Data Collection Survey on Geothermal Potential in Northern Area of India

FINAL REPORT

January 2013

JAPAN INTERNATIONAL COOPERATION AGENCY
WEST JAPAN ENGINEERING CONSULTANTS, INC.

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Abbreviations

APTEL: Appellate Tribunal for Electricity
BBMB: Bhakra Beas Management Board
BEE: Bureau of Energy Efficiency
CEA: Central Electricity Authority
CDM: Clean Development Mechanism
CERC: Central Electricity Regulatory Commission
CFC: Chlorofluorocarbon
CPRI: Central Power Research Institute
CSAMT: Controlled Source Audio-frequency Magneto-Telluric method
CTU: Central Transmission Utility
DPR: Detailed Project Report
DVC: Damodar Valley Corporation
EIA: Environmental Impact Assessment
FCRS: Fluid Collection and Reinjection System
FS: Feasibility Study
GSI: Geological Survey of India
HFC: Hydrofluorocarbon
IEE: Initial Environmental Examination
IIT: Indian Institute of Technology
IPCC: Intergovernmental Panel on Climate Change
IPP: Independent Power Producer
JETRO: Japan External Trade Organization
JICA: Japan International Cooperation Agency
LPG: Liquefied Petroleum Gas
MNRE: Ministry of Renewable Energy
MOEF: Ministry of Environment and Forests
MOP: Ministry of Power
MT: Magneto-Telluric Method
NCG: Non Condensable Gas
NEEPCO: North Eastern Electric Power Corporation Limited
NGRI: National Geophysical Research Institute
NHPC: National Hydro Electric Power Corporation Limited
NLDC: National Load Despatch Centre
NPC: Nuclear Power Corporation Limited
NPTI: National Power Training Institute
NRPC: Northern Region Power Committee

NTPC: National Thermal Power Corporation Limited
O&M: Operation & Maintenance
PFC: Power Finance Corporation Limited
PGCIL: Powergrid Corporation of India Limited
PTCUL: Power Transmission Corporation of Uttarkhand Limited
REC: Rural Electrification Corporation Limited
RLDC: Regional Load Despatch Centre
SEB: State Electricity Board
SEIAA: State/Union territory Environmental Impact Assessment Authority
SERC: State Electricity Regulatory Commission
SJVNL: Satluj Jal Vidyut Nigam Limited
SLDC: State Load Despatch Centre
SNA: State Nodal Agency
SNC: Ernst & Young ShinNihon LLC
STU: State Transmission Utility
THDC: Tehri Hydro Development Corporation India Limited
UERC: Uttarkhand Electricity Regulatory Comission
UPCL: Uttarkhand Power Corporation Limited

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CHAPTER I

I INTRODUCTION

I-1 Study Area

The study area is Uttarakhand State and other states in northern India (see Fig. I-1).

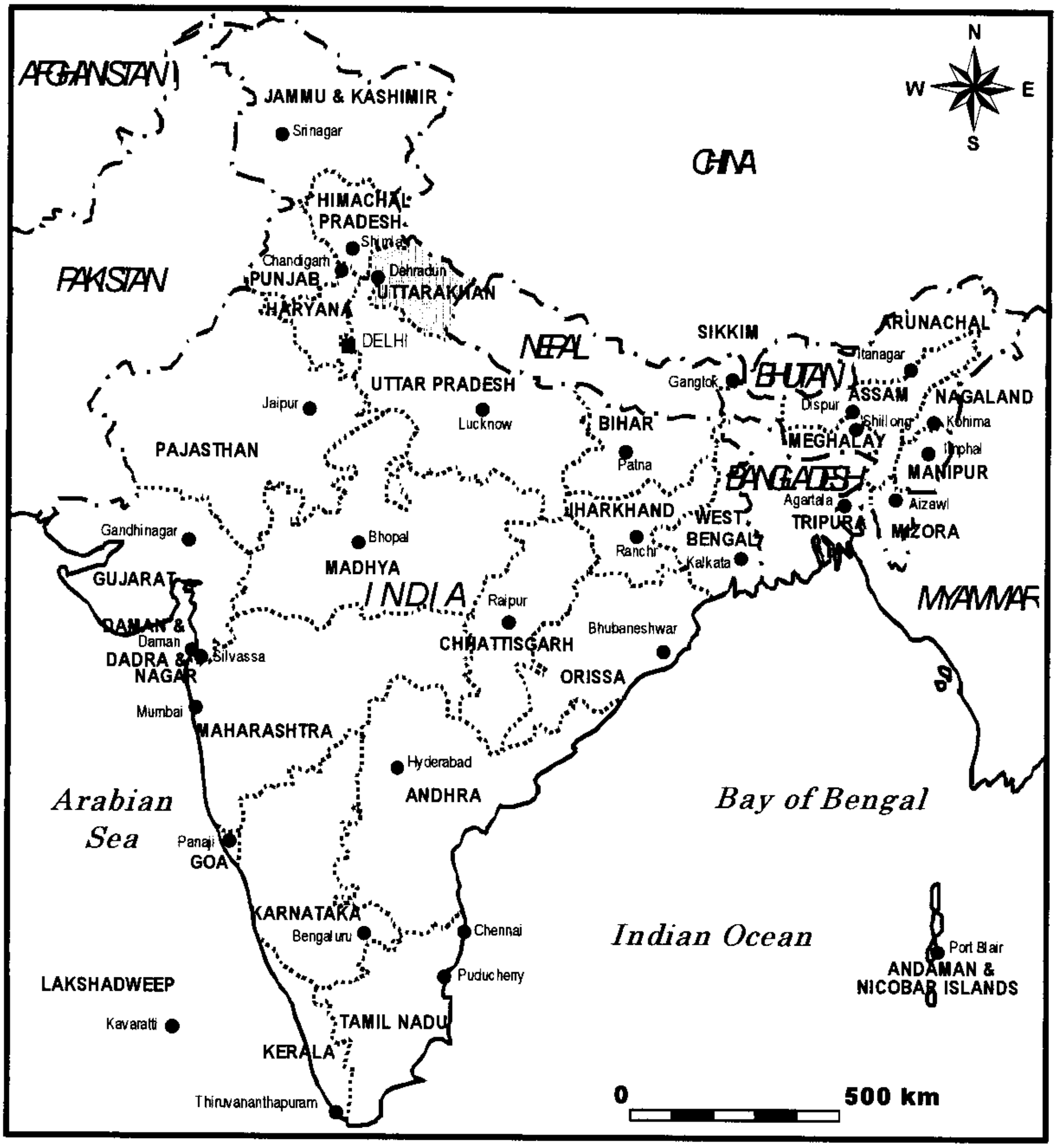


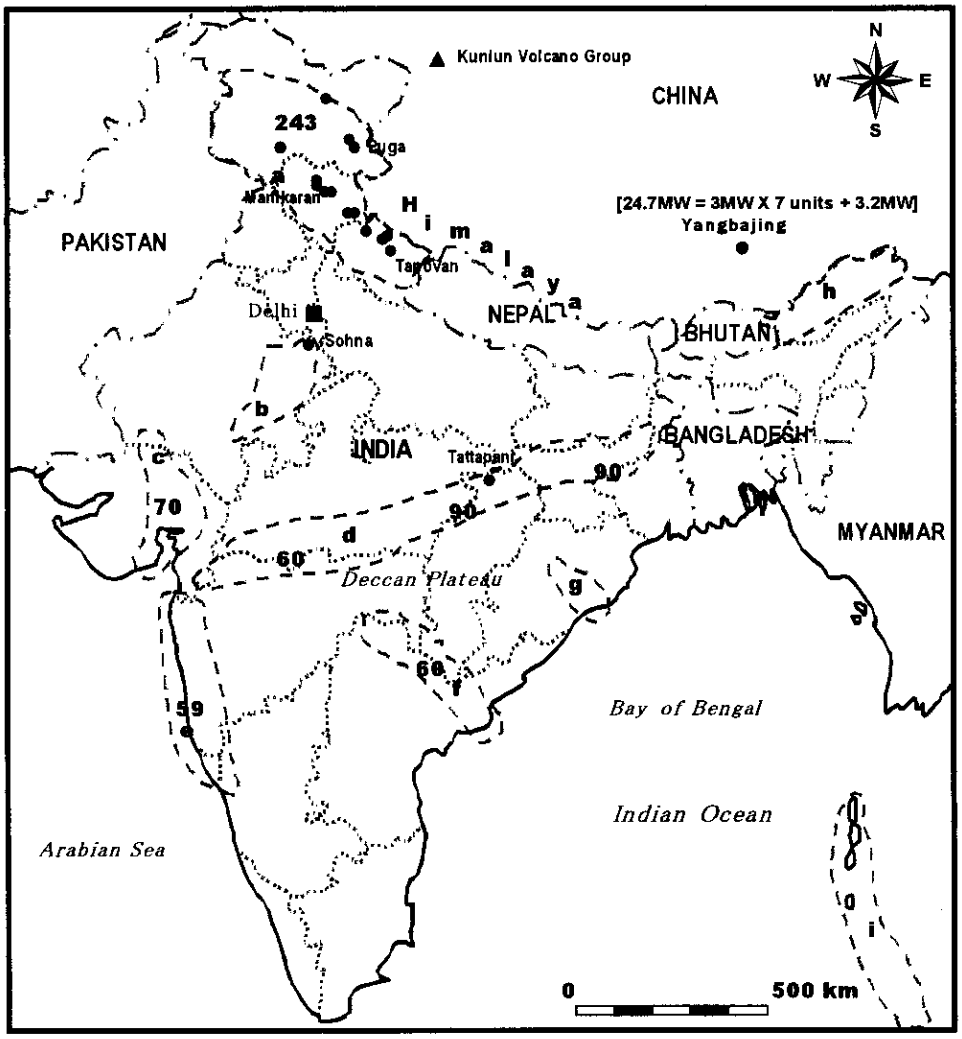
Fig. I-1 Study Area

I-2 Background

The necessity of energy 'self-sufficiency' for the country's energy security was made clear to India through the two oil shocks of the 1970s. Moreover, the Government of India is aiming to achieve CO_2 emissions reductions of 20 to 25% (ratio against GDP) following the Copenhagen Accord (COP15). Against this background, and with the recent increase in the price of oil, the significance of new and renewable sources of energy has been increasing in India. To meet the energy requirements of the country, the Ministry of New and Renewable Energy (MNRE) of the Government of India is aiming to develop and deploy new and renewable energy sourced from wind, solar, small hydro, biomass, hydrogen and so on.

Geothermal energy is also considered to be an important renewable energy. After the oil shocks, the Geological Survey of India (GSI) conducted studies on geothermal resources in the country and observed about 340 hot springs. The National Geophysical Research Institute (NGRI) conducted MT surveys, supported by MNRE, in some geothermal fields. The major geothermal provinces in India are represented in Fig. I-2. On and around the Deccan Plateau, there are some geothermal provinces with a geothermal gradient of 60°C/km to 90°C/km. Judging from these data, it is difficult to expect the discovery of sufficient geothermal resources for conventional power generation (requiring a resource temperature of higher than 200°C). On the other hand, the geothermal gradient in the Northwest Himalaya geothermal province is quite high (243°C/km), though these values are deduced from temperature data for shallow wells, not from deep wells reaching to a depth of 1,000 m.

There are a number of plans and projects aiming at geothermal development in India, but their final goals (power generation) have not yet been realized. This may be due to a lack of cumulated experience in geothermal development. In 2010, the Japan External Trade Organization (JETRO) and Ernst & Young ShinNihon LLC conducted a study entitled "Study on Geothermal Power Development Project at Uttarakhand State in India" (hereinafter referred to as JETRO and SNC (2010)). This study was one of the studies conducted in FY 2009 by the Ministry of Economy, Trade and Industry of the Government of Japan under the "Study on Economic Partnership Projects" rubric. Subsequently, in December 2010, the Government of India made a request to the Government of Japan for a Feasibility Study on the Tapovan Geothermal Development Project in Uttarakhand State. However, prospective geothermal fields in India, including the Tapovan geothermal field, have only reached the earlier exploration phase of the general process of geothermal development (described in the next chapter). In their present condition, fundamental information is still lacking that would permit the elaboration of an effective and successful contribution to geothermal development in India by the Government of Japan.



After Chandrasekharam (2000, 2005), A. Absar, Ravi Shanker, B. L. Jangi, A. K. Rajaj, R. K. Aggarwal and G. K. Gupta (1996), Ravi Shanker, A. Absar and G. C. Sfuvastava (1999)

a : NW Himalaya b : Sohana c : Cambay d : SONATA e : West coast f : Godavari g : Mahanadi
h : NE Himalaya I: Andaman & Nicobar 90 : Geothermal gradient (°C/km)

Fig. I-2 Major Geothermal Provinces in India

I-3 Purpose of the Survey

The main purpose of this survey is the collection and review of the following information in order to consider a possible and effective contribution by the Government of Japan to geothermal power development in India:

- Fundamental facts and the latest information about geothermal resources in India
- Information concerning the policies and organization of the Government of India for geothermal development

I-4 Executing Agency

The executing agency of the Project is NTPC (National Thermal Power Corporation Limited).

I-5 TOR of the Survey

The survey covers the following issues.

1) Review and confirmation of
    - Renewable energy policy in India (at the level of the Central Government and the Government of Uttarakhand State), especially concerning geothermal energy
    - Current status of the electricity sector in India and in Uttarakhand
    - Permissions required for geothermal development in India
    - Geothermal fields in India and geoscientific data from them
    - Present condition of the Tapovan field (geology, social and natural environment, infrastructure, river and river water utilization, etc.)
2) Collecting information about
    - Exploration/survey companies or institutes in India
    - Drilling companies in India
    - Well testing companies
    - Companies/laboratories for chemical analysis of geothermal fluid
3) Examination and proposal of an effective scheme for the Tapovan geothermal project

I-6 Survey Schedule

The data collection survey followed the schedule shown in Fig. I-3, and the overall service schedule of the data collection survey is shown in Table I-1.

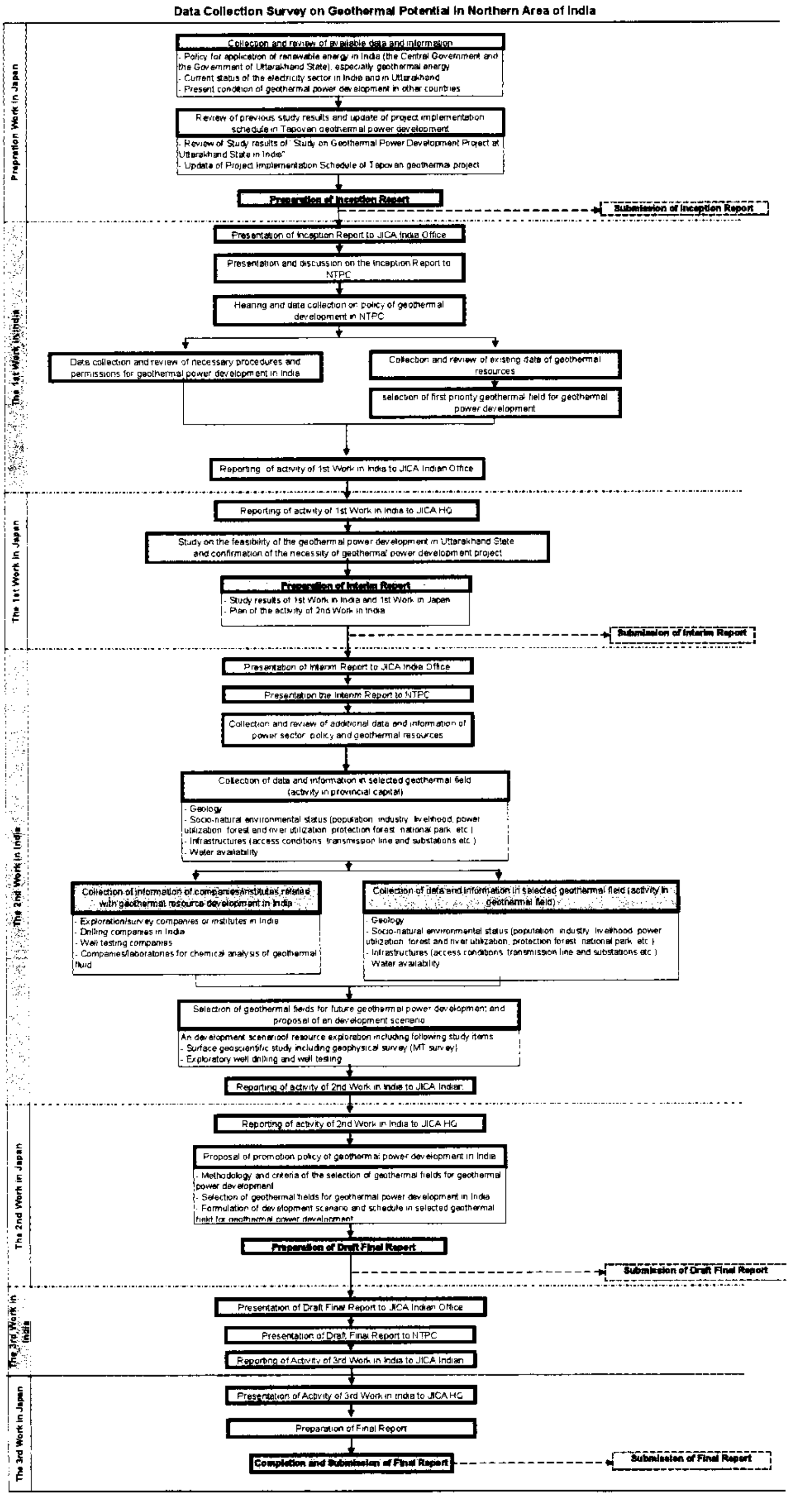
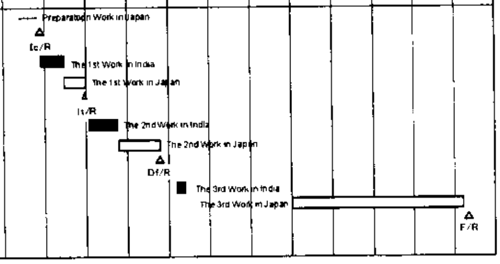


