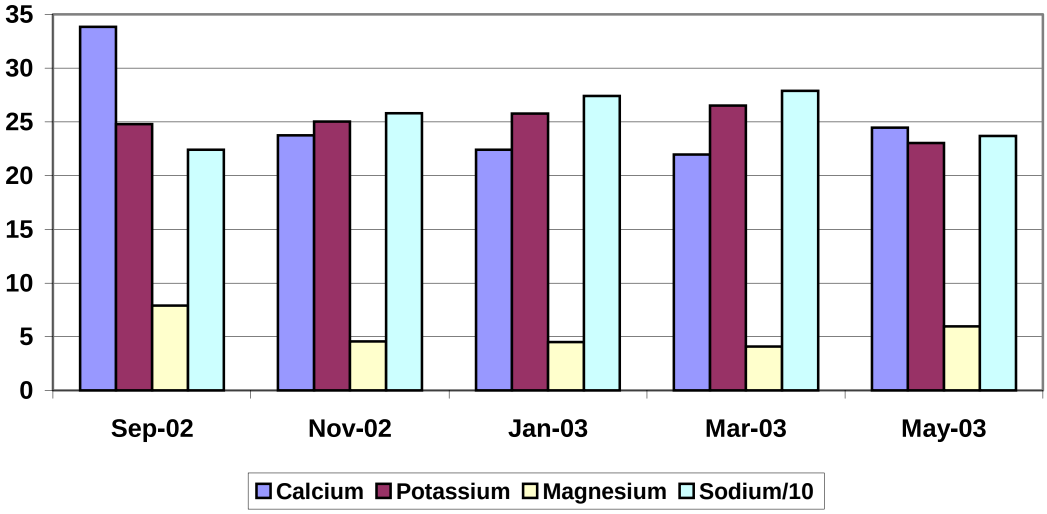

Figure 6.16. Calcium, potassium, magnesium, and sodium concentrations in R between September-2002 and May-2003

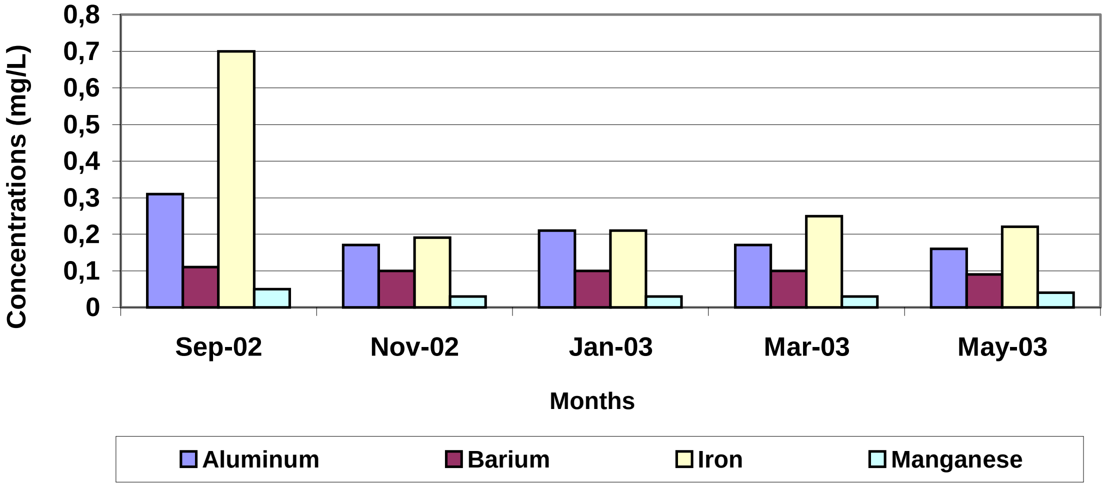

Figure 6.17. Aluminum, barium, iron, and manganese concentrations in R between September-2002 and May-2003

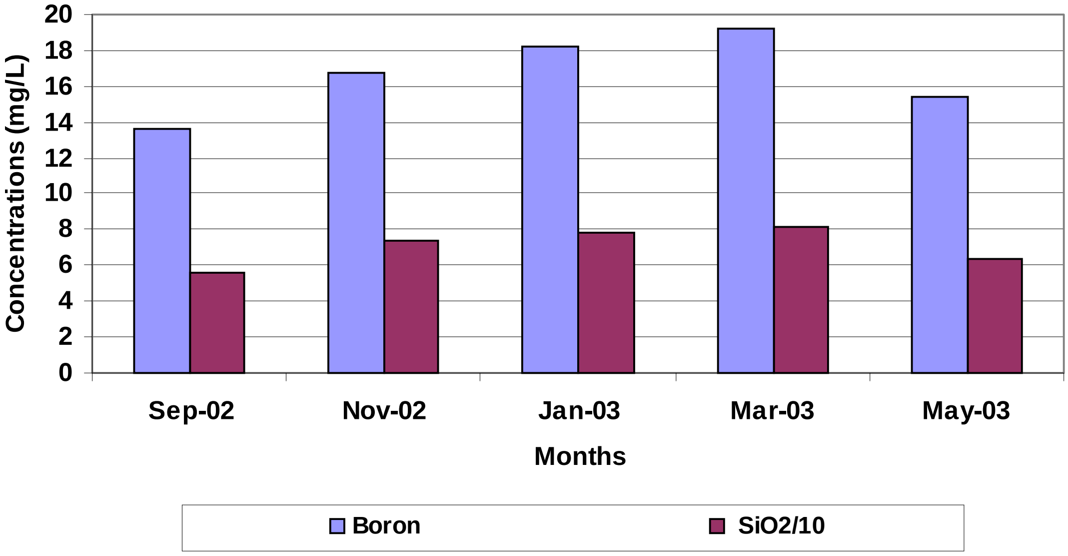

Figure 6.18. Boron and SiO_2 concentrations in R between September-2002 and May-2003

Table 6.3. Heavy metal concentrations in reinjection line (R)

Date	Cr	Cu	Ni	Pb	Zn
Sep-2002	0.10	0.17	0.01	0.01	0,66
Nov-2002	0.10	<LOD	<LOD	<LOD	0,01
Jan-2003	0.01	<LOD	<LOD	<LOD	0,01
Mar-2003	0.09	<LOD	<LOD	<LOD	<LOD
May-2003	0.10	<LOD	<LOD	<LOD	0,05

LOD: Limit of detection

The İzmirspor (I) well is used for irrigation, therefore the analysis results of the well was compared to the irrigation water standards which permissible limits of heavy metal and toxic elements are given in Table 6.4 (Teknik Usuller Tebliği, 1991). In addition, classification of irrigation water is given in Table 6.5 which based on Teknik Usuller Tebliği. The results of the physical properties, NH_4, F and TDS are given in Figure 6.4 and Figure 6.9. The pH and EC values were between 6.20-6.80 and 1480-1570 µS/cm, respectively. These values of the samples within the limits. Chloride and sulphate concentrations were about 117 mg/L which were within the permissible limits. Bicarbonate concentrations were not constant during the study period. The maximum concentration of HCO_3 was 534 mg/L which are shown in Figure 6.19. Ammonia concentrations of well I ranged between 0.12-0.53 mg/L. Fluoride and TDS concentrations were not constant during the monitoring period which are shown in Figure 6.8 and Figure-6.9. The concentrations of fluoride exceeded the permissible limit during the monitoring period.

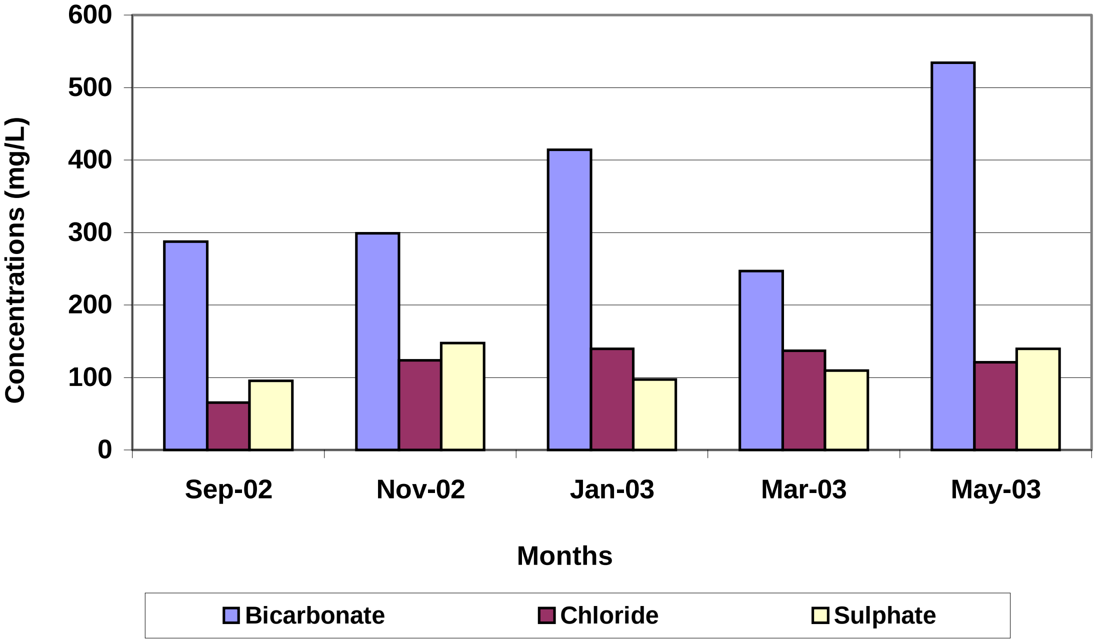

Figure 6.19. The changes of bicarbonate, chloride, and sulphate concentrations in well I between September-2002 and May-2003

Table 6.4. The maximum permissible limits of heavy metal and toxic elements in irrigation waters (Teknik Usuller Tebliği, 1991)

Parameter	**Threshold limit value for continuous irrigation (applicable to any soil) (mg/L)**
Aluminum	5.0
Arsenic	0.1
Chromium	0.1
Copper	0.2
Fluoride	0.1
Iron	5.0
Lead	5.0
Manganese	0.2
Nickel	0.2
Zinc	2.0

Table 6.5. Criteria that must be considered in the classification of irrigation water

	Class of irrigation water				
Quality Criteria	**Class I (very good)**	**Class II (good)**	**Class III (usable)**	**Class IV (suspicious)**	**Class V (injurious)**
$EC_{25}\times10^6$ (mmhos/cm)	0-250	250-750	750-2000	2000-3000	>3000
Cl^- (mg/l)	0-142	142-249	249-426	426-710	>710
SO_4^{2-} (mg/l)	0-192	192-336	336-775	576-960	>960
B (mg/l)	0-0.5	0.5-1.12	1.12-2	2	-
pH	6.5-8.5	6.5-8.5	6.5-8.5	6-9	<6 or >9
Temperature	30	30	35	40	>40

Calcium concentrations of well I were not constant and suddenly decreased or increased but potassium, magnesium and sodium concentrations were constant during the monitoring period which are shown in Figure 6.20. During the study period, barium could not be detected. Iron concentrations were about 0.07 mg/L which were under the permissible limit. Alumina and manganese concentrations were not constant during the monitoring period. The maximum alumina concentration was 0.28 mg/L in March-2003 which were within the limit. On contrary, the maximum manganese concentration was 1.12 mg/L in May-2003 which were higher than the permissible limit. The results of the samples are shown in Figure 6.21. Boron and SiO_2 concentrations are given in Figure 6.22. Boron concentration was about 11 mg/L which exceeded the permissible limit by irrigation standards. SiO_2 concentrations were constant and about 87 mg/L. Copper and nickel could not be detected after December-2002. Chromium, lead, nickel, copper and zinc concentrations were under the permissible limits of Turkish Standards.

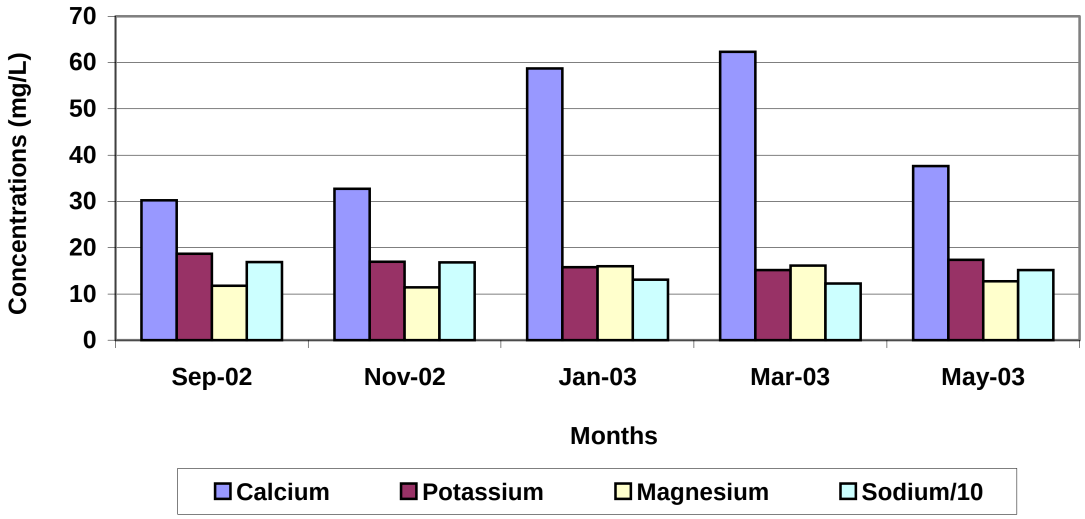

Figure 6.20. Calcium, potassium, magnesium, and sodium concentrations in well I between September-2002 and May-2003

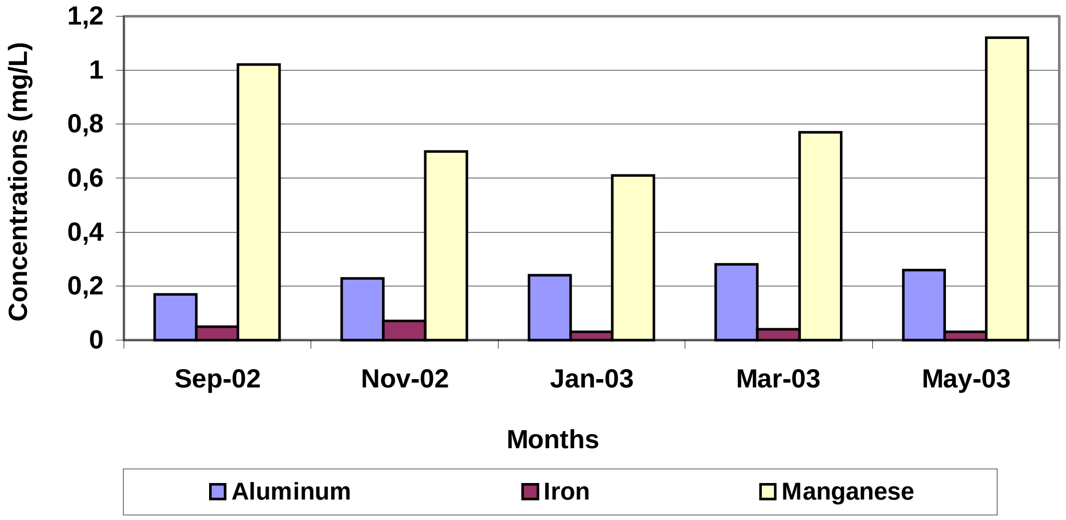

Figure 6.21. Aluminum, iron, and manganese concentrations in I since September-2002 to May-2003

(Limit value for Mn=0.2 mg/L)