Fig. I-3 Flow of the Data Collection Survey

Table I-1 Service Schedule of the Survey

Month Service Item	2012											2013
	2	3	4	5	6	7	8	9	10	11	12	1
1 Preparation Work in Japan	□											
1-1 Collection and review of available data and information	□											
1-2 Review of Study Results "Study on Geothermal Power Development Project at Uttarakhand State in India (SNC and JETRO 2010)" and update of Project Implementation Schedule of Tapovan geothermal project	□											
1-3 Preparation of Inception Report	□											
2 The 1st Work in India		■										
2-1 Presentation of Inception Report to JICA India Office		■										
2-2 Presentation and discussion on the Inception Report to NTPC		■										
2-3 Data collection and review of necessary procedures and permissions for geothermal power development in India		■										
2-4 Collection and review of existing data of geothermal resources and selection of fast priority geothermal field for geothermal power development		■										
2-5 Reporting of activity of 1st Work in India to JICA Indian Office		■										
3 The 1st Work in Japan		□										
3-1 Reporting of activity of 1st Work in India to JICA HQ		□										
3-2 Study on the feasibility of the geothermal power development in Uttarakhand State. and confirmation of the necessity of geothermal power development project		□										
3-3 Preparation of Interim Report		□										
4 The 2nd Work in India			■									
4-1 Presentation of Interim Report to JICA India Office			■									
4-2 Presentation the Interim Report to NTPC			■									
4-3 Collection and review of additional data and information of power sector policy and geothermal resources			■									
4-4 Collection of information of companies/institutes related with geothermal resource development in India			■									
4-5 Collection of data and information in selected geothermal field (activity in provincial capital)			■									
4-6 Collection of data and information in selected geothermal field (activity in geothermal field)			■									
4-7 Selection of geothermal fields for future geothermal power development and proposal of an development scenario			■									
4-8 Reporting of activity of 2nd Work in India to JICA Indian Office			■									
5 The 2nd Work in Japan				□								
5-1 Reporting of activity of 2nd Work in India to JICA HQ				□								
5-2 Proposal of promotion policy of geothermal power development in India				□								
5-3 Preparation of Draft Final Report				□								
6 The 3rd Work in India					■							
6-1 Presentation of Draft Final Report to JICA Indian Office					■							
6-2 Presentation of Draft Final Report to NTPC					■							
6-3 Reporting of Activity of 3rd Work in India to JICA Indian Office					■							
7 The 3rd Work in Japan												
7-1 Presentation of Activity of 3rd Work in India to JICA HQ								□	□	□	□	□
7-2 Preparation of Final Report								□	□	□	□	
7-3 Completion and Submission of Final Report											□	
Overall Schedule												



Legend- - - Preparation Work ■ Work in India □ Work in Japan

I-7 Members of the Survey Team

Members of the survey team are listed in Table I-2 together with their specialties and assignments.

Table I-2 Members of the Survey Team

Name	Specialty	Assignment
AKASAKO, Hideo	Survey Project Manager, Geologist	Team Leader, Project management, Technical Supervisor, Geothermal Development
SUEYOSHI, Yoshikazu	Geothermal Engineer (Drilling engineer)	Data collection and review of geothermal development, data collection on drilling companies, and elaboration of project implementation plan (drilling etc.)
NAGANO, Hiroshi	Geothermal Engineer (Geothermal geophysicist)	Data collection and review of geothermal development, data collection on geophysical survey companies/institutes, elaboration of project implementation plans (geophysical survey etc.)
YAHARA, Tetsuya	Geothermal Engineer (Reservoir engineer)	Data collection and review of geothermal development, data collection on Companies/laboratories for chemical analysis of geothermal fluid, and elaboration of project implementation plan (resource development etc.)
SUGIMURA, Maiko	Legal framework and policy	Study of power sector, legal framework, geothermal power development promotion policy
TAGOMORI, Koichi	Legal framework and policy	Study of power sector, legal framework, geothermal power development promotion policy
SOEDA, Yoshio	Geologist	Data collection and review of geothermal resources in India, field survey, selection of geothermal field for geothermal power development, Well testing companies
WADA, Takayuki	Well testing engineer and Environment	Data collection and review of geothermal resources in India, data collection on well testing companies, selection of geothermal field for geothermal power development
MALIK, Ranjeev	Environmental Researcher	Social and Environmental Considerations

I-8 Items Requested by the Team from the Recipient Side

The aim of the study is to collect and analyze the latest fundamental data and information about geothermal resources in India, and the policies and organization of the Government of India for geothermal development. In addition, recent geoscientific data and information concerning Tapovan and other geothermal fields in northern India, where available, is needed to update the existing information on geothermal resources in northern India. Those items that were requested by the survey team from the recipient side were summarized and attached at the end of the Inception report as questionnaires.

I-9 Reports

The Survey team will prepare and present the following reports in English and Japanese.

- Inception report (English/Japanese)
- Interim report (English/Japanese)
- Draft final report (English/Japanese)
- Final report (English/Japanese)

CHAPTER II

II PRESENT CONDITION OF THE INDIAN POWER SECTOR

II-1 Power Supply against Demand and Application of Renewable Energy

Remarkable economic growth in recent years has led to a considerable increase in power demand in India, which has in turn resulted in a shortfall of power supply: a shortfall of about 10.1% of power required and of about 12.7% of peak demand in 2009/2010, and a shortfall of about 8.5% of power required and of about 9.8% of peak demand in 2010/2011. The preparation of sufficient supply capacity to meet these increasing requirements for electricity is an essential problem that must be resolved expeditiously.

The electricity supply system in India is divided into the following five regions:

Northern Region = Chandigarh, Delhi, Haryana State, Himachal Pradesh State, Jammu & Kashmir State, Punjab State, Rajastan State, Uttar Pradesh State and Uttarakhand State

Western Region = Chattisgar State, Gujarat State, Madhya Pradesh State, Maharashtra State, Daman & Diu, Dadra & Nagar Haveli and Goa

Southern Region = Andhra Pradesh State, Karnataka State, Kerala State, Tamil Nadu State and Pondicherry

Eastern Region = Bihar State, Jharkhand State, Orissa State, West Bengal State and Sikkim State

North-Eastern Region = Arunachal Pradesh State, Assam State, Manipur State, Meghalaya State, Mizoram State, Nagaland State and Tripura State

According to the Northern Region Power Committee (NRPC), a shortfall in power supply (about 3.97% of requirements and about 5.96% of peak demand) in the Northern Region occurred in May, 2011. In Uttarakhand State and Himachal Pradesh State, a shortfall of about 2.78% of requirements (about 10.89% of peak demand) and of about 0.09% of requirements (0% of peak demand), respectively, were also noted in the same month.

The 11th Plan aimed to increase installed capacity by 78,577 MW over the five years to the end of 2011/2012. However, capacity increased by less than 50,000 MW. The 12th Plan (running from 2011/2012 to 2016/2017) aims to increase installed capacity by 100,000 MW over five years. The Indian Government has a positive policy for the application of renewable energy and puts emphasis on the development of wind and solar power.

According to the Central Electricity Authority (CEA), total installed capacity in India was 182,689.62 MW at the end of October, 2011; thermal generation accounts for 119,040.98 MW (about 65.2%) of this, hydro for 38,706.4 MW (about 21.2%), nuclear for 4,780 MW (about 2.6%) and renewable energy (including small hydro) for 20,162.24 MW (about 11.0%). Coal-fired power plants are the major power source in India, with an installed capacity of 100,098.38 MW (about 54.8% of total capacity in India). Power plants in the Northern Region have a capacity of 48,764.06 MW (thermal = 28,711.75 MW, hydro = 14,922.75 MW, renewable energy = 3,509.56 MW, nuclear = 1,620 MW) and their share of the total capacity in India is about 27%. According to Annual Report 2010-2011 of MOP (Ministry of Power), power plants in Uttarakhand State have a capacity of 2,410.04 MW (hydro = 1,924.18 MW, thermal = 330.61 MW, renewable energy = 132.97 MW, nuclear = 22.28 MW) and those in Himachal Pradesh State have a capacity of 2,284.15 MW (hydro = 1,731.94 MW, thermal = 180.31 MW, renewable energy = 337.82 MW, nuclear = 34.08 MW).

II-2 Organization for Power Supply

Administrative Bodies concerned with Power Supply

The Indian power sector is divided into the central sector, the state sector, and the private sector. The central government and state governments control the power business in India. The central government and state governments make policy, and regulate and oversee the business. A particularity of India is that each state has a difference supply system.

The relevant administrative body of the central government is the Ministry of Power (MOP). MOP started functioning from July 2, 1992 (it was previously known as the Ministry of Energy Sources). The main organizations concerned with electricity are shown in Fig. II-1. MOP is responsible for the administration of the Electricity Act of 2003 and the Energy Conservation Act of 2001. MOP is also responsible for undertaking such amendments to these acts as may be necessary from time to time in conformity with the Government's policy objectives. MOP is mainly responsible for evolving general policy in the field of energy and its main concerns are as follows.

- General Policy in the electric power sector and issues relating to energy policy and the coordination thereof
- All matters relating to hydro-electric power (except small/mini/micro hydro projects of less than 25 MW in capacity, for which the Ministry of New and Renewable Energy is responsible) and thermal power and the transmission & distribution system network
- Research, development and technical assistance relating to hydroelectric and thermal power, the transmission system network and distribution systems in the States and Union Territories
- Administration of the Electricity Act of 2003, (36 of 2003), the Energy Conservation Act of 2001 (52 of 2001)
- All matters relating to the Central Electricity Authority (CEA), Central Electricity Board (CEB) and Central Electricity Regulatory Commission (CERC)
- Rural Electrification
- Power schemes and issues relating to power supply/development schemes/ programmes/decentralized and distributed generation in the States and Union Territories
- Matters relating to the following Undertakings/Organizations
    - Damodar Valley Corporation
    - Bhakra Beas Management Board (except matters relating to irrigation)
    - NTPC
    - NHPC
    - Rural Electrification Corporation Limited
    - North Eastern Electric Power Corporation Limited
    - Power Grid Corporation of India Limited
    - Power Finance Corporation Limited
    - Tehri Hydro Development Corporation
    - Satluj Jal Vidyut Nigam Limited
    - Central Power Research Institute
    - National Power Training Institute
    - Bureau of Energy Efficiency
- All matters concerning energy conservation and energy efficiency pertaining to the Power Sector

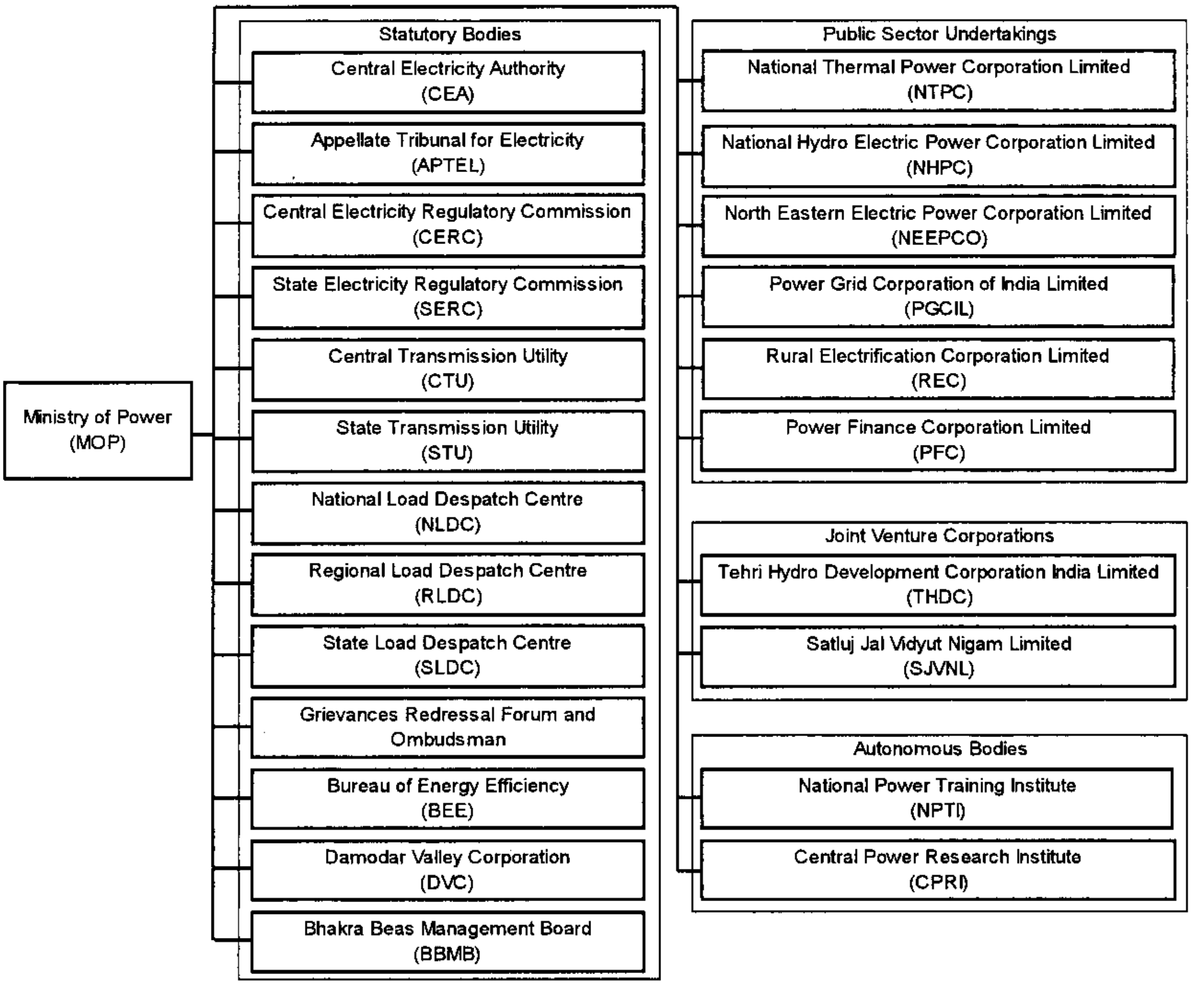


Fig. II-1 Organizations of the Central Electricity Sector in India

(1) Central Electricity Authority

CEA is a Statutory Body constituted under the erstwhile Electricity Supply Act of 1948. This act was replaced by the Electricity Act of 2003, where similar provisions exist, and CEA is an "Attached Office" of MOP. CEA is responsible for the technical coordination and supervision of programmes and is also entrusted with a number of statutory functions and is charged with preparing a National Electricity Plan in accordance with the National Electricity Policy and announcing such a plan once every five years. Any generating company intending to set up a hydro-generating station also requires the concurrence of the Central Electricity Authority. Section 73 of the Electricity Act of 2003 empowers the Authority to perform such functions and duties as the Central Government may prescribe or direct, and in particular to

- Advise the Central Government on matters relating to the national electricity policy, formulate short-term and perspective plans for development of the electricity system and coordinate the activities of the planning agencies for the optimal utilization of resources, to serve the interests of the national economy and to provide reliable and affordable electricity for all consumers,
- Specify the technical standards for construction of electrical plants, electric lines and connectivity to the grid,
- Specify the safety requirements for construction, operation and maintenance of electrical plants and electric lines,
- Specify the Grid standards for operation and maintenance of transmission lines,
- Specify the conditions for installation of meters for transmission and supply of electricity,

- Promote and assist in the timely completion of schemes and projects for improving and augmenting the electricity system,
- Promote measures for advancing the skill of persons engaged in the electricity industry and so on.