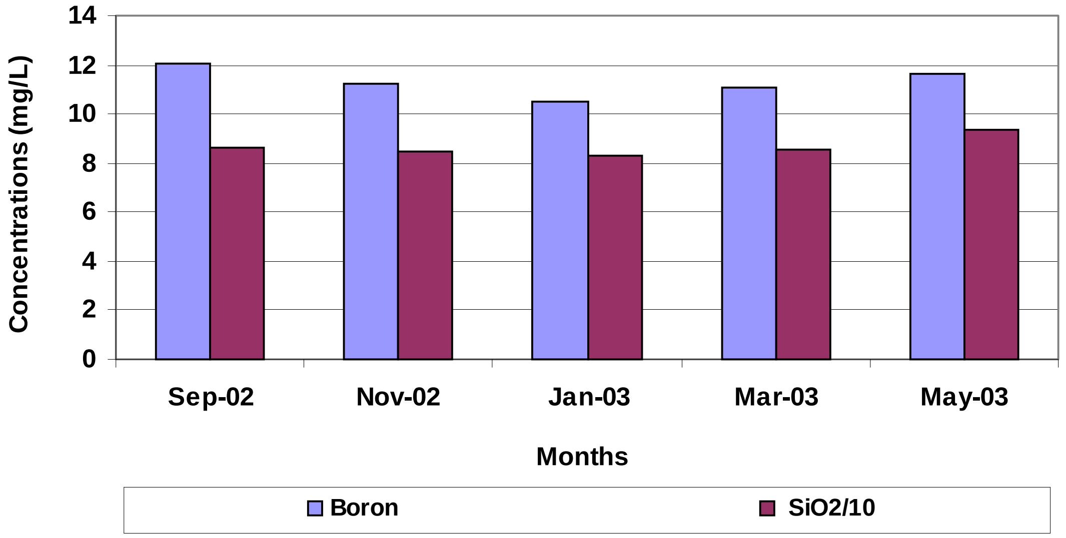

Figure 6.22. Boron and SiO_2 concentrations in well I between September-2002 and May-2003

(Limit value for B_{max}=2 mg/L)

Table 6.6. Heavy metal concentrations in mg/L in well I

Date	Cr	Cu	Ni	Pb	Zn
Sep-2002	0.09	0.02	0.03	<LOD	<LOD
Nov-2002	0.09	<LOD	<LOD	<LOD	0.81
Jan-2003	0.09	<LOD	<LOD	0.01	0.06
Mar-2003	0.08	<LOD	<LOD	0.01	0.07
May-2003	0.08	<LOD	<LOD	0.01	0.62

Well T is groundwater well, therefore the results of the well was compared to drinking water standards which are given in Table 6.7. The pH and electrical conductivity values of the samples were within the limits. Fluoride concentrations were constant which were within the limits of Turkish Standards. Ammonium concentrations suddenly increased to 0.60 mg/L in May-2003. Total dissolved solid concentrations were about 1315 mg/L. The results of the physical properties, NH_4, F and TDS are shown in Figure 6.4 and Figure 6.9. Bicarbonate concentrations were not constant and suddenly changed during the study. Chloride concentrations were constant which were within limits. Bicarbonate and chloride concentrations were about 257 mg/L and 15 mg/L, respectively. Sulphate concentrations were under limits of Turkish Standard which is given in Figure 6.22.

Table 6.7. The maximum concentration of the parameters in mg/L which were regulated by Environmental Protection Agency, Turkish Standard and European Union

Parameter	**TS**[*]	**EPA**[**]	**EU**[***]
pH	6.5-9.2	6.5-8.5	6.5-8.5
EC(µS/cm)	400-2000	Not regulated	400
Chloride	250	250	250
Sulphate	250	250	250
Calcium	200	Not regulated	100
Magnesium	50	Not regulated	50
Sodium	175	Not regulated	200
Potassium	12	Not regulated	12
Aluminum	0.2	1	0.2
TDS	Not regulated	500	500
Ammonium	0.5	Not regulated	0.5
Boron	2	Not regulated	1
Iron	0.2	0.3	0.2
Manganese	0.05	0.05	0.05
Copper	3	1	2
Zinc	5	5	0.1
Fluoride	1.5	0.7-0.24	1.5
Barium	0.3	1	Not regulated
Arsenic	0.05	0.05	0.01
Chromium	0.05	0.05	0.05
Nickel	0.001	Not regulated	0.001
Lead	0.05	0.05	0.01

[*] Turkish Standard (TS266, 1997)

[**] Environmental Protection Agency (National Primary Drinking Water Regulations and National Secondary Drinking Water Regulations)

[***] European Union (80/77/EEC)

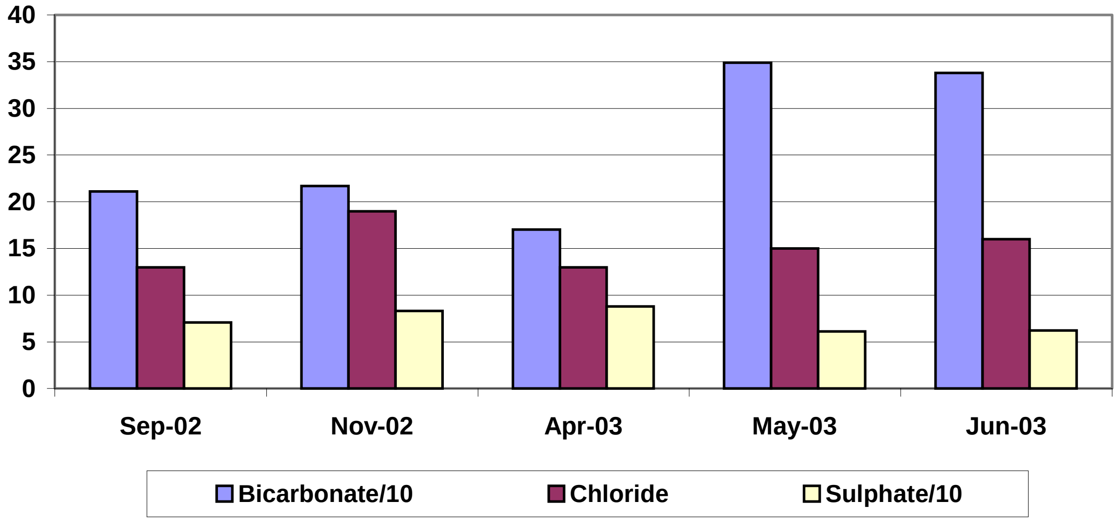

Figure 6.23. The changes of bicarbonate, chloride, and sulphate concentrations in well T during the study period

The results of calcium, potassium, magnesium, and sodium in well T are shown in Figure 6.24. Calcium, potassium, magnesium, and sodium concentrations of sample within the permissible limits according to TS 266. Concentrations of aluminum and manganese exceeded the permissible limits which are shown in Figure 6.25. The results of arsenic concentrations higher than 0.05 mg/L in September and November-2002, and May-2003 which are given in Figure 6.13. Boron concentrations were under the permissible limit in May and June-2003. The concentrations of SiO_2 were not constant during the monitoring period which suddenly decreased from 19.36 mg/L to 11.08 mg/L. The results of B and SiO_2 are shown in Figure 6.26.

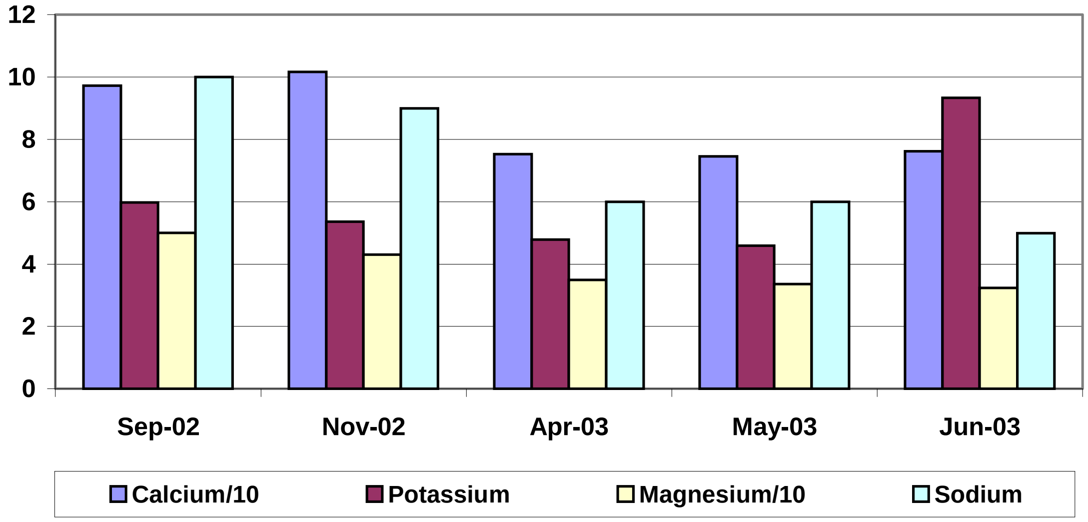

Figure 6.24. Calcium, potassium, magnesium, and sodium concentrations in well T during the monitoring period