(2) Appellate Tribunal for Electricity

The Appellate Tribunal for Electricity (APTEL) is a statutory body constituted for the purpose of hearing cases against the orders of the Regulatory Commissions and the Adjudicating officer. By virtue of Section 110 of The Electricity Act of 2003, APTEL has jurisdiction throughout India and has been set up to hear appeals or original petitions against the orders of the Adjudicating officer, or of the Central Regulatory Commission, the State Regulatory Commission or the Joint Commission constituted respectively under Sections 76(i), 82 and 83 of the Electricity Act of 2003. Original jurisdiction has been conferred on APTEL to hear petitions under Section 121 of the Act and to issue directions to all Commissions for the performance of its statutory functions.

(3) Central Electricity Regulatory Commission

The Central Electricity Regulatory Commission (CERC) is a statutory body constituted under the provision of the erstwhile Electricity Regulatory Commissions Act of 1998 and continued under the Electricity Act of 2003. The main functions of CERC are to regulate the tariffs of generating companies owned or controlled by the Central Government, to regulate the tariffs of generating companies other than those owned or controlled by the Central Government, to regulate the inter-State transmission of energy including tariffs charged by the transmission utilities, if such generating companies enter into or otherwise have a composite scheme for generation and sale of electricity in more than one State, to grant licenses for inter-State transmission and trading and to advise the Central Government in the formulation of the National Electricity Policy and Tariff Policy.

(4) State Electricity Regulatory Commissions

The concept of a State Electricity Regulatory Commission (SERC) as a statutory body responsible for the determination of tariffs and granting of licenses at the intra-State level was envisaged in the erstwhile Regulatory Commissions Act of 1998 and has been continued in the Electricity Act of 2003. The main responsibilities of SERCs are to determine the tariffs for generation, supply, transmission and wheeling of electricity and wholesale, bulk or retail sales within the State; to issue licenses for intra-State transmission, distribution and trading; to promote co-generation and generation of electricity from renewable sources of energy etc. In Uttarakhand State, the Uttarakhand Electricity Regulatory Commission (UERC) was constituted by the Government of Uttarakhand (vide Notification 03/9-3-URJA/2002 dated January 1, 2002) under the Electricity Regulatory Commission Act of 1998.

(5) Central Transmission Utility

The Central Transmission Utility (CTU) first appeared as a statutory body in section 27 A of the Indian Electricity Act of 1910 and has been retained in the Electricity Act of 2003. The functions of the CTU are to undertake transmission of energy through the inter-State transmission system and discharge all functions of planning and coordination with State Transmission Utilities, the Central Government, State Governments, generating companies etc. relating to the inter-State transmission system The Power Grid Corporation of India Limited functions as the Central Transmission Utility.

(6) State Transmission Utilities

The State Transmission Utility (STU) first appeared as a statutory body in section 27 B of the

Indian Electricity Act of 1910 and has been retained in the Electricity Act of 2003. The functions of STUs are to undertake transmission of energy through the intra-state transmission system and discharge all functions of planning and coordination with the Central Transmission Utility, State Governments, generating companies etc. relating to the intra-State transmission system.

(7) National Load Despatch Centre

The Electricity Act of 2003 has provided for the constitution of a National Load Despatch Centre (NLDC) for optimum scheduling and despatch of electricity among the Regional Load Despatch Centres. The constitution and functions of NLDC are yet to be prescribed by the Central Government.

(8) Regional Load Despatch Centre

Section 25 of the Electricity Act of 2003 requires the Central Government to divide the country into regions for the efficient, economical and integrated transmission and supply of electricity, and in particular to facilitate the voluntary inter-connection and co-ordination of facilities for inter-State, Regional and inter-regional generation and transmission of electricity. To ensure an integrated power system across all such regions, a Regional Load Despatch Centre (RLDC) has been envisaged as an apex body. RLDC is responsible inter alia for the despatch of electricity within the regions, monitoring grid operations etc. The directions given by RLDC to ensure grid stability etc. must be complied with by the licensees, generating companies, generating stations, sub-stations and any other person connected with the operation of the power system.

(9) State Load Despatch Centres

State Load Despatch Centres (SLDC) have been envisaged at the State level with the responsibility of ensuring integrated operations of the power system in the State.

(10) Grievance Redressal Forums and Ombudsmen

The Electricity Act of 2003 requires every distribution licensee to establish a forum for consumers for the Redressal of Grievances. The Ombudsman is a statutory authority to be appointed or designated by the State Commission to hear and settle grievances which could not be addressed at the level of the Grievance Redressal Forum. In Uttarakhand State, there is a Consumer Grievance Redressal Forum under UERC.

(11) Bureau of Energy Efficiency

The Bureau of Energy Efficiency (BEE) was set up by the Government of India on March 1, 2002 as a Statutory Body as per Section 3 of the Energy Conservation Act of 2001. The mission of BEE is to develop policies and strategies within the overall framework of the Energy Conservation Act of 2001 that focus on self-regulation and market principles, with the primary objective of promoting energy-saving measures and in turn reducing the energy intensity (i.e. energy consumed per unit of GDP) of the Indian economy.

II-2-1 Power Supply System in India

(1) Generation

In India, the central and state governments and private companies (licensed operators and IPPs) are engaged in the power generation business. Since the liberalization of the electricity industry in 1991, approximately 100 IPP businesses have been approved so far, of which 44 are still operating (Ministry of Power, CEA, PFC: Power Finance Corporation Limited). Through the Electricity Act of 2003, the power generation business was opened up to the private sector, and since then 30 IPP businesses (generating 22,038 MW in total) have reached an investment agreement. However, there has been no foreign investment in the IPP business up to now.

The power demand of the country has been increasing remarkably due to economic growth in recent years. The shortfall of power supply was about 10.1% and the shortfall of supply during peak hours was about 12.7% in fiscal year 2009-2010. The shortfall of supply was about 8.5% and the shortfall of supply during peak hours was about 9.8% in fiscal year 2010-2011. Part of the shortfall (about 0.7% of total electricity supply in fiscal 2010-2011) has been made up with electricity (hydroelectric power) imported from Bhutan. However, increasing the power supply capacity in India has become an important issue. In the 11th Five-Year Plan, which was elaborated in 2007, a total 78,577 MW increase in generation capacity in the country was targeted. Table II-I shows the total installed capacity and its composition on December 31, 2011. The total installed capacity in India is 182,654.62 MW, of which 122,963.98 MW is thermal power (about 65.9%), 38,748.4 MW is hydropower (about 20.8%), 4,780 MW is nuclear power (about 2.6%) and 20,162.24 MW is renewable energy including small hydro (about 10.8%). This indicates that, in India, thermal power generation is the major generation source. In particular, the installed capacity of coal-fired power plants is 104,021.38 MW, which accounts for about 55.7% of total generation capacity. In terms of generation entities, State governments account for 44.8% (83,605.65 MW) of the total generation business, while the central government accounts for 30.9% (57,732.63 MW) and the private sector, 24.3% (45,316.34 MW).

The principal generation entities of the central government are NTPC, Damodaru Valley Corporation (DVC), NHPC, Nuclear Power Corporation of India Limited (NPC), and Tehri Hydro Development Corporation India Limited (THDC). NTPC has an installed capacity of 32,442.23 MW which corresponds to approximately 17.4% of the total installed capacity in the country, and this capacity reaches 35,662.23 MW (19.1% of the total installed capacity of the country) if joint ventures are included.

Table II-1 Sector-Wise and Source-Wise Installed Capacity in India

Source		Thermal				Nuclear	Hydro	R.E.S (MNRE)	Total	Share (%)
		Coal	Gas	Diesel	Subtotal					
Installed Capacity (MW)	State Sector	48,112.00	4,327.12	602.61	53,041.73	0.00	27,338.00	3,225.92	83,605.65	44.79
	Central Sector	37,365.00	6,702.23	0.00	44,067.23	4,780.00	8,885.40	0.00	57,732.63	30.93
	Private Sector	18,544.38	6,713.50	597.14	25,855.02	0.00	2,525.00	16,936.32	45,316.34	24.28
	Total	104,021.38	17,742.85	1,199.75	122,963.98	4,780.00	38,748.40	20,162.24	186,654.62	100.00
Share (%)		55.73	9.51	0.64	65.88	2.56	20.76	10.80	100.00	

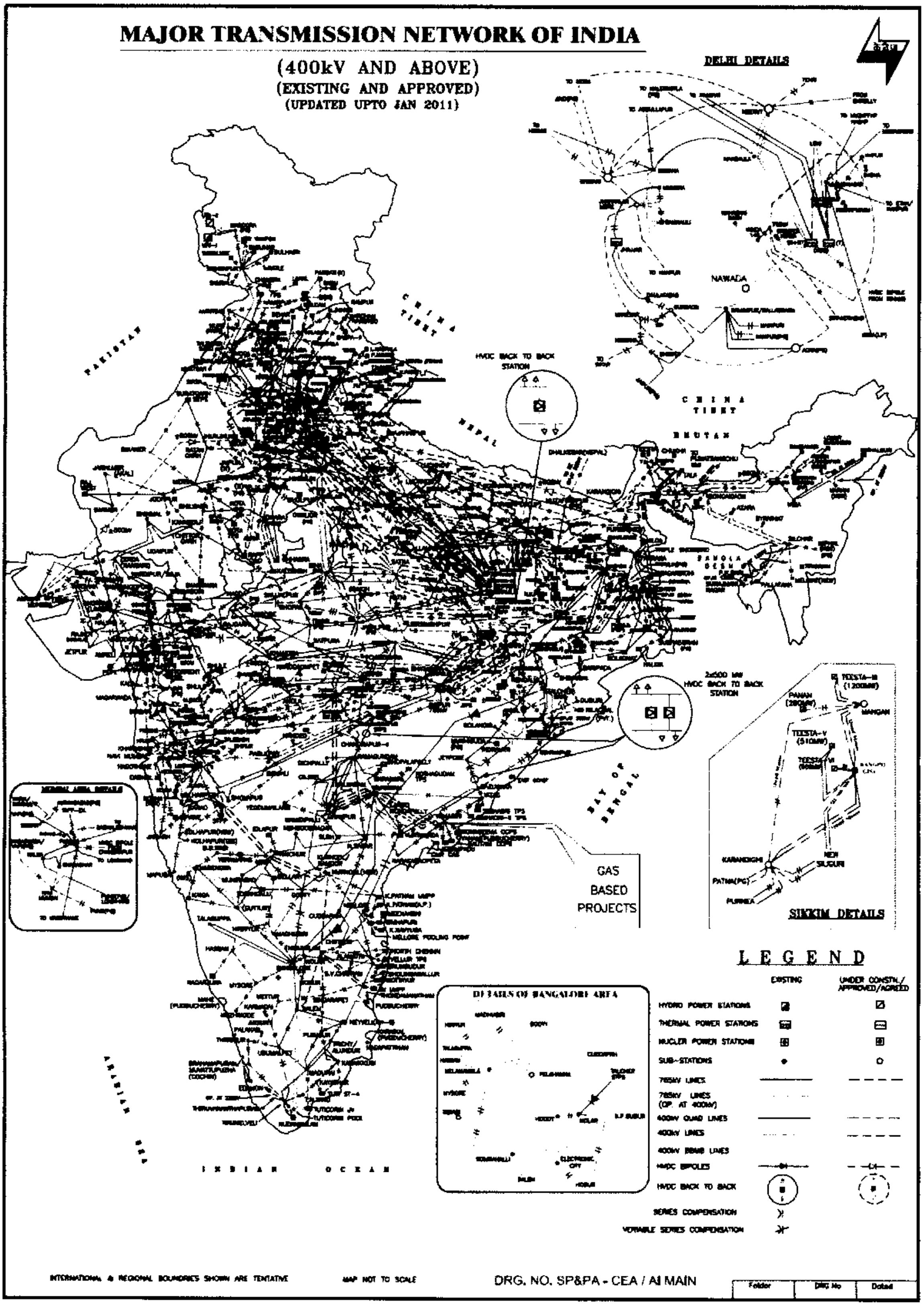
R.E.S. Renewable energy resources including small hydro projects, biomass gasifier, biomass power, urban & industrial waste power and wind power.

As of December 31, 2011

Source: CEA website (www.cea.nic.in/)

(2) Transmission and distribution

In India, the transmission and distribution business are basically undertaken by entities approved at the state level. In addition, the central government-run Power Grid Corporation of India Limited (PGCIL) is in charge of connecting the power system among the state levels. Figure II-2 shows the main transmission network of the country.



Source: MOP Annual Report 2010-11 (www.powermin.nic.in/JSP_SERVLETS/internal.jsp)

Fig. II-2 Major Transmission Network of India

II-2-2 Power Supply System of Uttarakhand State

(1) Generation

According to NRPC (the Northern Region Power Committee), the shortfall of power supply in the northern area was 3.97% in May, 2011. This supply shortfall rose to 5.96% during peak hours. In the same year, the power shortfall in Uttarakhand State was 2.78% and the power shortage during peak hours was 10.89%. In Himachal Pradesh State, the power shortfall was 0.09% and the power shortfall during peak hours was 0%. Table II-2 shows the current installed capacity as of August 31, 2011 of power plants in the northern region, where the survey area of this study is located. The total generation capacity of the northern region was 47,932.56 MW. Of this, 28,380.25 MW is thermal power, which accounts for about 59.2% of the total installed capacity. The second largest generation source in the region is hydropower, which accounts for 14,422.75 MW. The region also taps into 3,509.56 MW of renewable energy and 1,620 MW of nuclear power. Table II-3 shows the installed capacity of the principal power generators in the northern region as of March 31, 2011. The largest producer is NTPC, which accounts for 25.57% (1,128 MW) of the total installed capacity in the northern region.

The total installed capacity in Uttarakhand State was 2,453.74 MW on August 31, 2011 (see Table II-2), of which 1,956.18 MW (79.7%) is hydropower and 330.61 MW is thermal power. Entities of the state government account for 56.5% (1,386.77 MW) of this total installed capacity. Those entities include Uttarakhand Jal Vidyut Nigam Limited (UJVNL) , which operates the hydroelectric plants ranging from 0.2 MW to 376 MW. Central government entities are responsible for the operation of the thermal plants operated by NTPC, the hydro plants operated by NHPC, Tehri Hydro Development Corporation India Limited (THDC) and Satluj Jal Vidyut Nigam Limited (SJVNL), and the nuclear power plants are operated by NPC.