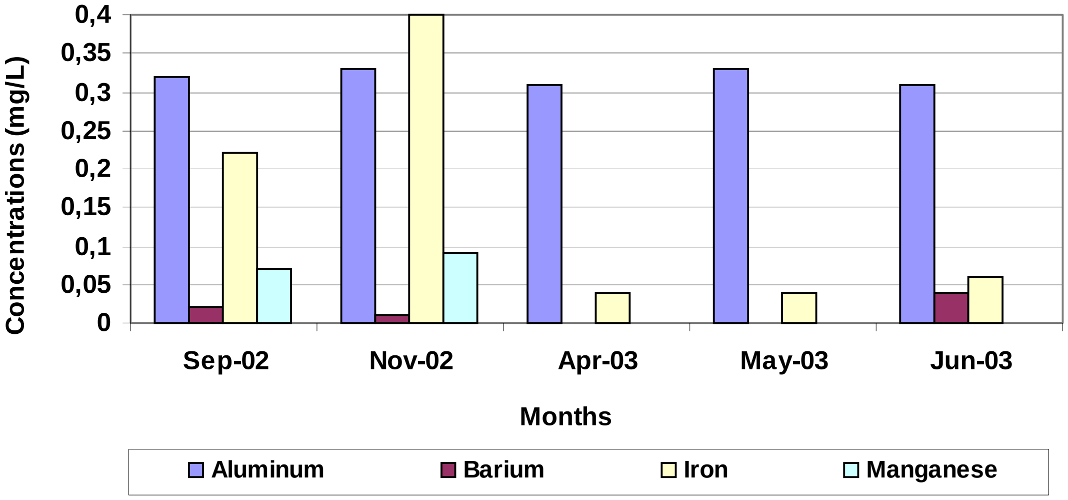

Figure 6.25. Aluminum, barium, iron, and manganese concentrations in well T during the study period

(Limit value for Al= 0.2 mg/L and Mn=0.05 mg/L)

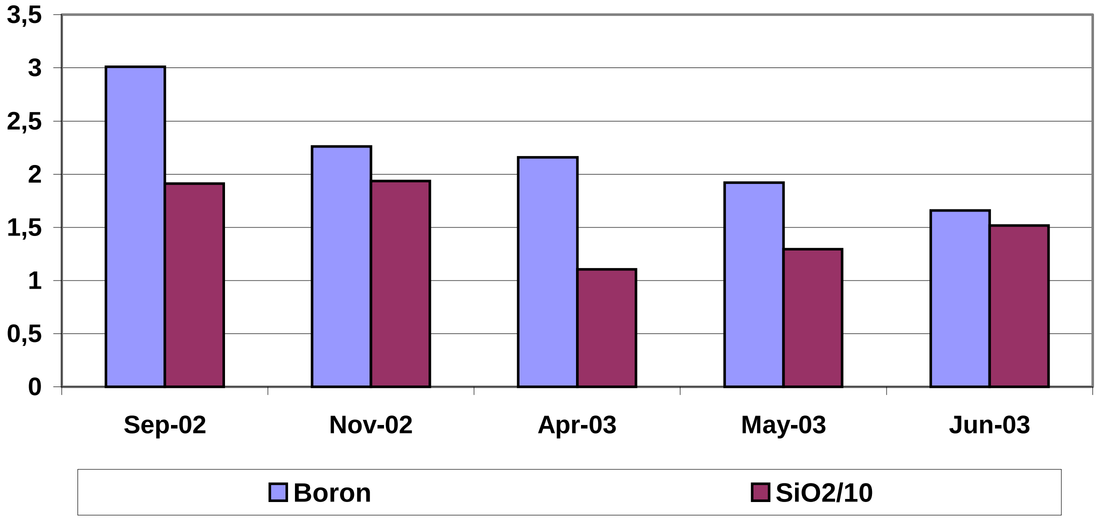

Figure 6.26. Boron and SiO_2 concentrations in well T during the study period

Heavy metal concentrations in well T are given in Table 6.8. During the study, copper, nickel and lead could not be detected expect well T after September-2002. Chromium concentrations were constant during the study but it exceeded permissible limits. Zinc concentrations of the sample were under the permissible limits.

Table 6.8. Heavy metal concentrations in mg/L in well T

Date	Cr	Cu	Ni	Pb	Zn
Sep-2002	0.10	0.17	0.01	0.01	0,66
Nov-2002	0.10	<LOD	<LOD	<LOD	0,01
Jan-2003	0.01	<LOD	<LOD	<LOD	0,01
Mar-2003	0.09	<LOD	<LOD	<LOD	<LOD
May-2003	0.10	<LOD	<LOD	<LOD	0,05

Well BD4 is one of the hottest wells in the field. It was assumed at the beginning that, thought out the study, the properties of the geothermal fluid in this well would not change significantly. Therefore, only one sample was taken from well BD4, the results of the analysis were compared with the results obtained previous years and it was concluded that further sampling was unnecessary since the difference was negligible. The results of the study of well BD4 are given in Figure 6.28 and Figure 6.36 and is given Table 6.9. The pH and EC values were between 7.19-8.26 and 1917-2060 μS/cm, respectively, at well BD4. Chloride and sulfate concentrations were constant. Bicarbonate concentrations were not constant. The minimum bicarbonate concentration was 421 mg/L in November-2002 and the maximum bicarbonate concentration was 825 mg/L in May-2002. Ammonia concentrations suddenly changed in February-2001. It can be explained by leachate of sewage to geothermal fluid. Fluoride concentrations were under the limits by TS266. Total dissolved solid concentrations were about 1644 mg/L. Calcium, potassium, and sodium were constant but magnesium concentrations were increased to 16 mg/L in November-2000. The suddenly changes can be explained by the leachate of groundwater to geothermal fluid. Aluminum, barium, iron, and manganese concentrations were not constant. Arsenic concentrations could not be detected until May-2002 which were not constant during the study period. Boron and SiO_2 concentrations were within the limits of Turkish Standards. Nickel concentrations could not be detected for all samples.