Table II-2 Sector-Wise and Source-Wise Installed Capacity in the Northern Region

Source			Thermal				Nuclear	Hydro	R.E.S (MNRE)	Total	Share (%)
			Coal	Gas	Diesel	Subtotal					
All Northern Region	Installed Capacity (MW)	State Sector	13,612.00	1,719.20	12.99	15,344.19	0.00	7,052.55	1,052.86	23,449.60	48.92
		Central Sector	9,750.50	2,344.06	0.00	12,094.56	1,620.00	5,792.20	0.00	19,506.76	40.70
		Private Sector	870.00	71.50	0.00	941.50	0.00	1,578.00	2,456.70	4,976.20	10.38
		Total	24,232.50	4,134.76	12.99	28,380.25	1,620.00	14,422.75	3,509.56	47,932.56	100.00
	Share (%)		50.56	8.63	0.03	59.21	3.38	30.09	7.32	100.00	
Uttarakhand	Installed Capacity (MW)	State Sector	0.00	0.00	0.00	0.00	0.00	1,252.15	134.62	1,386.77	56.52
		Central Sector	261.26	69.35	0.00	330.61	22.28	304.03	0.00	656.92	26.77
		Private Sector	0.00	0.00	0.00	0.00	0.00	400.00	10.05	410.05	16.71
		Total	261.26	69.35	0.00	330.61	22.28	1,956.18	144.67	2,453.74	100.00
	Share (%)		10.65	2.83	0.00	13.47	0.91	79.72	5.90	100.00	
Himachal Pradesh	Installed Capacity (MW)	State Sector	0.00	0.00	0.13	0.13	0.00	393.60	418.96	812.69	27.36
		Central Sector	118.30	61.88	0.00	180.18	34.08	765.34	0.00	979.60	32.98
		Private Sector	0.00	0.00	0.00	0.00	0.00	1,178.00	0.00	1,178.00	39.66
		Total	118.30	61.88	0.13	180.31	34.08	2,336.94	418.96	2,970.29	100.00
	Share (%)		3.98	2.08	0.00	6.07	1.15	78.68	14.11	100.00	

R.E.S. Renewable energy resources including small hydro projects, biomass gasifier, biomass power, urban & industrial waste power and wind

As of August 31, 2011

Source: CEA website (www.cea.nic.in/)

Table II-3 Agency/State and Source-Wise Installed Capacity in the Northern Region

(Unit: MW)

Agency/State	Hydro	Thermal	Gas	Nuclear	Diesel	RES	Total
NTPC		8780.00	2348.00				11128.00
Uttar Pradesh	501.60	4672.00				45.00	5218.60
Rajasthan	411.00	3760.00	443.80			30.25	4645.05
Punjab	1051.00	2630.00	25.00			243.20	3949.20
Haryana	0.00	3160.00	25.00		3.92	70.10	3259.02
NHPC	3118.00						3118.00
BBMB	2866.30						2866.30
Uttarakhand	1652.15					139.00	1791.15
NPC				1620.00			1620.00
SJVNL	1500.00						1500.00
Delhi		135.00	1172.00				1307.00
THDC	1200.00						1200.00
Jammu & Kashimir	660.00		175.00		8.94	129.33	973.27
Himachal Pradesh	366.00				0.13	578.00	944.13
Chandigarh							0.00
Total	13326.05	23137.00	4188.80	1620.00	12.99	1234.88	43519.72

RES: Renewable energy resources including small hydro projects, biomass gasifier, biomass power, urban & industrial waste power and wind power.

NTPC: National Thermal Power Corporation Limited

NHPC: National Hydro Electric Power Corporation Limited

BBMB: Bhakra Beas Management Board

NPC: Nuclear Power Corporation

SJVNL: Satluj Jal Vidyut Nigam Limited

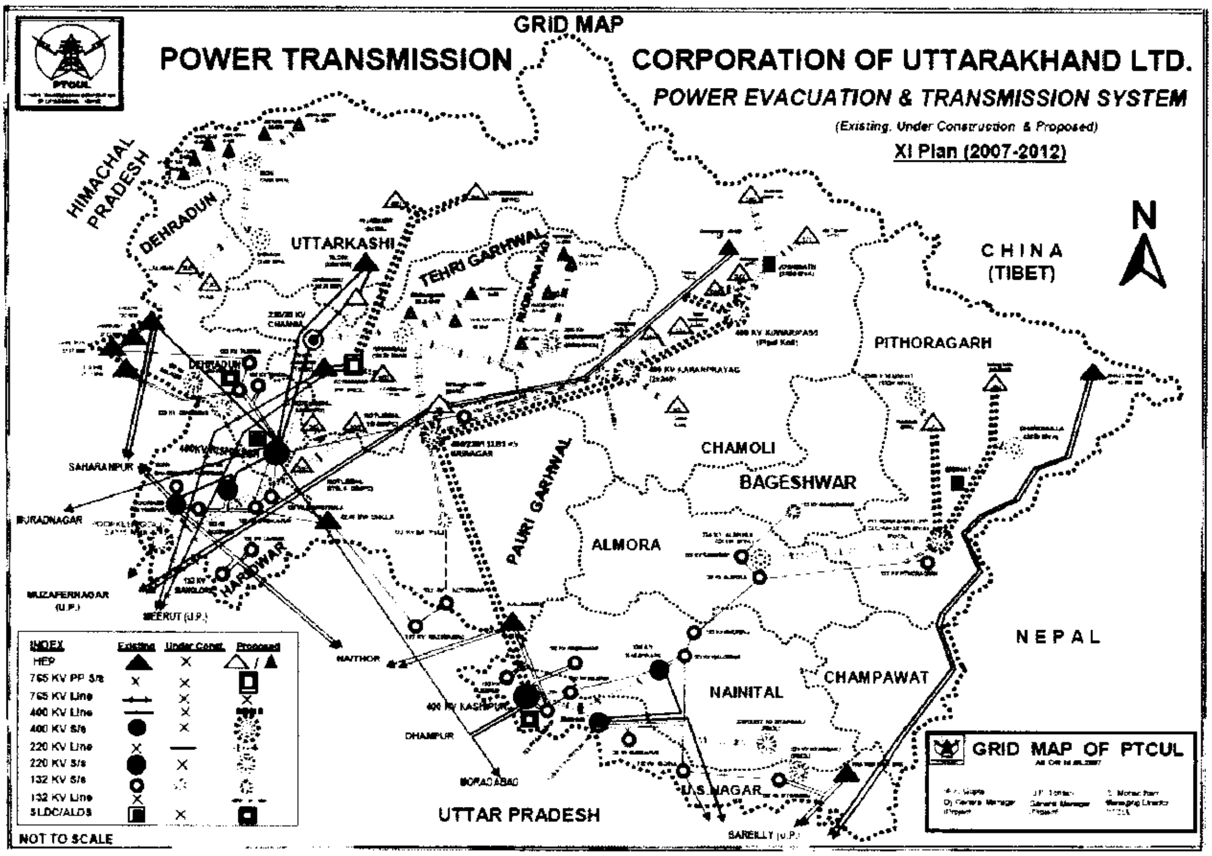
THDC: Tehri Hydro Development Corporation India Limited

As of March 31, 2011

Source : NRPC 2010-2011 Annual Report (www.nrpc.gov.in/reports/annual.html)

(2) Transmission and Distribution

Figure II-3 shows the transmission system in Uttarakhand State. In that state, the Power Transmission Corporation of Uttarakhand Limited (PTCUL) operates the transmission system under license from the Electricity Regulatory Commission of Uttarakhand (Uttarakhand Transmission and Bulk Supply Licence, Licence No. 1 of 2003, Dated 20 June, 2003). Uttarakhand Power Corporation Limited (UPCL:) holds the license for the distribution business, which was granted on the same date.



Source: Power Transmission Corporation of Uttarakhand Ltd. website (www.ptcul.org)

Fig. II-3 Transmission Network in Uttarakhand

II-3 Policy of Introduction of New and Renewable Energy in India

The role of new and renewable energy has been assuming increasing significance in recent times with the growing concern for the country's energy security. Energy self-sufficiency was identified as the major driver for new and renewable energy in the country in the wake of the two oil shocks of the 1970s. The sudden increase in the price of oil, uncertainties associated with its supply and the adverse impact on the balance of payments position led to the establishment of the Commission for Additional Sources of Energy (CASE) in the Department of Science & Technology in March, 1981. The Commission was charged with responsibility for formulating and implementing policies and programmes for the development of new and renewable energy in addition to coordinating and intensifying R&D in the sector. In 1982, a new department incorporating CASE, the Department of Non-conventional Energy Sources (DNES) , was created in the then-Ministry of Energy. In 1992, DNES became the Ministry of Non-conventional Energy Sources. In October, 2006, the Ministry was re-christened as the Ministry of New and Renewable Energy (MNRE).

MNRE is the nodal Ministry of the Government of India for all matters relating to new and renewable energy. The broad aim of the Ministry is to develop and deploy new and renewable energy to supplement the energy requirements of the country. The mission of the Ministry is to ensure

- Energy Security [lesser dependence on oil imports through development and deployment of alternate fuels (hydrogen, bio-fuels and synthetic fuels) and their application to contribute towards bridging the gap between domestic oil supply and demand],

- An increase in the share of clean power [renewable (bio, wind, hydro, solar, geothermal & tidal) electricity to supplement fossil fuel-based electricity generation],
- Energy Availability and Access [supplement energy needs for cooking, heating, motive power and captive generation in rural, urban, industrial and commercial sectors],
- Energy Affordability [cost-competitive, convenient, safe, and reliable new and renewable energy supply options],
- Energy Equity [per-capita energy consumption at par with the global average level by 2050, through a sustainable and diverse fuel-mix].

MNRE is a Scientific Ministry which has been assigned authority over the following areas/entities under the Allocation of Business Rules:

- Research and development of Biogas and programs relating to Biogas units;
- Commission for Additional Sources of Energy (CASE);
- Solar Energy including Solar Photovoltaic devices and their development, production and applications;
- Programs relating to improved chulha cooking stoves and research and development thereof;
- Indian Renewable Energy Development Agency (IREDA);
- All matters relating to small/mini/micro hydro projects of less than 25 MW capacity;
- Research and development of other non-conventional/renewable sources of energy and programs relating thereto;
- Tidal energy;
- The Integrated Rural Energy Program (IREP);
- Geothermal Energy;
- Bio-fuels: (i) National Policy; (ii) research, development and demonstration of transport, stationary and other applications; (iii) setting up of a National Bio-fuels Development Board and strengthening the existing institutional mechanism; and (iv) overall coordination.

MNRE is also tasked with facilitating research, design, development, manufacture and deployment of new and renewable energy systems/devices for transportation and portable and stationary applications in the rural, urban, industrial and commercial sectors through:

- Technology Mapping and Benchmarking;
- Identifying Research, Design, Development and Manufacturing focus areas and facilitating the same;
- Laying down standards, specifications and performance parameters on a par with international levels and assisting industry to attain the same;
- Aligning costs of new and renewable energy products and services with international levels and assisting industry to attain the same;
- Establishing appropriate international level quality assurance accreditation and assisting industry to obtain the same;
- Providing sustained feed-back to manufacturers on performance parameters of new and renewable energy products and services with the aim of effecting continuous upgrading so as to attain international levels in the shortest possible time;
- Facilitating industry in becoming internationally competitive and a net foreign exchange earner, especially through (ii) to (v) above and related measures;
- Carrying out Resource Surveys, Assessment, Mapping and Dissemination of that information;
- Identifying areas in which new and renewable energy products and services need to be deployed in keeping with the goal of national energy security and energy independence;
- Developing a deployment strategy for various indigenously developed and manufactured new

and renewable energy products and services; and

- Provision of cost-competitive new and renewable energy supply options.

According to the MNRE Annual Report 2009-10, geothermal energy is regarded as an important renewable energy source that can be applied to the generation of electrical energy and to other direct uses like green house heating, space heating, refrigeration and so on. In India, the report says, 340 hot springs have been identified through surveys by the Geological Survey of India, and MT surveying has been conducted by the National Geophysical Research Institute (NGRI) with support from MNRE in Chhattisgarh State, Jammu & Kashmir State, Jharkhand State and Uttar Pradesh State.

II-4 Approvals and Permissions Required for Geothermal Development in India

Exploration of geothermal energy resources on a national scale has been conducted up to now in part by government agencies, such as the Geothermal Survey of India (GSI) and the National Geophysical Research Institute (NGRI). Private sector interest in geothermal development has been increasing recently, and the government is currently preparing guidelines and policy for the exploration of geothermal energy resources. In addition, considering the high risk and capital cost involved in geothermal energy generation, the government is evaluating the possibility of assisting the private sector by formulating a clear geothermal policy, preferably with a single window where all clearances for execution of geothermal projects can be obtained, and by making available some monetary support in the form of tariff support or capital incentives. The guidelines are being prepared by the Ministry of New and Renewable Energy (MNRE), and draft versions are currently available. Given that geothermal energy development in the country will be carried out under these guidelines, it is worth summarizing them in this chapter, even though it's possible that there will be changes in the final versions. Until the guidelines come into force, prospecting licenses are granted by the relevant State Government, as was the case for the geothermal development project at Tapovan in Uttarakhand.

In the draft guidelines, geothermal resources/prospects are considered to be a National Resource, as is the case with hydrocarbons. However State guidelines may be followed in providing relevant approvals and/or licenses for exploration and mining. Even though it is a National Resource, the central government will not seek royalties on the production of geothermal power.

Proposals for the prospecting and exploration of geothermal energy resources would be submitted to MNRE through the State Nodal Agency (SNA). The proposals would be reviewed with representation of the relevant state governments. SNA would convey the decision to the applicant/Agency. Prospecting and/or exploration programs undertaken by government agencies may be intimated to the MNRE. The reconnaissance survey and prospecting of the geothermal resource may take up to a maximum of six months and the Report may be submitted to MNRE by the Agency at the end of a twelve-month period. The period for the exploration of a particular prospect may be fixed at a maximum of three years. The progress of the work will be reviewed every six months, and the final report has to be submitted at the end of three years.

Licenses for projects leading to or involving power generation may be granted by pooling together the applications received every three months and evaluating the technical and financial capability of the agency to carry out the project, in a process similar to open bidding. This procedure is especially useful for the geothermal prospects in Puga-chhumthang in Ladakh, Parvati Valley (Manikaran, etc) in Himachal Pradesh, Tatapani in Chhattisgarh, Unhavare (Khed & Tamhane), and Tural in West Coast, where it is considered that the necessary baseline data are available to initiate exploration/exploitation activity.

The application for exploration activity may contain:

- Maps of the area with co-ordinates and drainage indicated
- Dug hole/trench plan and Borehole Plan
- Drilling plan with depth and size of the boreholes
- Details of the work plan including ancillary studies such as geological, geophysical, or geochemical surveys
- Estimated cost of exploratory drilling
- Supporting financial documents to substantiate the availability of funds for exploration
- Technical expertise or collaboration agreements for undertaking exploratory studies

The Applicant/Agency will be expected to follow the forest and environmental laws applicable to exploration.

An Applicant/Agency which has already completed prospecting/exploration in a particular field will be given priority consideraton for the development of the geothermal prospect and power generation. The party willing to undertake development will submit a Detailed Project Report (DPR), comprising exploration data, a statement of the potential of the prospect, a power plant construction plan, a transmission plan, environmental and social plans, a statement of the estimated project cost and expected income, a financing plan and so on. The following is the list of documents to be included in the DPR;

- Entrepreneur Certificate from Competent Authority
- Permission from State Govt. / Electricity Board for power plant construction
- Certificate of MNRE/ CEA for electricity generation, technical and financial feasibility
- Environmental clearances
- Forest clearance
- Land acquisition certificate and NOC to use land for industrial purpose
- NOC of local village panchayat (if required)
- Clearance for use of surface/ground water
- Clearance for construction of high rise buildings, if any
- NOC from private land owners if construction is on private land
- Technical collaboration certificate, if required
- Bank guarantee, detailed financial documents from banks and financial institutions
- Registration as a power plant producer
- Agreement for sales/purchase of power
- Manpower planning documents.

In the draft guidelines, the MNRE is proposing to provide the following incentives to geothermal prospect exploration and development:

- The geothermal prospect/energy may be declared a priority for energy development.
- The same incentives may be granted for geothermal energy development as those encouraging the development of solar energy.
- MNRE may provide a subsidy/financial grant of up to 50% of the cost of the exploration and fuel supply (pipelines etc.) for power production.
- MNRE will provide a subsidy/financial grant of up to 25% of the cost of the power production stage.
- MNRE may facilitate through State Governments/SNA the development of infrastructure at the site, i.e., roads, water facilities, electricity power grid connection to the nearest input station, etc.

- Soft loans may be made available at a concessional interest rate of 4% p.a. over a plant-life period of 25-30 years to support exploration activity.
- A five year income tax, sales tax, and VAT holiday may be declared for geothermal exploration and power development activity, similar to the concessions for wind energy programs.
- The import of machinery/equipment for exploration and power production may be exempted from customs duty and import duty.
- Generationbased incentives in line with those for the solar energy program may be provided.
- The Agency is entitled to carbon credits acquired through geothermal heat utilization/electricity generation.

In addition to these incentives, MNRE is evaluating its support for Research and Development, Technology Demonstration Projects and capacity building for the creation of a basic geothermal workforce in the country.

The transmission of generated electricity to the nearest grid will be the responsibility of the producer. The power will be transmitted to the nearest grid point/local distribution point as per the agreement with the State Electricity Board. The State Electricity Board may purchase power from the producer as per MNRE guidelines for renewable energy sources. A minimum 25% of the power generated should be sold to the State Electricity Board at mutually agreed rates.

As for the licensing of direct heat uses, it is proposed that such licenses be granted separately from prospecting and exploration licenses. Prospecting proposals should be submitted to the State Nodal Agency. The survey period, including geological mapping, and geophysical and geochemical surveys, will be limited to six months, with final submission of the Report and the DPR preparation to be completed within twelve months. It is proposed that direct heat use schemes be treated as a vehicle for infrastructure development and that up to 50% of project costs may be funded by the Public Sector/Government. State Governments may contribute 50% in the form of incentives and funding.

The guidelines which are currently being developed are summarized above. However, since the geothermal development project at Tapovan has begun before the guidelines enter into force, approval for the detailed survey for development of the geothermal project at Tapovan was requested by NTPC from the State Government of Uttarakhand in November, 2008, and the approval was issued in March, 2009.

The procedures which NTPC should follow as the project progresses are described in the following paragraphs, which are based on the results of a hearing held by the State Government.

After completing resource exploration, NTPC will submit a final report to the State Government with the detailed survey results and a drilling plan, which should include a map of the area, a contour map of the drilling sites, a statement of the drilling budget, and a statement of the methodology and budget for the elaboration of the DPR subsequent to drilling. Upon receipt of the report from NTPC, the State Government will take approximately two months to review it and will grant (or deny) permission for drilling. At this point, the state Government will sign an MOU with NTPC, which will be a preliminary agreement between the two parties on the expected potential for geothermal power generation within the State in the future. After NTPC completes the drilling activities and the elaboration of the DPR, the DPR will be submitted to the State Government seeking their permission for power plant construction (permission for utilization of the natural resources within the State). At this point, the State Government and NTPC will sign an agreement on power sales/purchase at mutually agreed rates. The approval of the Environmental Impact Assessment by the Ministry of Environment and Forests will also be required for power plant construction.

According to the State Government, it is not necessary to obtain the approval of the EIA from the Ministry of Enviroment and Forests to drill geothermal wells. Actually, geothermal exploration is not listed as a project requiring EIA authorization by the Ministry. However, it is assumed that this is because no geothermal wells have yet been drilled in the country. Thus, it seems reasonable to assume that an EIA will be required for geothermal exploration, as is the case for oil and gas exploration in the country today.

CHAPTER III

III GEOTHERMAL POWER DEVELOPMENT IN THE WORLD

As a measure to mitigate global warming, the development of electrical power through the application of renewable energy has become a focus of attention around the world, and in recent years the interest of countries with geothermal resources in the development of geothermal power generation has been increasing. The 2010 installed capacity of geothermal generation facilities around the world is shown in Table III-1. The country with the largest generation facility capacity in the world is the United States. Its installed capacity is 3,093 MW, accounting for 29% of the world total. Most of its geothermal generation facilities are located in the western part of the mainland U.S. along the Rocky Mtn. Range (in states such as Nevada and California). Second to the United States is the Philippines, with an installed capacity of 1,904 MW (about 18% of the world total). These are followed by Indonesia with 1,197 MW (about 11% of the world total), Mexico with 958 MW (about 9% of the world total), Italy with 843 MW (about 8% of the world total), New Zealand with 628 MW (about 6% of the world total), Iceland with 575 MW (about 5% of the world total), and Japan with 536 MW (also about 5% of the world total). The following sections will discuss in more detail the situation of geothermal power development in Japan, the Philippines and Indonesia as the main achievements of geothermal development in Asia.

Table III-1 Installed Capacity of Geothermal Power Plants in the World

Country	Installed Capacity (MW)	Share (%)
United States of America	3,093	28.9
Philippines	1,904	17.8
Indonesia	1,197	11.2
Mexico	958	8.9
Italy	843	7.9
New Zealand	628	5.9
Iceland	575	5.4
Japan	536	5.0
El Salvador	204	1.9
Kenya	167	1.6
Costa Rica	166	1.5
Nicaragua	88	0.8
Russia	82	0.8
Turkey	82	0.8
Papua New Guinea	56	0.5
Guatemala	52	0.5
Portugal	29	0.3
China	24	0.2
France	16	0.1
Ethiopia	7.3	0.1
Germany	6.6	0.1
Austria	1.4	0.0
Australia	1.1	0.0
Thailand	0.3	0.0
Total	10,715	100.0

As of 2011

Source: Ruggero Bertani (2010) Geothermal power generation in the world. *Pro. W. G. C. 2010*

III-1 Geothermal Power Development in Japan

Japan's geothermal power plants are shown in Fig. III-1 and Table III-2. The first Japanese geothermal power plant, the Matsukawa power plant in Iwate prefecture, came into service on October 8, 1966 as a 9.5 MW project of Japan Metals and Chemicals (JMC) Co. Ltd. for in-house use. The output of the power plant was increased to 23.5 MW in June of 1993. Subsequently, the plant was taken over by Tohoku Electric Power Company, which continued to generate electricity for commercial use. Following on the Matsukawa plant, Kyushu Electric Power Company commenced generation for commercial use at the Otake power plant in Oita prefecture on August 12, 1967, with an approved output of 10 MW (current approved output is 12.5 MW). At present, the approved output of geothermal power plants operating in Japan amounts to 522.6 MW for commercial use and 12.61 MW for in-house use, for a total of 535.21 MW. Among these plants, there are only two (2) binary geothermal power plants, the 2 MW Hatchobaru binary plant and the 0.22 MW Kirishima binary power plant.

In the wake of the 1970s oil shocks, a national policy came into effect promoting the development of geothermal energy and other new forms of energy like solar energy that could replace oil and be entirely domestically produced. In 1980, the Ministry of International Trade and Industry (MITI; now the Ministry of Economy, Trade and Industry, METI) established the New Energy and Industrial Technology Development Organization (NEDO, now an independent administrative agency) as a special agency under MITI jurisdiction. At that time, because the technology of geothermal resource exploration was not yet established anywhere in the world and exploration techniques were being applied on a trial and error basis, geothermal development required a large initial investment in exploration costs. For this reason, geothermal development projects came to be seen as high-risk, low-return projects, and private sector interest in development gradually began to decline. Given these circumstances, NEDO carried out a "Review of Geothermal Exploration and related Technologies" from 1980 to 2002 with the aim of establishing the technology of geothermal exploration. Today's geothermal exploration technology was established on the basis of this "Review of Geothermal Exploration and related Technologies" and the accumulation of private sector achievements in geothermal resource exploration.

Also, in order to reduce development risk, NEDO carried out a "Nationwide Geothermal Resource Inventory" from 1980 to 1992 to clarify the distribution of geothermal resources in Japan. In addition, NEDO initiated "Promotion Surveys for Geothermal Development" in 1980 to promote development by taking a leading role in surveying promising areas where private sector geothermal development was stalled due to development risk. Although there was initially only a single type of survey program, as a result of several revisions, the four types of survey program shown below were instituted.

Survey A: In areas where promising geothermal resources are expected to be present, but the area has remained undeveloped due to a lack of survey data, a broad survey (covering an area of 100–300 km^2) is carried out to investigate the possible presence of geothermal resources. As a rule, the period of the survey is limited to three years, and geological surveying, geochemical surveying and geophysical surveying (gravity and electromagnetic surveying etc.) is carried out in addition to the drilling of small-diameter heat-flow test wells and so on.

Survey B: In areas where there is a high possibility that geothermal resources are present, but the area has remained undeveloped because the risk is still great, a survey is carried out (over an area of 50–70 km^2) to confirm the presence of a geothermal reservoir. As a rule, the period of the survey is limited to three years, and geological surveying, geochemical surveying and geophysical surveying (gravity and electromagnetic surveying etc.) is carried out in addition to the drilling of small-diameter heat-flow test wells and small-diameter exploratory (slim hole) wells. Such things as environmental surveying are also carried out.

Survey C-1: A survey is carried out (over an area of 5–10 km^2) in areas where the presence of a promising, high-temperature geothermal reservoir is expected in order to obtain a rough idea of the size of the geothermal resource. As a rule, the period of the survey is limited to four years, and supplementary geological, geochemical and geophysical surveying is carried out. Also, Standard to big (large) diameter exploratory wells, production wells and re-injection wells permit the quantitative evaluation of the resource and long-term production testing. In addition, a summary evaluation of economic feasibility, an environmental assessment and so on are carried out.

Survey C-2: In order to obtain a rough idea of the size of the geothermal resource, a survey is carried out (over an area of 5–10 km^2) in areas where the presence of a promising reservoir of less than 200 °C is expected that can be developed through a small or medium-scale geothermal power plant (of less than 10 MW). As a rule, the period of the survey is limited to two years, and supplementary geological, geochemical and geophysical surveying is carried out. Also, medium to large diameter exploratory wells are drilled for the quantitative evaluation of the resource and long-term production testing. In addition, a summary evaluation of economic feasibility, an environmental assessment and so on are carried out.

Yanaizu-Nishiyama Geothermal PP and Hachijojima Geothermal PP are examples of the linkage between "Promotion Surveys for Geothermal Development" and the construction of geothermal power plants. Also, the production results of wells drilled under the "Review of Geothermal Exploration and related Technologies" program contributed to the construction of Sumikawa Geothermal PP. In addition, the construction of a geothermal power plant is being planned on the eastern shore of Lake Ikeda in Kagoshima prefecture, where a C-2 Survey was carried out.

In recent years, as the task of reducing CO_2 emissions to mitigate global warming has become increasingly important, the use of geothermal energy has entered the limelight not only in Japan, but all over the world. Under these circumstances, there are advocates today for a re-evaluation of the framework for national government encouragement of geothermal development, including programs and executing authorities.

Also, there are three examples of existing geothermal generation making use of surplus energy from hot springs at Suginoi Hotel (1.9 MW, flash generation) and Kuju Kanko Hotel (0.99 MW, flash generation) in Oita prefecture, and Kirishima Kokusai Hotel (0.22 MW, binary generation) in Kagoshima prefecture, and the hot spring industry is showing increasing interest in geothermal generation. In light of these developments, there has been an accelerating move on the part of Japanese manufacturers towards the development and implementation of small-scale geothermal power plants.

Including overlapping areas, "Promotion Surveys for Geothermal Development" have been carried out in a total of 67 areas, but there are few examples where this has led to geothermal power plants actually being constructed. In Japan, a large number of promising areas are located in nature parks such as national parks or quasi-national parks. This, together with opposition from local hot spring entrepreneurs, has been a major factor impeding the construction of geothermal power plants.

In Japan, unlike mineral resources or fossil fuel resources like coal, gas and oil, geothermal resources cannot be the object of mining concessions. However, although it is not stipulated in the law, it is customary to submit to the prefectural governor in advance an "Application for a Hot Spring Drilling Permit" under the Hot Spring Law before drilling geothermal wells (including exploratory wells and so on). The main laws which may affect the regulation of geothermal development in Japan include the Nature Park Law, the Hot Spring Law, the Forest Law, the National Forest and Wilderness Law, the Erosion Control Law, the River Law, the Agricultural Land Law, the Cultural Treasure Preservation Law, the Landslide Prevention Law, the Law concerning the Maintenance of Agriculture Promotion Areas, the Road Law, the Law concerning the Prevention of Damage from the Collapse of Steeply Sloping Land, the Law concerning the Management and Cleanup of Waste Materials, and the Law concerning the Preservation of Endangered Species of Wild Plants and Animals.