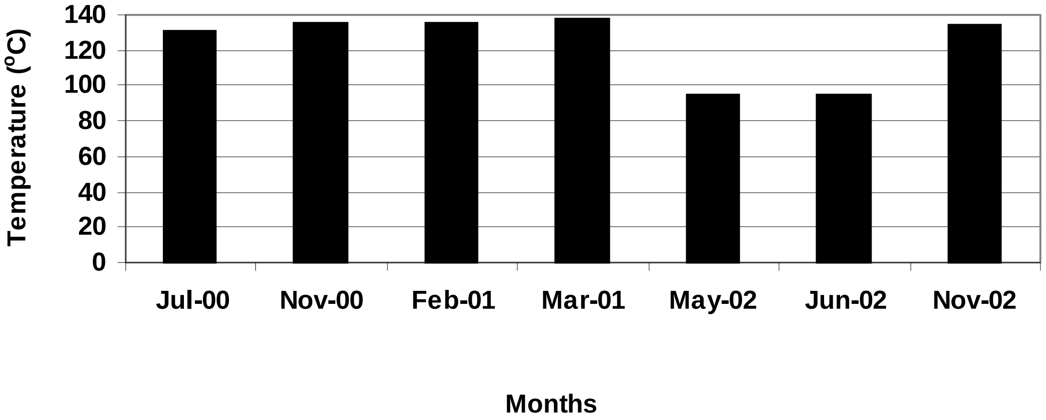

Figure 6.27. The changes of temperature values in well BD4 by years

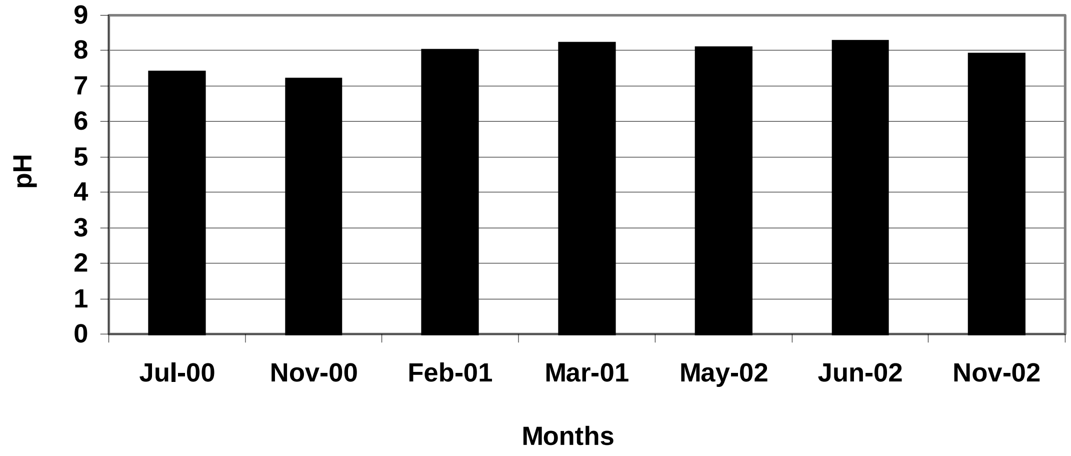

Figure 6.28. pH values of well BD4 by years

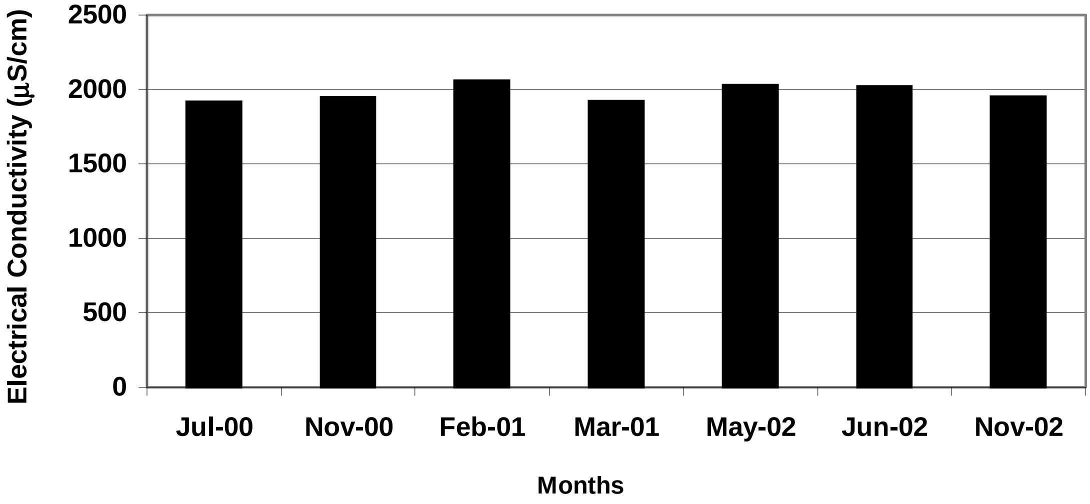

Figure 6.29. Electrical Conductivity values in well BD4 by years

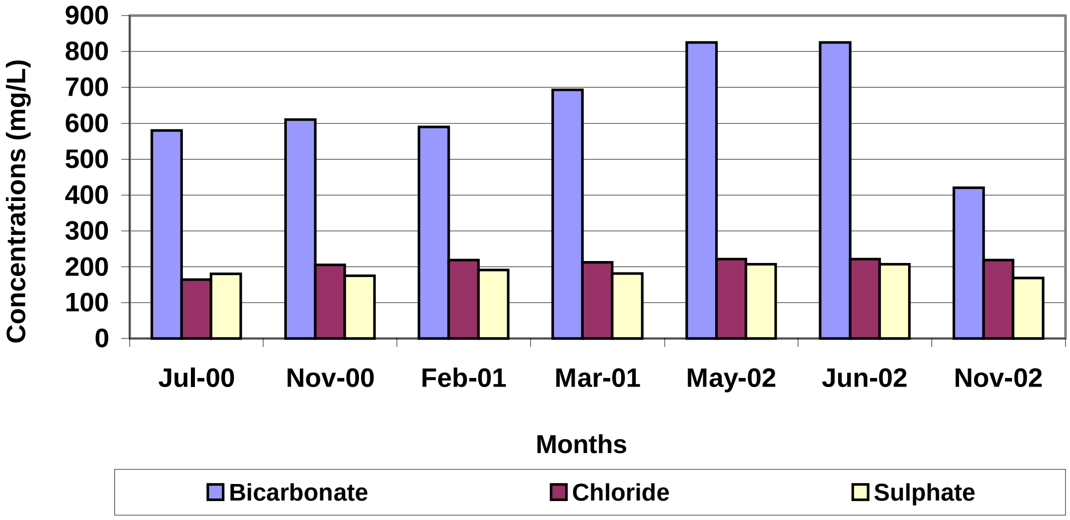

Figure 6.30. The changes of bicarbonate, chloride, and sulphate concentrations in well BD4 by years

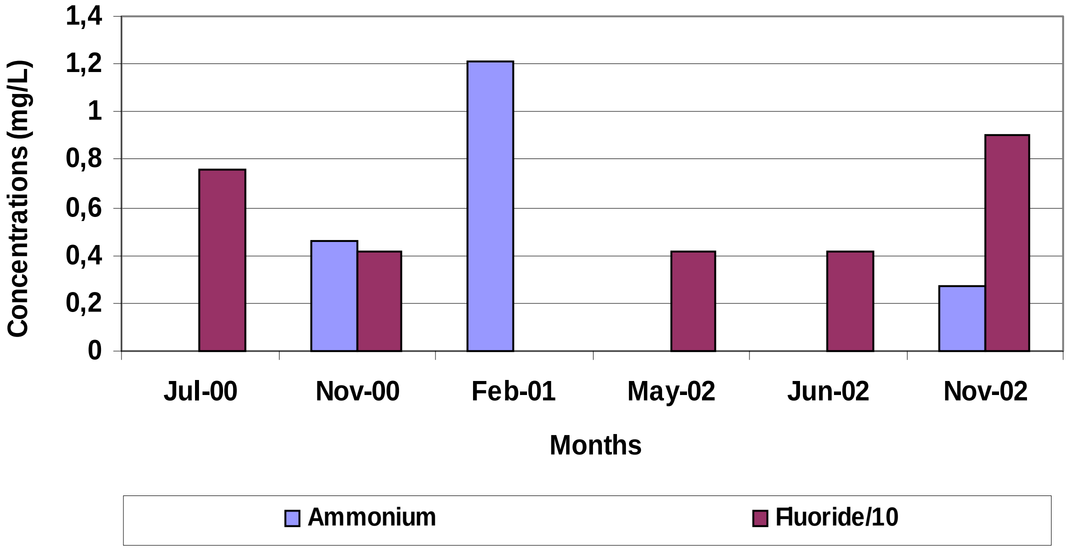

Figure 6.31. The changes of ammonium and fluoride concentrations in well BD4 by years

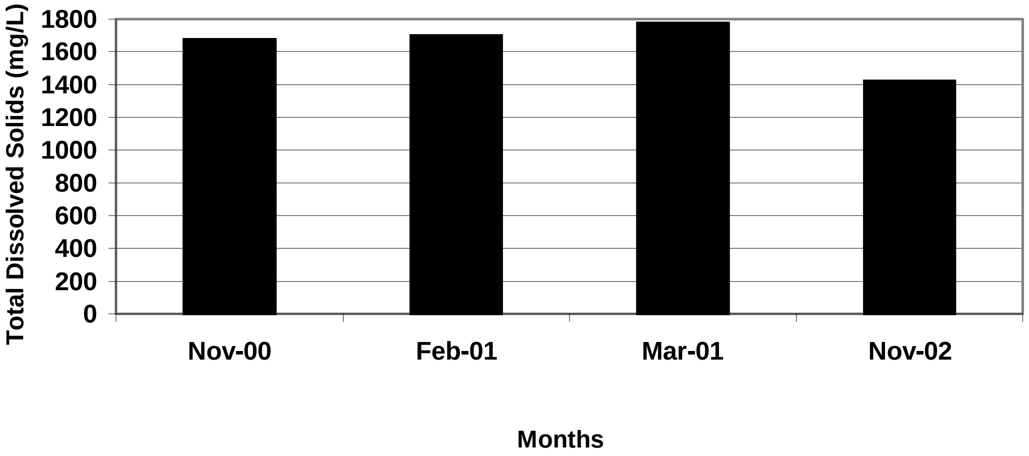

Figure 6.32. The results of TDS concentrations in well BD4 by years

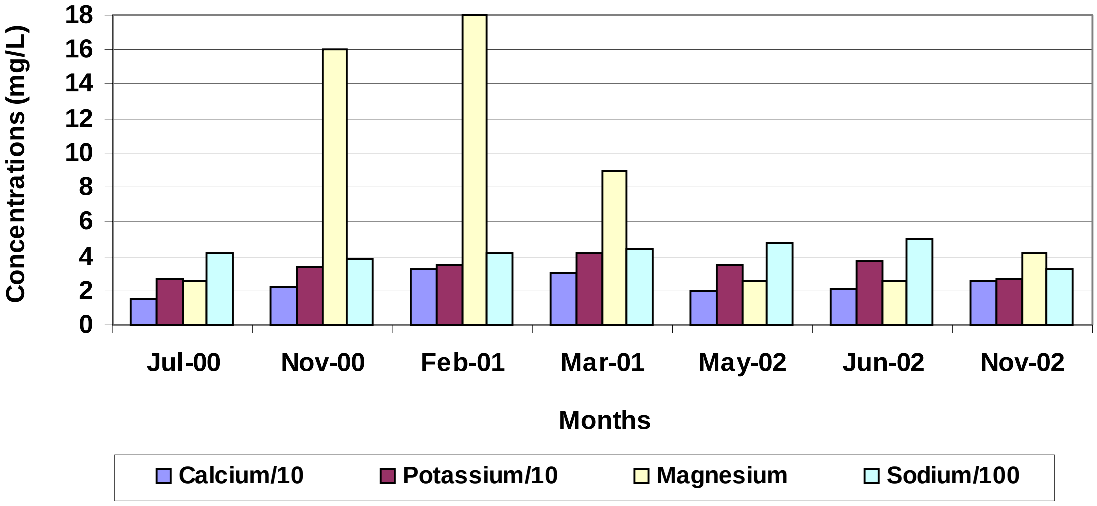

Figure 6.33. Calcium, potassium, magnesium, and sodium concentrations in well BD4 by years

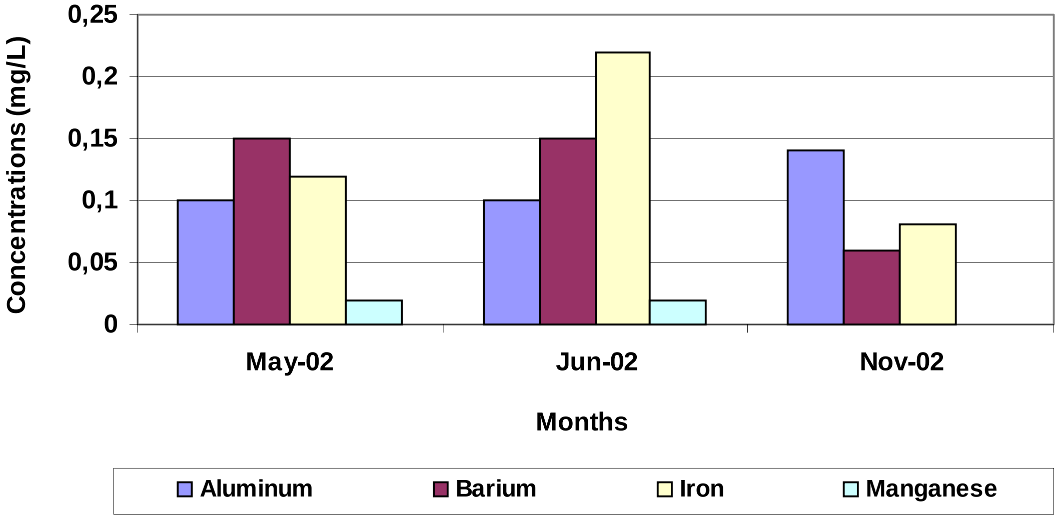

Figure 6.34. Aluminum, barium, iron, and manganese concentrations in well BD4 by years

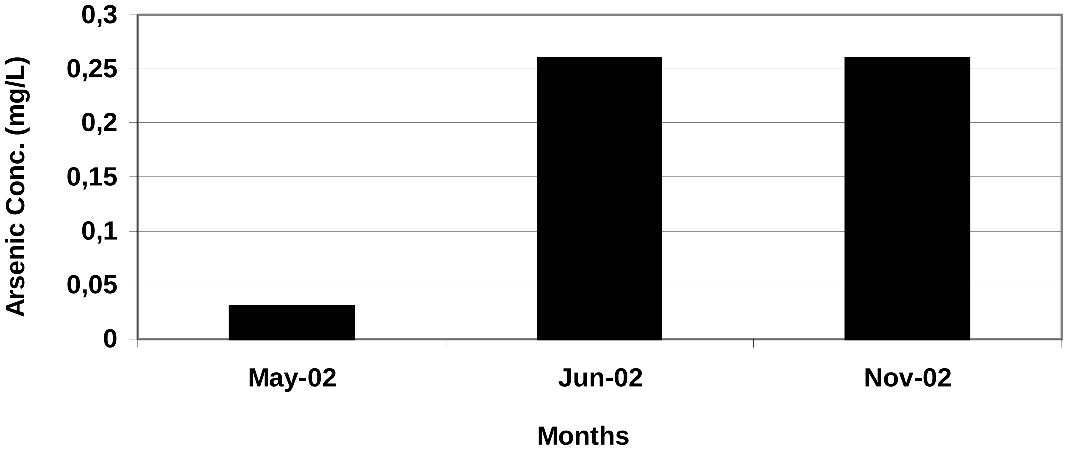

Figure 6.35. The results of arsenic in well BD4 by years

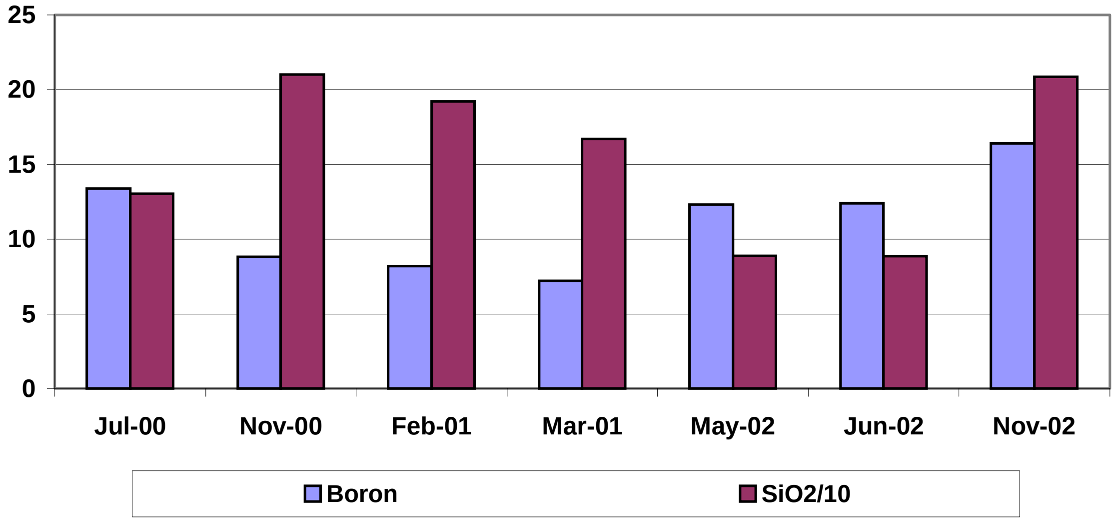

Figure 6.36. Boron and SiO_2 concentrations in well BD4 by years

Table 6.9. Heavy metal concentrations in mg/L in well BD4

Date	Cu	Pb	Zn
May-02	0.01	0.02	0,07
Jun-02	0.05	0.02	0,04
Nov-02	<LOD	<LOD	<LOD

Bicarbonate concentrations of the samples change gradually in all samples. This means that HCO_3 concentrations of samples increased or decreased in the same month because of the rainfall. In geothermal fluid samples bicarbonate alkalinity is only exist. During the analysis of alkalinity, the color of the samples did not change with the addition of the phenolphthalein, so the samples had only bicarbonate alkalinity, there was no carbonate alkalinity.