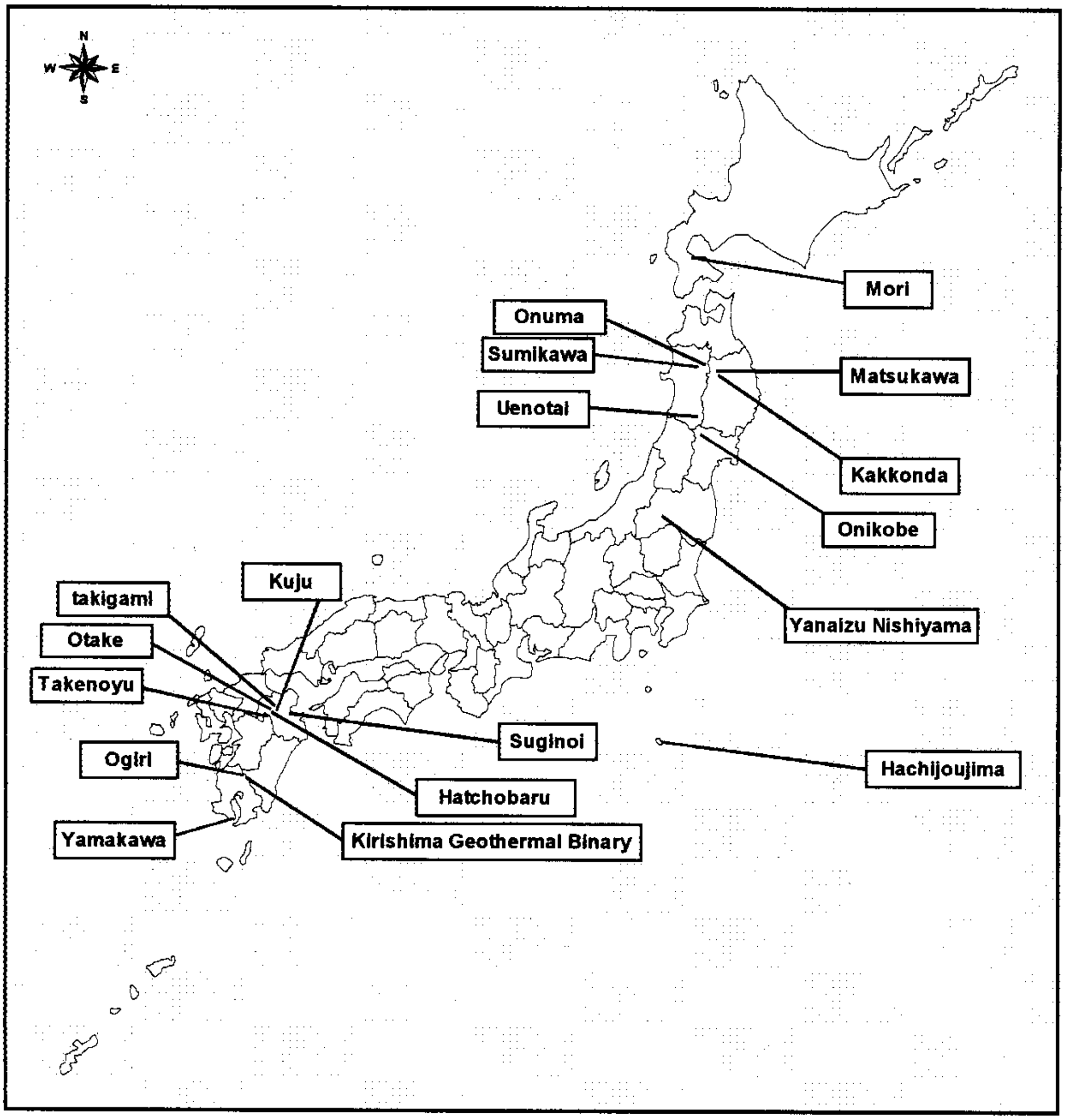


Fig. III-1 Location Map of Geothermal Power Stations in Japan

Table III-2 Geothermal Power Stations in Japan

Power Station		Location (Prefecture)	Power Generating Steam Supplying	Installed Capacity (MW)	Permitted Output (MW)	Comissioning	Turbine Maker	Remarks
Matsukawa		Iwate	Tohoku Hydropower & Geothermal Energy Co., Inc.	23.5	23.5	Oct. 1966	Toshiba	Permitted output at comissining was 9.5 MW, it was changed to 22 MW in 1973 and to 23.5 MW in Jun 1993. This plant (including steam supplying) was originally operated by Japan Metals and Chemicals Co., Ltd., for self-use.
Otake		Oita	Kyushu Electric Power	13	12.5	Aug. 1967	MHI	Permitted output at comissining was 10 MW, it was changed to 11 MW in 1967 and to 12.5 MW in 1979.
Onuma		Akita	itsubishi Materials Corporati	10	9.5	Jun 1974	MHI	For self-use; permitted output at comissining was 6 MW, it was changed to 7.5 MW in 1975, to 8.6 MW in 1977 and to 9.5 MW in 1986.
Onikobe		Miyagi	Electric Power Development Co., Ltd.	25	12.5	Mar. 1975	KHI	Permitted output at comissining was 9 MW, it was changed to 12.5 MW in 1976.
Hatchobaru	Unit 1	Oita	Kyushu Electric Power	55	55	Jun 1977	MHI	Permitted output at comissining was 23 MW, it was changed to 55 MW in 1980.
	Unit 2			55	55	Jun 1990	MHI	Permitted output at comissining was 23 MW, it was changed to 55 MW in 1980.
	Binary			2	2	Apr. 2006	Ormat	Binary system
Kakkonda	Unit 1	Iwate	Tohoku Electric Power Tohoku Hydropower & Geothermal Energy Co., Inc.	50	50	May 1978	Toshiba	Previous steam supplyer was Japan Metals and Chemicals Co., Ltd.
	Unit 2			30	30	Mar. 1996	Toshiba	Previous steam supplyer was Tohoku Geothermal Energy Co., Ltd.
Suginoi		Oita	Suginoi Hotel	3	3	Mar. 1981	MHI	For self-use; permitted output at comissining was 1.17 MW, it was changed to 3 MW in 1981. This plant was removed in January 2006.
Suginoi		Oita	Suginoi Hotel	1.9	1.9	Apr. 2006	Fuji	For self-use
Mori		Hokkaido	Hokkaido Electric Power	50	50	Nov. 1982	Toshiba	Previous steam supplyer was Donan Geothermal Energy Co., Ltd.
Kirishima Kokusai Hotel		Kagoshima	Daiwabo Kanko Co., Ltd.	0.1	0.1	Feb. 1984	Fuji	For self-use, this plant was removed in May 2008.
Kirishima Geothermal Binar		Kagoshima	Fuji Electric Systems Co.,Ltd Daiwabo Kanko Co., Ltd.	0.22	0.22	Aug. 2006	Shin Nippon Machinery Co., Ltd. JN&G	For self-use, binary system
Takenoyu		Kumamoto	Hirose Trading Co., Ltd.	0.2	0.05	Oct. 1991	MHI	For self-use, operation is recently stopped.
Uenotai		Akita	Tohoku Electric Power Tohoku Hydropower & Geothermal Energy Co., Inc.	28.8	28.8	Mar. 1994	Toshiba	Permitted output at comissining was 27.5 MW, it was changed to 28.8 MW in February 1997. Previous steam supplyer was Akita Geothermal Energy Co., Ltd.
Sumikawa		Akita	Tohoku Electric Power Mitsubishi Materials Corporation	50	50	Mar. 1995	MHI	
Yamakawa		Kagoshima	Kyushu Electric Power	30	30	Mar. 1995	MHI	Previous steam supplyer was Japex Geothermal Kyushu Co., Ltd.
Yanaizu Nishiyama		Fukushima	Tohoku Electric Power Okuaizu Geothermal Co., Ltd.	65	65	May 1995	Toshiba	
Ogiri		Kagoshima	Kyushu Electric Power Nittetsu Kagoshima Geothermal Co., Ltd.	30	30	Mar. 1996	MHI	
Takigami		Oita	Kyushu Electric Power. Idemitsu Oita Geothermal Co., Ltd	25	25	Nov. 1996	MHI	
Hachijozima		Tokyo	Tokyo Electric Power	3.3	3.3	Mar. 1999	Fuji	
Kuju		Oita	Kuju-Kanko Hotel	2	0.99	Dec. 2000	KHI	For self-use

MHI = Mitsubishi Heavy Industry
KHI = Kawasaki Heavy Industry

Source: Thermal and Nuclear Power Engineering Society (2009) Current situation and trend of geothermal power generation.

III-2 Geothermal Power Development in Philippines

The organization responsible for setting policy for the electricity sector in the Philippines is the Department of Energy (DOE). Originally, the state-run National Power Corporation (NPC) undertook electricity generation and transmission projects. However, as a step towards privatization, the electricity transmission division was split off in 2001, and TransCo (National Transmission Corporation) was established. In March, 2002, the Electric Power Industry Reform Act (EPIRA) came into effect, and in order to introduce competition into the electricity industry, 70% of the generation assets of NPC were privatized through competitive auction. The geothermal generation facilities at Pilipino, Bacon-Manito (Bacman), Makiling-Banahaw (Makban) and Tiwi were transferred into private hands. Geothermal power plants operating in the Philippines are shown in Fig. III-2 and Table III-3. Through the introduction of competition into the electricity industry, it became necessary for new entrepreneurs in electricity generation to construct power plants and to conclude power sales contracts with regional transmission companies and large-scale users (over 1 MW). It should be noted that in the past a drying facility for agricultural and marine products was operating at the Manitororando of Bakman, using about 850 kW of electricity and surplus steam.

Geothermal resource development was carried out mainly by the Philippine National Oil Company Energy Development Corporation (PNOC-EDC), which is under the umbrella of the state-run Philippine National Oil Company (PNOC). However, at MakBan and Tiwi in Luzon, geothermal resource development is being carried out by Philippine Geothermal, Inc. (PGI), a local subsidiary of Unocal (now Chevron). Furthermore, PNOC-EDC was privatized and changed its name to EDC in June, 2008.

To undertake geothermal resource development in the Philippines it is necessary to conclude a Geothermal Service Contract (GSC) with DOE, in accord with Presidential Decree 1442 (PD1442). In addition, it is not possible for foreign capital alone to develop geothermal resources, because the constitution of the Philippine Republic stipulates that Philippine nationals must hold at least 60% of the stock of Philippine companies or Philippine-foreign joint ventures that are developing national energy resources.

In order to increase its energy self-sufficiency, the Philippine government is doing its best to accelerate the exploration, development and use of domestic energy. To this end, the government has introduced a competitive bidding system for promising oil, coal and geothermal fields, and has taken the initiative in providing development fields to bidders by deploying the Philippine Energy Contracting Round (PECR). The government is aiming to make the Philippines the world's leading producer of geothermal energy, and in August of 2005 presented 11 areas through PECR2005 that are promising for generation and non-generation uses. Among these, the following fields were approved as new development fields for electricity generation: Daklan, Natib, Mabini, Montelago, Biliran and Amacan. Although there is some preferential tax treatment for geothermal generation activities, the government is thoroughly committed to a system in which the private sector takes the lead on the basis of market competition. It should be noted that, under the influence of the steep rise in the cost of raw materials and tightening demand for them and the subsequent worldwide financial crisis, there has been a general delay in geothermal projects.

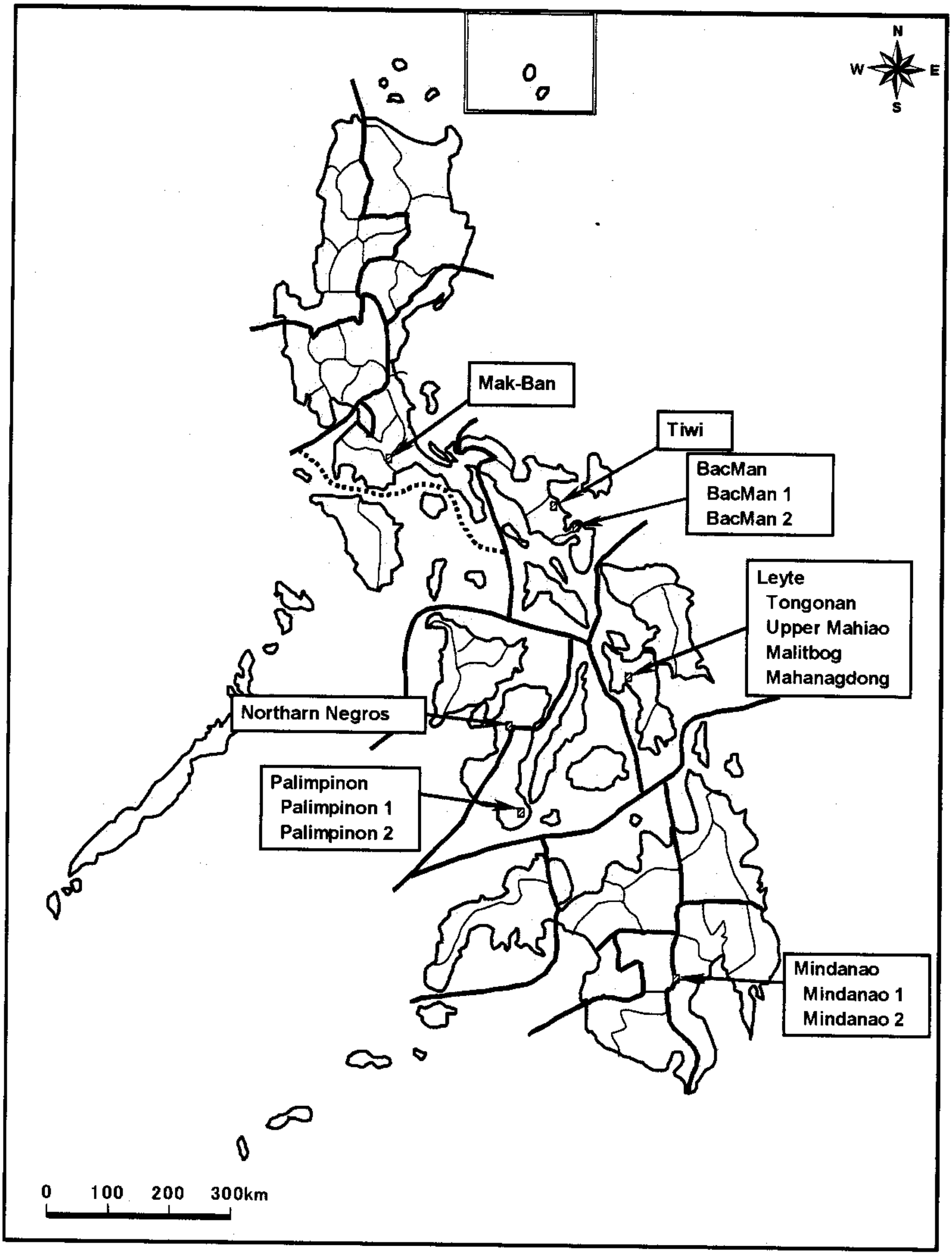


Fig. III-2 Location Map of Geothermal Power Stations in the Philippines

Table III-3 Geothermal Power Stations in the Philippines

Power Station			Location (Province)	Power Generating Steam Supply	Installed Capacity (MW)	Comissioning	Turbine Maker	Remarks
Mak-Ban	A B C D E		Laguna	Aboitiz Power Renewables Inc. Chevron Geothermal Philippines Holdings Inc.	55 x 2 55 x 2 55 x 2 20 x 2 20 x 2	Jul. 1979 Jun 1980 Sep. 1984 Aug. 1995 Aug. 1995	MHI MHI MHI MHI MHI	Originally, owner of power plants was NPC (National Power Corporation), but APRI was obtained the assets through bidding
	Binary 1 Binary 2 Binary 3			Ormat Aboitiz Power Renewables Inc.	3 x 2 3 x 2 3 + 0.73	Jun 1994	Ormat Ormat Ormat	
Tiwi	A B C		Albay	Aboitiz Power Renewables Inc. Chevron Geothermal Philippines Holdings Inc.	55 x 2 55 x 2 55 x 2	May 1979 Apr. 1980 Mar. 1982	Toshiba Toshiba Toshiba	Originaly, owner of power plants was NPC, but APRI was obtained the assets through bidding
BacMan	BacMan 1		Albay, Sorsogon	EDC (Energy Development Corporation)	55 55	Oct. 1993 Dec. 1993	Ansaldo	Originaly, owner of power plants was NPC, but EDC was obtained the assets through bidding
	BacMan 2	Botong Kawayan		EDC	20 20	Mar. 1994 Apr. 1998	MHI MHI	Originaly, owner of power plants was NPC, but EDC was obtained the assets through bidding
Northern Negros			Negros Occidental	EDC	49	Feb. 2007	Fuji	Scale-down of the plant is considered, as steam shortage arosed (mainly due to restriction by national park)
Palimpinon	Palimpinon 1		Negros Oriental	EDC	37.5 x 3	Sep. 1983	Fuji	Originaly, owner of power plants was NPC, but EDC was obtained the assets through bidding
	Palimpinon 2	Okoy Nasuji Sogongon		EDC	20 20 20 x 2	Dec. 1993 1994 1995	Fuji Fuji Fuji	Originaly, owner of power plants was NPC, but EDC was obtained the assets through bidding
Leyte	Tongonan		Leyte	NPC EDC	37.5 x 3	Jun 1983	MHI	
	Tongonan Topping			NPC EDC	5.8 x 2	Sep. 1997	Ormat	
	Upper Mahiao			EDC	34.12 x 4	Sep. 1996	Genral Elctric	Originaly, power plants were operated by California Energy, on BOT
	Upper Mahiao Binary			EDC	5.5	Sep. 1996	Ormat	
	Malitbog			EDC	77.5 77.5 x 2	May 1996 Oct. 1996	Fuji Fuji	Originaly, power plants were operated by California Energy, on BOT
	Malitbog Bottoming			EDC	16.7	Jan. 1998	Ormat	
	Mahanagdong A Mahanagdong B			EDC	60 x 2 60	Jul. 1997	Toshiba Toshiba	Originaly, power plants were operated by California Energy, on BOT
	Mahanagdong A Topping Mahanagdong B Topping			EDC	6.5 x 2 6.5	Sep. 1997	Ormat Ormat	
Mindanao	Mindanao 1 Mindanao 2		North Cotabato	EDC	54.24 54.24	Dec. 1996 Jun 1999	MHI MHI	Originaly, power plants were operated by Marubeni and Oxbow, on BOT

MHI = Mitsubishi Heavy Industry

Source: Thermal and Nuclear Power Engineering Society (2009) Current situation and trend of geothermal power generation.

III-3 Geothermal Power Development in Indonesia

It is said that Indonesia has the greatest geothermal potential of any country in the world. It has been reported that Indonesia's geothermal potential is equivalent to 27,000 MW and constitutes 40% of world potential. For this reason, a great deal is expected of geothermal energy development, in terms of meeting the increasing demand for electricity and diversifying energy sources. The geothermal power plants in Indonesia are shown in Fig. III-3 and Table III-4. Geothermal generation is taking place at 7 locations, with a current generation capacity exceeding 1,100 MW. However, although this generation capacity is the third largest in the world, when one considers the tremendous potential available, it cannot be said that this bounty is being fully utilized at present.

In Indonesia, economic expansion has led to a sharp rise in electricity demand. In the Indonesian electricity sector, it has become an urgent priority to ensure a stable supply by balancing power plant construction with demand. In 2006, the Indonesian government issued a Presidential decree announcing Crash Program I to develop 10,000 MW of electricity in the Java-Bali system. Also, because electricity demand is increasing sharply with the expansion of rural electrification and local economies, Crash Program II of a similar scale (9,522 MW) has been instituted to continue the work of Crash Program I. One of the chief merits of the Crash Program II is that it emphasizes the development of renewable energy, in particular through the development of geothermal generation capacity (which accounts for 42% of the proposed total) and the enabling of independent power producers (IPP).

In addition, the government of Indonesia adopted a National Energy Policy in 2002, and is aiming to meet more than 5% of its primary energy needs through renewable energy by 2020. In order to achieve this objective, the government is giving an important role to the geothermal energy in which the country abounds. Furthermore, in 2006, a Presidential Decree (2006-5) was issued concerning the National Energy Policy, underlining the high priority in national policy that the National Energy Policy has. At the same time, in order to encourage the participation of domestic and foreign private sector enterprises in geothermal development, the Indonesian government enacted a Geothermal Energy Law for the first time in 2003, clarifying the legal regimen governing geothermal development.

Moreover, in order to realize the national energy plan, in 2004 the Ministry of Energy and Mineral Resources (MEMR) adopted the "Road Map Development Plan for Geothermal Energy", setting even higher development targets for geothermal generation of 6,000 MW by 2020 and 9,500 MW by 2025. Also in 2004, geothermal organizations were reformed, with the breakup of Pertamina (the State Oil and Natural Gas Mining Company) and the establishment of Pertamina Geothermal Energy, Inc. (PGE). In this way, a new framework was instituted for the promotion of geothermal development, and a good start has been made towards vigorous development.

The framework for geothermal development in Indonesia in recent years has been as follows: the Center for Geological Resources (CGR) of the Ministry of Energy and Mineral Resources carries out basic surveys of geothermal resources, and, on the basis of these survey results, MEMR establishes Geothermal Working Areas (Wilayah Kerja Pertambangan Panas Bumi or WKP in Indonesian). Subsequently, the private sector entrepreneur that has won the geothermal mining concession through competitive bidding evaluates the geothermal resource, conducts feasibility studies and environmental impact assessments and proceeds to commercialize the project. It should be noted that IPP entrepreneurs must conclude electric power sales contracts with the state-run, public electricity corporation, PLN.