Chloride concentrations were constant only well T. The chloride concentrations of other sample point decreases or increases during the study period. Well T did not exceed the permissible limits of TS 266 and well I was within the limits of irrigation water standard. Sulphate concentrations in well T were under the permissible limit according to drinking water standard.

According to TS 266, the permissible limit for ammonium is 0.5 mg/L. Ammonium concentrations of well T did not exceeded the permissible limit during the monitoring period. The concentrations of ammonium suddenly increased in well B10 and well BD4. This result can be explained by leachate sewage to geothermal fluid. The results of ammonia were constant for other sampling point.

According to the TS 266, the permissible limit for fluoride is 1.5 mg/L. Fluoride concentrations of samples were under the permissible limit except well T but it exceeded the limits in well I by irrigation water standard.

Total Dissolved Solids values range from a few hundred to more than 300,000 mg/L for geothermal fluid. The concentrations of TDS were expected quantity in R, wells B10, I, and BD4.

Calcium concentrations of all samples were not constant during the monitoring period. According to TS 266 calcium ion concentrations mustn't exceed 200 mg/L. Calcium ion concentrations were not exceeded the permissible limits at well T. In addition, in well T calcium concentration suddenly decreased from 101.63 to 75.24 mg/L in November-2002 and was stay stable after this point. At well T, bicarbonate concentration changed like calcium. It shows groundwater of the well T interact with calcite which is permeable rock.

At wells B10 and T, sodium ion concentration decreased gradually every month during the study. At R, wells BD4 and I, sodium cation concentrations were not constant. At well T, the concentrations of sodium were under the permissible limits according to TS 266.

The permissible limit for magnesium ion is 50 mg/L. at well T magnesium ion concentrations were within the limits. In well BD4 calcium ion concentration suddenly increased from 2.5 to 16 mg/L in November-2000. The sudden changes can be explained by the leachate of groundwater to geothermal fluid.

The concentration of potassium mustn't exceed 12 mg/L. At well T potassium cation concentrations were under the permissible limits.

According to TS 266, the permissible limits for aluminum, barium, iron and manganese are 0.2 mg/L, 0.3 mg/L, 0.2 mg/L, and 0.05 mg/L. Alumina, iron, and manganese exceed the limits. The results of manganese were not under the limits in well I.

According to TS 266 boron concentration must be less than 2 mg/L. In well I boron concentrations were higher than the limits. The concentration of boron exceeded the permissible limit in well T. Generally, geothermal fluid has higher boron concentrations than groundwater or surface water.

The concentrations of SiO_2 increased gradually every month during the study in well B10. SiO_2 concentrations of other sampling points were not constant during the study period.

The concentrations of arsenic mustn't exceed 0.05 mg/L. Arsenic concentrations in well T were higher than the limits.

All samples were analyzed to investigate heavy metals. Inductively coupled plasma-atomic emission spectrophotometry is used to detect Cr, Cu, Ni, Pb, Zn. During the study period, some heavy metals could not be detected. At well T chromium concentrations were constant during the study but it exceeded permissible limits. Zinc and copper concentrations of the sample were under the permissible limits in well T. The results of nickel and lead were higher than the permissible limits.

CHAPTER VII

CONCLUSIOUNS AND RECOMMENDATIONS

The objective of this study was to determine the positive and negative environmental effects and the sources of contamination in Balçova District Heating System.

To observe the changes in geothermal fluid composition and to investigate the contamination in BGF, the samples were collected monthly in well B10 and every two months in R, wells I and T from September-2002 to June-2003. Finally one sample was taken from well BD4 in November-2002. Samples were collected by using an appropriate collection method for each parameter. Physical properties such as temperature, electrical conductivity, total dissolved solids, alkalinity; non-metallic constituents such as ammonia, boron, chloride, silica, sulfate; and metals and semi metals such as calcium, magnesium, sodium, potassium etc. were analyzed.

İzmir-Balçova District Heating System is one example of the high temperature district heating application. The environmental impacts associated with the low or moderate temperature applications are often minimal compared to those associated with the high temperature applications.

As a result of interactions between geothermal fluid and the geological materials through which it flows, geothermal fluid samples of Balçova field have bicarbonate alkalinity.

Aluminum, arsenic, iron, manganese, and boron values were recorded above the limits of drinking water standard. In Balçova geothermal field, sampling points are monitored by determining heavy metal contamination. Chromium, nickel, and lead were higher than the permissible limits of Turkish Standards.

The results of fluoride, boron, and manganese concentrations exceed the permissible limits according to irrigation water standard. Heavy metal contaminations were not found in irrigation water.

Geothermal fluids generally carry a variety of toxic chemicals in solution: arsenic, lead, zinc, boron, together with significant amounts of carbonates, silica, sulfates and chlorides. Discharge of waste waters is also a potential source of chemical pollution. Spent geothermal fluids with high concentrations of chemicals should be treated or reinjection into reservoir, or both. Reinjection of thermal waters to the reservoir is the best way to dispose of the geothermal waste water and prevent contamination problems. In the contrary, ground water may be contaminated if the reinjection wells fail, which may allow to the fluid pass into shallow aquifers. However, this can be eliminated by careful design, attention to quality control, during drilling and construction and monitoring during operational. Since the shallow wells in the field exhibit geothermal characteristics, drilling of the cold water wells without permission should be prevented.

The results of various analysis, shows that all geothermal water in the investigated area was found to be inappropriate for drinking purposes according to various parameters measured by physical and chemical analyses. In addition; geothermal fluid is unsuitable to be used as irrigation water because of high boron concentrations. Since the geothermal fluid is not suitable for drinking and irrigation purposes, the adverse effects should be declared to the public.

In order to determine the effects of Balçova District Heating System on physical environment noise measurements were conducted at and around heat center and a drilling site. Measurements recorded on both sites were above the permissible limits according to Noise Control Regulation.

Noise associated with the operational phase of direct use projects is generally significant. Drilling rigs and construction equipment pump, and compressors are principal noise sources for direct use projects. On the site itself, workers can be protected by wearing ear mufflers during drilling and production phase. The impacts of noise during drilling and construction can be reduced by the use best practice. Suitable muffling on the exhausts of the earth moving equipment can often reduce noise.

In the study, soil assessment was not applied for Balçova geothermal field; therefore soil contamination requires further studies. Air contamination can also be determined in the field in another study. Leachate from reinjection well to surface water should be determined by using advanced monitoring methods. Samples were collected for ten months, in this study. Monitoring the geothermal field is the most important part of field management. For Balçova geothermal field monitoring of environmental effects of geothermal applications should be implemented regularly. Therefore, this study should not be the last study for the field.

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APPENDIX A

Table 1. The results of physical properties in B10 from Octaber-2002 to June-2003

Sample	Date	T (^{o}C)	pH	EC µS/cm	TDS
B10	Oct-02	98	6.85	1966	1427
B10	Dec-02	96	6.92	1913	1216
B10	Jan-03	82	6.75	1793	1443
B10	Feb-03	90	6.90	1771	1037
B10	Mar-03	90	6.94	1757	1278
B10	Apr-03	80	6.79	1925	1170
B10	May-03	90	6.65	1910	1188
B10	Jun-03	82	6.66	1978	1118

Table 2. Analysis of non-metallic, semi metals and metals in B10 from Octaber-2002 to June-2003

Sample	Date	Al	As	B	Ba	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	SiO_2	Zn	HCO_3	Cl	NH_4	F	SO_4
B10	Oct-02	0.17	0.14	12.09	0.11	30.12	0.11	<LOD	0.76	28.85	8.10	0.04	525	<LOD	<LOD	112.77	0.19	554	184	ND	8.43	156
B10	Dec-02	0.17	0.28	13.09	0.10	29.95	0.10	<LOD	0.34	29.10	7.60	0.04	351	<LOD	<LOD	116.73	0.07	350	186	0.33	8.67	169
B10	Jan-03	0.17	0.23	14.22	0.11	30.80	0.11	<LOD	0.28	28.60	7.40	0.04	280	<LOD	<LOD	122.18	0.14	503	187	0.23	8.68	150
B10	Feb-03	0.16	0.18	14.30	0.10	34.40	0.11	<LOD	0.19	31.60	8.15	0.04	272	<LOD	<LOD	121.79	0.05	319	183	0.15	8.42	149
B10	Mar-03	0.17	0.16	14.51	0.10	32.45	0.11	<LOD	0.22	29.30	7.65	0.04	266	<LOD	<LOD	123.06	0.14	342	172	0.43	8.88	155
B10	Apr-03	0.15	0.21	14.82	0.10	27.86	0.11	<LOD	0.44	26.01	6.53	0.04	253	<LOD	<LOD	125.17	0.16	324	171	0.55	8.69	156
B10	May-03	0.17	0.20	14.46	0.09	27.54	0.11	<LOD	1.70	25.83	6.39	0.04	223	<LOD	<LOD	127.18	0.15	641	156	0.65	8.82	150
B10	Jun-03	0.15	0.26	14.31	0.09	20.75	0.10	<LOD	0.61	19.13	4.50	0.04	232	<LOD	<LOD	128.34	0.15	634	151	1.92	9.16	147

<LOD: limit of detection
ND: not detected
*: Ion charges are not shown for convenience
**: All analysis are in mg/L

Table 3. The results of physical properties in reinjection line (R) from September-2002 to May-2003

Sample	Date	T (^{o}C)	pH	EC µS/cm	TDS
R	Sep-02	53	7.84	1799	1178
R	Nov-02	52	7.80	1750	1565
R	Jan-03	58	6.80	1804	1419
R	Mar-03	78	6.40	1757	1307
R	May-03	66	6.72	1789	1106

Table 4. Analysis of non-metalic, semi metals and metals in reinjection line (R) from September-2002 to May-2003

Sample	Date	Al	As	B	Ba	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	SiO_2	Zn	HCO_3	Cl^-	NH_4	F	SO_4
R	Sep-02	0.31	0.15	13.61	0.11	33.83	0.10	0.17	0.70	24.78	7.88	0.05	224	0.01	0.01	119.66	0,66	326	170	ND	8.21	141
R	Nov-02	0.17	0.20	16.73	0.10	23.74	0.10	<LOD	0.19	25.03	4.64	0.03	258	<LOD	<LOD	158.78	0,01	334	178	0.45	8.41	181
R	Jan-03	0.21	0.27	18.18	0.10	22.41	0.01	<LOD	0.21	25.77	4.49	0.03	274	<LOD	<LOD	166.31	0,01	525	191	0.23	8.13	160
R	Mar-03	0.17	0.29	19.18	0.10	21.96	0.09	<LOD	0.25	26.52	4.07	0.03	279	<LOD	<LOD	174.33	<LOD	349	185	0.37	8.75	166
R	May-03	0.16	0.19	15.44	0.09	24.45	0.10	<LOD	0.22	23.04	5.96	0.04	237	<LOD	<LOD	136.81	0,05	653	133	0.60	8.46	156

<LOD: limit of detection
ND: not detected
*: Ion charges are not shown for convenience
**: All analysis are in mg/L

Table 5. The results of physical properties in well I from September-2002 to May-2003

Sample	Date	T(°C)	pH	EC µS/cm	TDS
I	Sep-02	41	6.49	1570	949
I	Nov-02	39	6.80	1610	1267
I	Jan-03	34	6.20	1487	1194
I	Mar-03	31	6.24	1550	977
I	May-03	32	6.56	1490	1005

Table 6. Analysis of non-metalic, semi metals and metals in well I from September-2002 to May-2003

Sample	Date	Al	As	B	Ba	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	SiO_2	Zn	HCO_3	Cl	NH_4	F	SO_4
I	Sep-02	0.17	0.05	12.03	<LOD	30.23	0.09	0.02	0.05	18.69	11.77	1.02	169	0.03	<LOD	86.07	<LOD	287	65	ND	5.61	95
I	Nov-02	0.23	<LOD	11.27	<LOD	32.67	0.09	<LOD	0.07	16.99	11.43	0.70	168	<LOD	<LOD	84.58	0.81	299	123	0.22	5.41	147
I	Jan-03	0.24	0.05	10.47	<LOD	58.68	0.09	<LOD	0.03	15.76	15.99	0.61	131	<LOD	0.01	83.14	0.06	414	139	0.32	4.67	97
I	Mar-03	0.28	0.01	11.11	<LOD	62.28	0.08	<LOD	0.04	15.14	16.14	0.77	123	<LOD	0.01	85.65	0.07	247	137	0.12	4.39	109
I	May-03	0.26	<LOD	11.62	<LOD	37.67	0.08	<LOD	0.03	17.35	12.73	1.12	152	<LOD	0.01	93.26	0.62	534	121	0.53	5.01	139

<LOD: limit of detection
ND: not detected
*: Ion charges are not shown for convenience
**: All analysis are in mg/

Table 7. The results of physical properties in well T

Sample	Date	T (°C)	pH	EC µS/cm	TDS
T	Sep-02	27	7.15	634	515
T	Nov-02	24	6.50	589	865
T	Apr-03	14	7.22	552	949
T	May-03	18	7.50	597	413
T	Jun-03	19	7.55	626	327

Table 8. Analysis of non-metallic, semi metals and metals in well T

Sample	Date	Al	As	B	Ba	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	SiO_2	Zn	HCO_3	Cl	NH_4	F	SO_4
T	Sep-02	0.32	0.13	3.01	0.02	97.27	0.08	0.02	0.22	5.98	50.08	0.07	10	0.05	<LOD	19.12	0.15	211	13	ND	0.30	71
T	Nov-02	0.33	0.07	2.26	0.01	101.63	0.06	<LOD	0.40	5.36	43.06	0.09	9	0.04	<LOD	19.36	0.21	217	19	0.34	0.26	83
T	Apr-03	0.31	0.03	2.16	<LOD	75.24	0.07	<LOD	0.04	4.79	34.96	<LOD	6	<LOD	0.04	11.08	<LOD	170	13	0.28	0.25	88
T	May-03	0.33	0.08	1.92	<LOD	74.56	0.07	<LOD	0.04	4,.6	33.62	<LOD	6	<LOD	0.04	12.96	0.06	349	15	0.17	0.45	61
T	Jun-03	0.31	0.03	1.66	0.04	76.18	0.07	<LOD	0.06	9.33	32.36	<LOD	5	0.12	0.06	15.17	1.213	338	16	0.14	0.20	62

<LOD: limit of detection
ND: not detected
*: Ion charges are not shown for convenience
**: All analysis are in mg/L

Table 9. The results of physical properties in well BD4 by years

Sample	Date	T (^{o}C)	pH	EC µS/cm	TDS
BD4	Jul-00	131	7.40	1917	n/d
BD4	Nov-00	136	7.19	1947	1676
BD4	Feb-01	136	8.00	2060	1700
BD4	Mar-01	138	8.08	1922	1778
BD4	May-02	95	8.26	2030	n/d
BD4	Jun-02	95	8.16	2019	n/d
BD4	Nov-02	134	7.50	1950	1422

Table 10. Analysis of non-metallic, semi metals and metals in well BD4 by years

Sample	Date	Al	As	B	Ba	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	SiO_2	Zn	HCO_3	Cl	NH_4	F	SO_4
BD4	Jul-00	ND	ND	13.4	ND	15	ND	0,02	ND	27	2,5	ND	420	ND	ND	130.5	ND	580	164	ND	7.60	180
BD4	Nov-00	ND	ND	8.8	ND	22	ND	ND	ND	34	16	ND	388	ND	ND	210	ND	610	205	0.46	4.15	175
BD4	Feb-01	ND	ND	8.2	ND	32	ND	ND	ND	35	18	ND	415	ND	ND	192	ND	590	218	1.21	ND	191
BD4	Mar-01	ND	ND	7.2	ND	30	ND	ND	ND	42	9	ND	438	ND	ND	167	ND	693	212	ND	ND	181
BD4	May-02	0.10	0.,03	12.3	0.15	19.6	ND	0,01	0,12	34,3	2,5	0.02	477.6	ND	0.02	88.5	0.07	825	221	ND	4.20	207
BD4	Jun-02	0.10	0.26	12.4	0.15	20.,4	ND	0,05	0,22	36,7	2,5	0.03	497.1	ND	0.02	86.5	0.04	825	221	ND	4.20	207
BD4	Nov-02	0.14	0.24	16.4	0.06	25.7	0,09	ND	0,08	26,5	4,2	ND	325	ND	ND	208.55	ND	421	218	0.27	9.07	168

<LOD: limit of detection
ND: not detected
*: Ion charges are not shown for convenience
**: All analysis are in mg/L