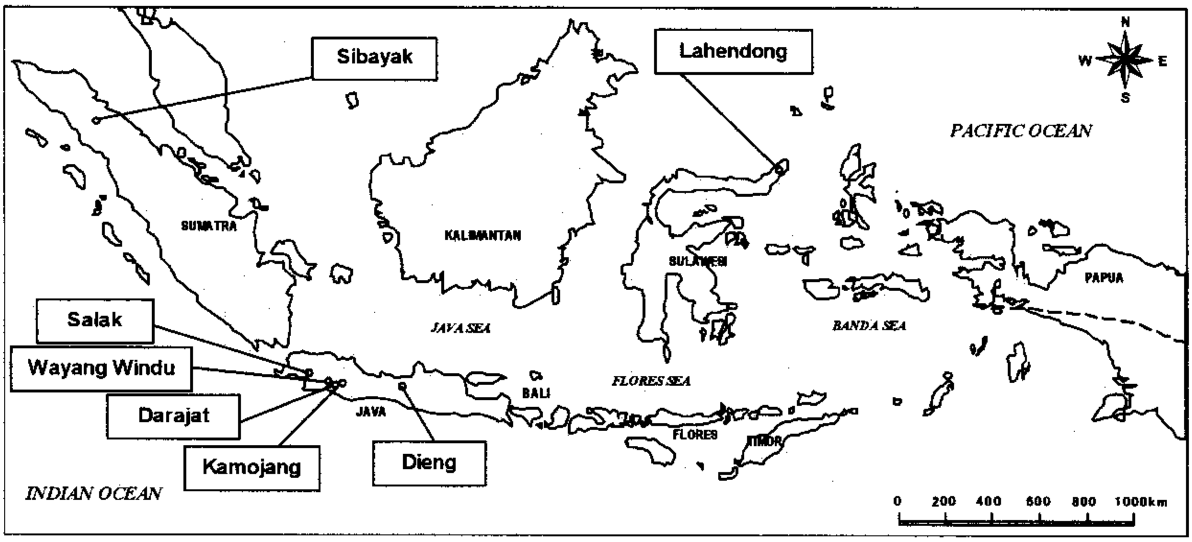


Fig. III-3 Location Map of Geothermal Power Stations in Indonesia

Table III-4 Geothermal Power Stations in Indonesia

Power Station		Location (Province)	Power Generating Steam Supplying	Intalled Capacity (MW)	Comissioning	Turbine Maker	Remarks
Sibayak		North Sumatra	Pertamina	2 5 5	1996 2007 2007	Uncertain	
Salak	Unit 1 Unit 2 Unit 3	West Java	PLN Chevron Geothermal Indonesia	55 55 55	Mar. 1994 Jun 1994 Aug. 1997	ANSALDO ANSALDO ANSALDO	
	Unit 4 Unit 5 Unit 6	West Java	Chevron Geothermal Indonesia	55 55 55	1997	Fuji Fuji Fuji	
Wayang Windu		West Java	Mandala Nusantara Ltd.	110 117	2000 2009	Fuji	
Kamojang	Unit 1 Unit 2 Unit 3	West Java	PLN Pertamina	30 55 55	Oct. 1982 Jul. 1987 Sep. 1987	MHI MHI MHI	
	Unit 4	West Java	Pertamina	63	2008	Fuji	
Darajat	Unit 1 Unit 2	West Java	PLN Chevron Geothermal Indonesia	55 81.3	Oct. 1994 2000	MHI MHI	
	Unit 3	West Java	Chevron Geothermal Indonesia	110	2007	MHI	
Dieng		Central Java	Geodipa Energi	60	Mar. 1997	ANSALDO	
Lahendong	Unit 1 Unit 2 Unit 3	North Sulawesi	PLN Pertamina	20 20 20	2001 2007 2009	ALSTOM Fuji Fuji	

MHI = Mitsubishi Heavry Industry

Source: Thermal and Nuclear Power Engineering Society (2009) Current situation and trend of geothermal power generation.

III-4 General Process of Geothermal Development

III-4-1 Geothermal Resources

The presence of water (as a carrier of heat energy) is an important factor in the utilization of geothermal resources for power generation, together with an elevated temperature (heat energy) and a reservoir where heated water is stored or flows. For power generation in a conventional system, a temperature higher than 200°C is usually required and for generation in a binary system, a temperature higher than 100°C. A layer near the ground surface composed of unconsolidated coarse grain materials (sand, pebbles, etc.) usually has good permeability and can store water. However, the permeability of rock bodies extending under the ground is generally not so good, though there are some exceptions. Moreover, the presence of an impermeable layer lying over the geothermal reservoir is desirable. When a reservoir is associated with an overlying impermeable layer, it is expected that the impermeable layer will prevent the reservoir from being cooled by the inflow of cold groundwater.

Identified geothermal reservoirs in the world are roughly classified into two categories according to the medium storing the geothermal fluid: "fracture type" and "porous media type". A fracture type geothermal reservoir lies in a fractured zone where the constituent rocks are fractured (see Fig. III-4). Faulting and intrusion of rock bodies will cause fracturing in existing rock formations. Considering the geological conditions around the identified geothermal reservoirs in the world, it can be seen that the majority of fracture type geothermal reservoirs occur in a fractured zone associated with a fault. The impermeable layer lying over the reservoir is usually composed of argillized rocks characterized by the occurrence of smectite. This argillization results from a water-rock interaction under relatively low temperature conditions (lower than 200°C). This impermeable layer is often detected as a low resistivity layer (zone) by resistivity surveying.

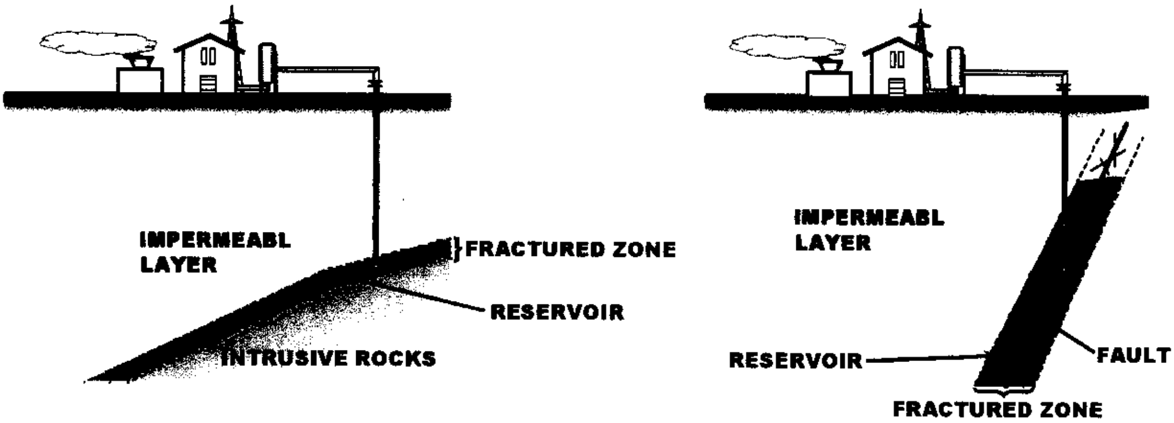
A porous media type geothermal reservoir lies in a permeable stratum and has a greater lateral extent (see Fig. III-5). The overlying impermeable stratum is usually composed of a compact formation such as intensively welded tuff. On the whole, occurrence of this type reservoir is rather rare. Moreover, geothermal fluid stored in such a reservoir is generally supplied by a fracture type reservoir.

For successful geothermal development and geothermal well drilling, geological and geothermal structures should be clarified mainly through the use of geological and geophysical techniques. Delineation of geothermal reservoirs based on the surface survey results is vital work for estimating the distribution and extent of the reservoirs. The results of these studies, namely the geothermal structures and reservoir extents, are used as working assumptions for exploratory well drilling. These assumptions concerning the geothermal structure and reservoir extent are ascertained using exploratory wells.

Geothermal reservoirs are sometimes categorized by the phase of the stored geothermal water (H_2O) into a water-dominated type, a vapor-dominated type and so on. The majority of geothermal reservoirs are of the water-dominated type. In a water-dominated reservoir, the water is present in the liquid phase. In a vapor-dominated reservoir, water in the liquid phase and water in the gas phase (steam) coexist in the reservoir (a two-phase reservoir). In rare cases, a reservoir may consist of superheated steam.

In consideration of the interference problems and decline problems attendant on steam production and brine reinjection, a water-dominated reservoir is favored for geothermal development. However, a vapor-dominated reservoir has the advantage of scarcely requiring reinjection wells for waste brine. A vapor-dominated reservoir is sometimes identified above a water-dominated reservoir, as shown in Fig. III-6. In such a case, the vapor-dominated reservoir is often called a "steam cap". In some geothermal fields, the steam cap has a considerable extent and high potential. Steam caps have been identified underneath impermeable layers.

The fluid type a well discharges is a critical factor in geothermal field operation. The fluid type of geothermal reservoirs is usually studied using geochemical methods and confirmed by exploratory well drilling and flow tests.



(a) Fractured zone associated with intrusive body (b) Fractured zone associated with fault

Fig. III-4 Example of Fracture Type Geothermal Reservoir

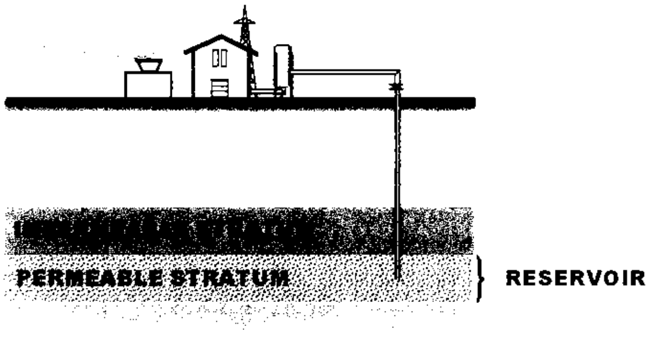


Fig. III-5 Example of Porous Media Type Geothermal Reservoir

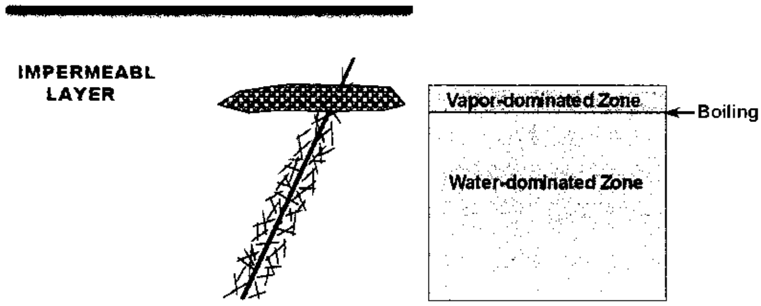
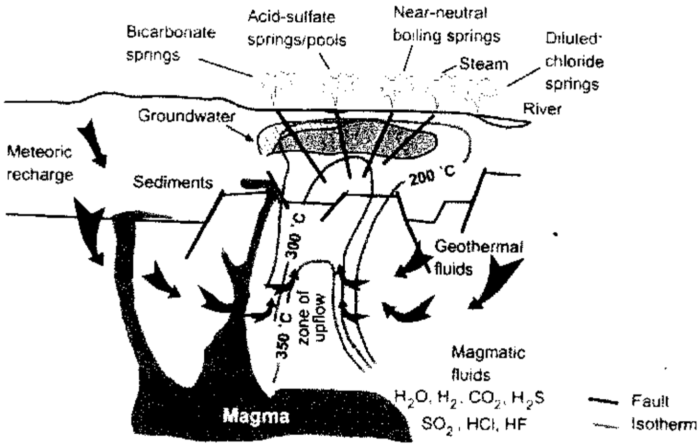


Fig. III-6 Example of Vapor-dominated Reservoir above a Water-dominated Reservoir

The chemical characteristics of the geothermal fluids are controlled by water-rock interactions under high temperature conditions and/or chemical reaction with gases such as H_2S, CO_2 etc. Figure III-7 shows a schematic cross section of a typical geothermal system (from D.Chandrasekharam and Jochen Bundschuh 2008). Due to the involvement of magma intrusion, several chemical constituents present in the magma mix with the circulating geothermal fluids. These chemical components provide vital clues for assessing the reservoir characteristics, its temperature, and other information that is crucial during the pre-drilling exploratory stages of geothermal resource development. In particular, high-temperature, chloride-type hot water is regarded as most important, because this type of water is usually derived from a water-dominated reservoir with a temperature higher than 200°C. Acidic sulfate-type hot water and fumaroles are also important, because this water and the fumarolic gases may originate from high-temperature geothermal reservoirs. Detecting these manifestations and clarifying the reservoir characteristics using geochemical techniques provide crucial information concerning the geothermal reservoirs.



Heat: The heat for the system is provided by magmatic intrusion in volcanic areas.

Fluid: The percolating meteoric waters, indicated by solid arrows, react with "host rocks", mix with magmatic fluids and give rise to different chemical types of geothermal fluids. Ascending geothermal fluid mixes with shallow groundwater and further changes its chemical composition.

(D.Chandrasekharam and Jochen Bundschuh, 2008)

Fig. III-7 Schematic Cross Section of a Typical Geothermal System

III-4-2 Process of Geothermal Power Development

As development risk (leading to an unfavorable result) is not negligible in steam field development, a phased process of steam field development is usually adopted. One typical process of steam field development is shown in Fig. III-8. The development process is composed of the following four stages:

1st Stage	Exploration Stage
2nd Stage	Feasibility Study Stage
3rd Stage	Project Implementation Stage
4th Stage	Operation and Maintenance Stage

The goal of the First Stage (Exploration Stage) is to confirm the presence of a geothermal resource, to identify the chemical and physical properties of the geothermal resource and to estimate the resource capacity (optimum output to maintain sustainable operation). The exploration stage is subdivided into the following three phases:

Phase 1	Regional Exploration Phase, to select a prospective area (or areas)
Phase 2	Detailed Exploration Phase, to clarify the presence of a geothermal resource, to identify the geothermal structure and to select drilling targets
Phase 3	Resource Evaluation Phase, to identify the chemical and physical properties of a targeted geothermal reservoir by well drilling and to evaluate resource capacity

In Phase 1 (Regional Exploration Phase), exploration is carried out over the whole of an objective field to select a prospective area (first priority area to study in detail). In Phase 2 (Detailed Exploration Phase), detailed exploration of sufficient accuracy to permit selection of drilling targets is carried out. In Phase 3 (Resource Evaluation Phase), several exploratory wells (more than three wells is desirable) are drilled to tap the selected targets, and production (discharge) tests are carried out. Moreover, resource evaluation to estimate the optimum sustainable geothermal power generation output is conducted through reservoir simulation using a 3-D numerical model based on the results of the production tests and exploration.

A conceptual model of geothermal resources is usually constructed at the end of each phase, to draw up a revised strategy for the development. In this model, information about the distribution of geological elements controlling geothermal activity, the extent of high temperature anomalies and the flow pattern of geothermal fluid, which are sometimes referred to as "geothermal structure", are represented in a way that is easy to understand. There are many kinds of geothermal exploration technologies contributing to this estimation of geothermal structure for modeling, but no single technology is sufficient on its own.

Therefore, a variety of exploration technologies must be applied in order to prepare an adequate model for geothermal development. However, the best combination of technologies to be applied depends on the particular field, as an objective field has unique geothermal resource characteristics and surrounding geological conditions differing from other fields. Although geological, geochemical and MT surveying are rather commonly conducted, consideration of the suitable combination of technologies for the objective field is required at the planning stage. Furthermore, comprehensive analysis and integrated interpretation of the obtained geothermal exploration results will be required.

The work of Phases 1 and 2 in private geothermal development can be undertaken either by the Government or by the private sector. Phase 2 work is of particular importance and is believed to significantly affect the outcome of the geothermal power development project.

In the Second Stage (Feasibility Study Stage), the conceptual design of the future geothermal power station is elaborated, based on estimated optimum output and steam quality as clarified by production tests. At this stage, economic and financial evaluation of the proposed geothermal project is also carried out. It is desirable that a full environmental assessment, including the power plant and associated transmission line, should be completed before the inception of the following stage (Project Implementation Stage).

In the Third Stage (Project Implementation Stage), a detailed design of the power plant and FCRS (Fluid Collection and Reinjection System) is prepared. If the power plant, including pipelines, is constructed using a competitive tendering system to select an EPC contractor, bidding documents for procurement are prepared based on information in the detailed design. Then, the power plant and FCRS are constructed. During construction, the necessary number of additional production and reinjection wells to meet the power plant operation requirements are constructed. Those wells are also subject to long term production tests, following which a review of the geothermal reservoir simulation is conducted.

In the Fourth Stage (Operation and Maintenance Stage), ongoing refinement of the conceptual model on the basis of data accumulated through steam field operation will be required to maintain sustainable steam production (reservoir management).

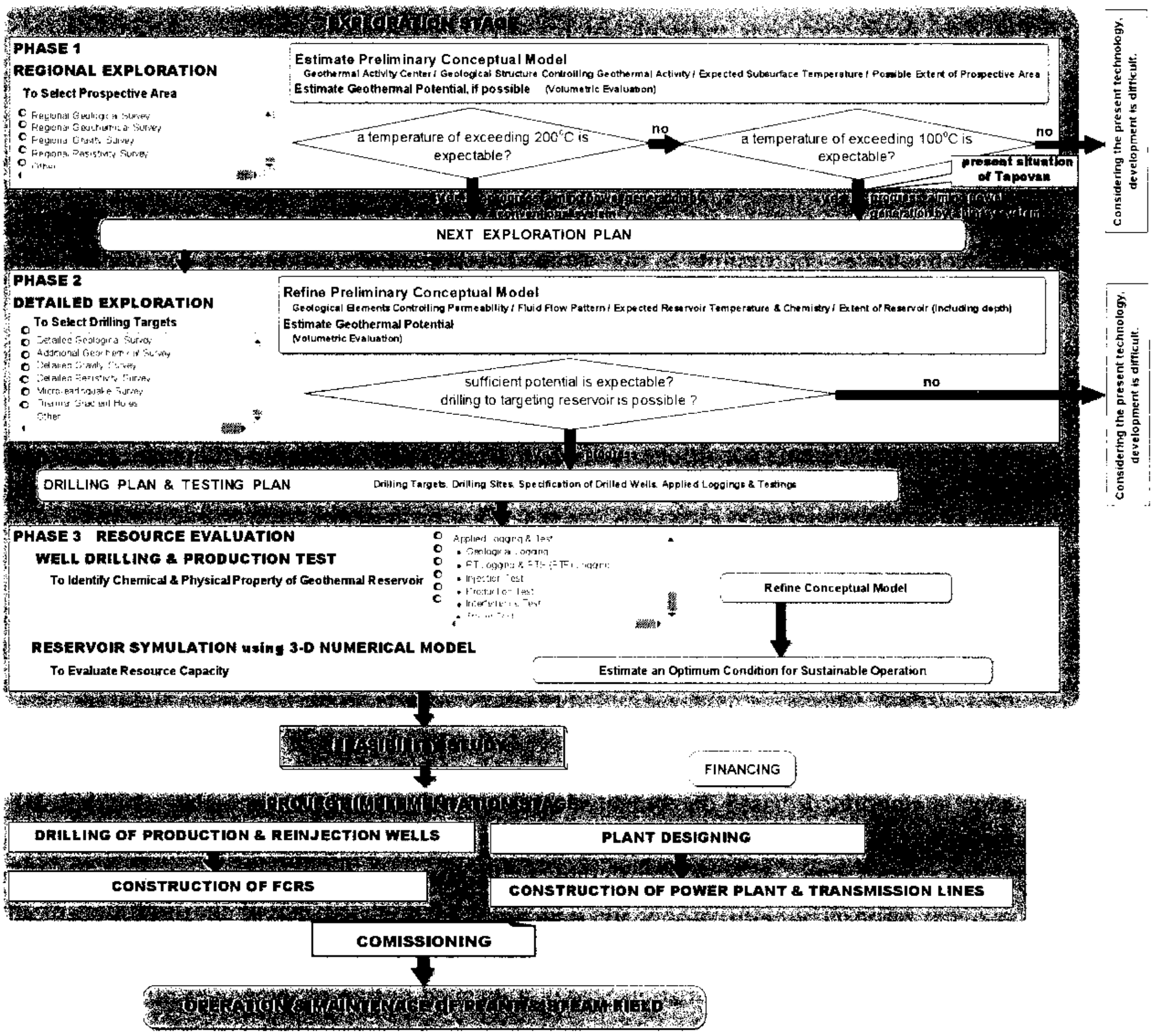


Fig. III-8 General Flow of Geothermal Power Development

III-4-3 Desired Process of Geothermal Power Development in India

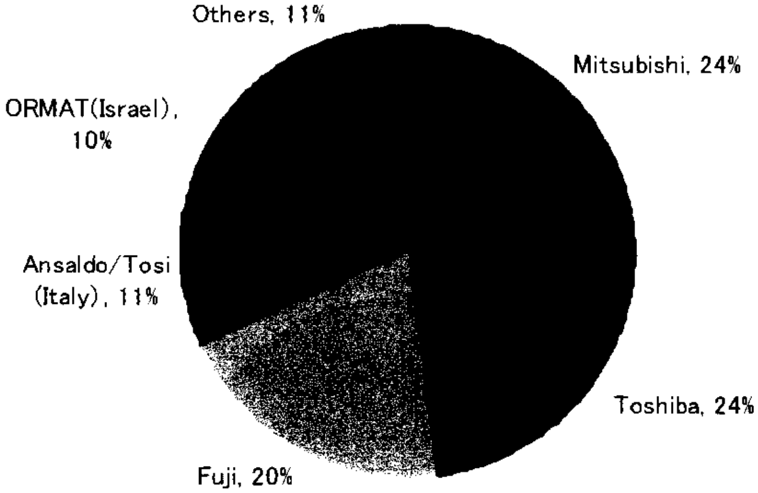
Geothermal power development has been regarded as a typical high-risk (but low-return) undertaking. To ascertain the resource capacity (the optimum output of the power plant to maintain sustainable operation) in an objective geothermal field, the following steps are required. First, a regional exploration (Phase 1) is conducted to select a prospective area. After Phase 1, detailed exploration (Phase 2) is conducted in the selected area to clarify the extent of the geothermal resource and to select drilling targets. In this phase, the geothermal resource potential is roughly estimated by the volumetric (or stored heat) method. Although this estimated potential will establish a tentative goal for the project, it must be noted that this estimated potential is not the same thing as resource capacity. To evaluate resource capacity, it is necessary to carry out resource evaluation (Phase 3) based on the drilling of exploratory wells followed by discharge (production) testing.

In the earliest phase, the expected geothermal power generation output is uncertain, as mentioned above. To ascertain the possible output (that will maintain sustainable operation), the types of exploration characteristic of the three phases outlined above will be required, and these will require a considerable budget. However, a geothermal power project does not always progress successfully to the final goal of sustainable power generation, and this is a major reason why the private sector is hesitant to participate in the geothermal power business.

To promote the participation of the private sector, incentives for geothermal power projects (for example, giving preferential treatment under the taxation system, as in the Philippines) have been introduced in some countries. In Japan, the government conducts geothermal exploration from the Regional Exploration Phase to the Resource Evaluation Phase and this governmental program reduces the development risk faced by the private sector. In Indonesia, the government also conducts geothermal exploration covering the Regional Exploration Phase and Detailed Exploration Phase. Considering that India has little experience in geothermal power development, it is to be hoped that a geothermal exploration program that is supported by Indian Government and covers the Regional Exploration Phase and Detailed Exploration Phase will be introduced to promote geothermal power development in India.

III-5 The Global Geothermal Manufacturing Business

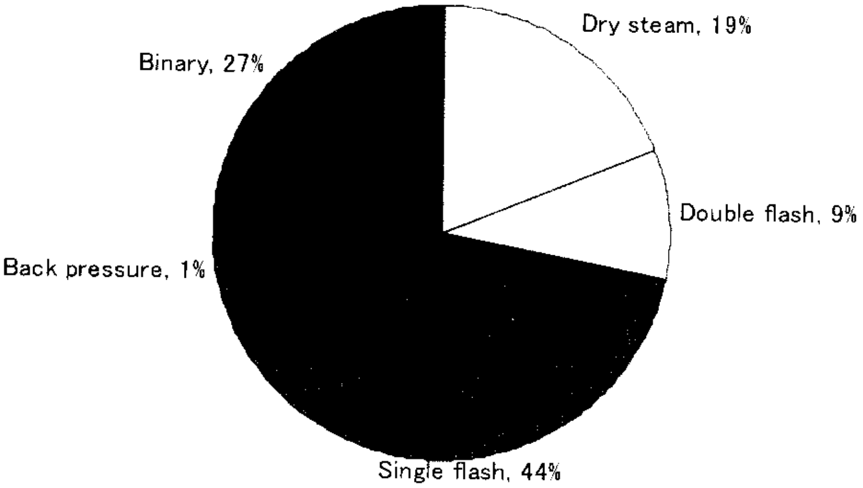
In the business of geothermal power plant construction, Japanese manufacturers occupy a leading position in the world market. The total installed capacity of geothermal power plants in the world is 10,716 MW, of which about 70% are manufactured by the major Japanese manufacturers (Mitsubishi Heavy Industries, Fuji Electric Systems, and Toshiba), as shown in Fig. III-9.



Source : Study on trend of consulting business on geothermal power development, Institute of Energy Economics, Japan,2011

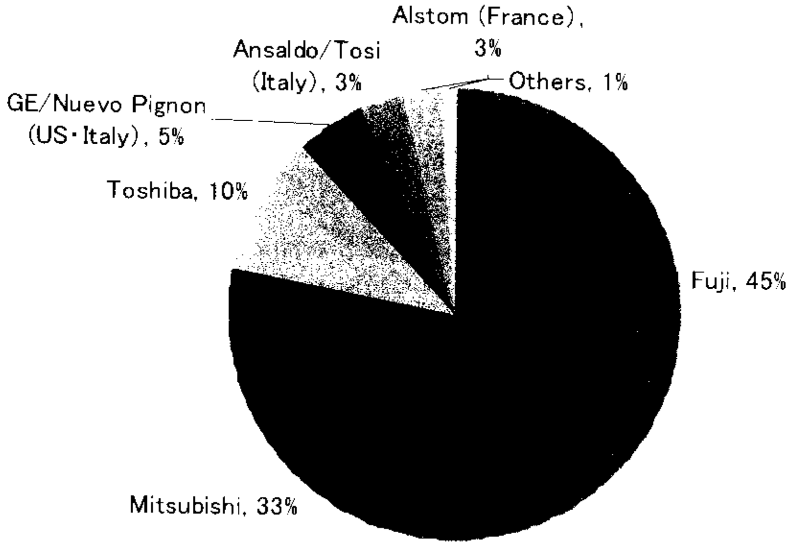
Fig. III-9 Global Market Share of Geothermal Power Plant Manufacturers

There are two different generation systems for geothermal power plants. One is the steam turbine system and the other is the binary system. About 90% (9,500 MW) of the world's geothermal power plants use the steam turbine system, and the remaining 10% use the binary system. However, the use of binary systems has been increasing recently, and they accounted for 27% of the global geothermal market over the period from 2005 to 2009 (see Fig. III-10). The major Japanese manufacturers are maintaining a strong presence in the steam turbine business. As shown in Fig. III-11, they have supplied as much as 88% of the world steam turbine market during the past ten years (from 2001 to 2011). To design and manufacture geothermal power plant equipment, particularly the turbines, requires a high level of technology to efficiently utilize geothermal steam at relatively low temperatures and pressures, while taking into account the characteristics of geothermal fluid and gas that can lead to corrosion. It is considered that the equipment from Japanese manufacturers is generally good at efficient generation and easily maintained, while the Italian and the American manufacturers are also competitive in the market. On the other hand, with binary systems, the Israeli company ORMAT accounts for approximately 80% of the world market, as shown in Fig. III-12. It is noteworthy that ORMAT not only supplies power generation equipment but also develops geothermal fields on their own account.



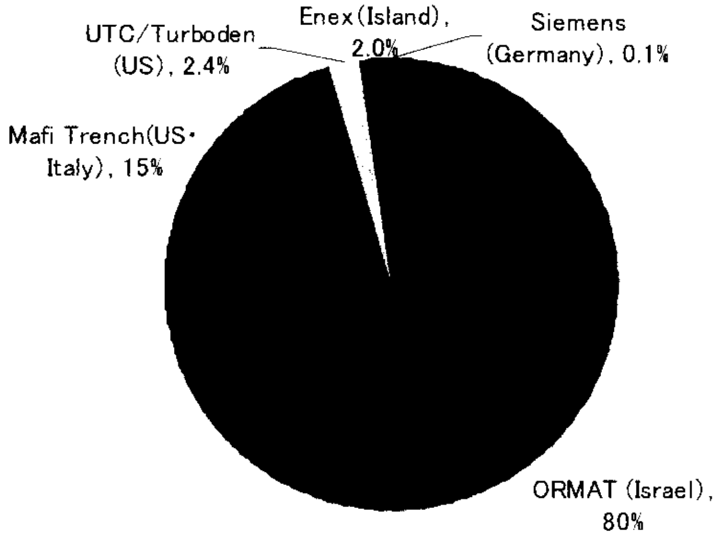
Source : Study on trend of consulting business on geothermal power development, Institute of Energy Economics, Japan,2011

Fig. III-10 Market Share of the Various Geothermal Power Plant Technologies (2005-2009)



Source : Study on trend of consulting business on geothermal power development, Institute of Energy Economics, Japan,2011

Fig. III-11 Market Share of Steam Turbine Systems by Manufacturer (2001-2010)



Source : Study on trend of consulting business on geothermal power development, Institute of Energy Economics, Japan,2011

Fig. III-12 Market Share of Binary Systems by Manufacturer (2005-2009)

In geothermal power development projects, the generation method and the economic efficiency of the project are significantly affected by field conditions such as the temperature of the geothermal fluid. The generation capacity per unit in a binary system is relatively small and limited to the use of geothermal resources of low and medium temperature. For this reason, it has been considered that binary generation projects are too expensive to be implemented in developing countries, where electricity prices are usually kept low. However, in recent years a binary system which can also be applied to high-temperature and water-dominant geothermal resources has been developed, and the generation capacity of this binary system is as large as that of the steam turbine system. In the United States, binary power plants have been actively constructed in recent years and many projects under development will also apply a binary system in the future. As a result, the binary system is becoming more cost competitive.

For those countries with high-temperature and water-dominant geothermal resources, such as Indonesia, the Philippines, and countries in Latin American and Africa, the steam turbine system will remain the mainstream choice in the future. On the other hand, for those countries with geothermal resources of low to medium temperatures, such as the United States, where the Enhanced Geothermal System (EGS) is being developed, the European countries, particularly Germany, and also Australia, the use of binary systems is expected to expand significantly in the future. The Japanese manufacturers are expected to respond to this market trend in the geothermal power plant business by expanding more into binary systems, while maintaining a strong presence in steam turbine systems.

Extensive utilization of renewable energy as a countermeasure against climate change is being demanded around the world. This worldwide trend is obvious in Japan, where attempts to utilize geothermal resources of low to medium temperatures as an alternative power source have been begun. For this purpose, Japanese companies have propose a variety of power generating systems, which are still in development. These plants will be commercialized in the near future.

Table III-5 shows the geothermal power plants built in the world between 2005 and 2009 by country and installed capacity. The installed capacity of the geothermal power plants constructed in those five years is 1,700 MW in total. There are 16 power plants newly constructed in the United States, seven in Iceland, seven in New Zealand, six in Indonesia and four in Italy. The power plant with the largest installed capacity constructed in the United States is a dry-steam system from Fuji Electric with a capacity of 55 MW. The rest of plants constructed in the United States are binary systems with installed capacities of 50 MW, 49 MW and 48 MW. Even though these are binary systems, their generation capacities are equivalent to those of steam turbine systems. The largest power plant constructed in Indonesia is a single-flash system from Fuji Electric generating 117 MW, and the second largest is a dry-steam system from Mitsubishi Heavy Industries generating 110 MW. Currently, the largest power plant in the world in terms of generation capacity is Nga Awa Purua power plant in New Zealand, which entered into operation on April, 2010, generating 140 MW with a Fuji Electric steam turbine.

Table III-5 Geothermal Power Plant Facilities Constructed between 2005 and 2009 (by Country and Installed Capacity)

Country	Plant	Unit	COD	Installed Capacity (MW)	Type	Operator	Manufacturer
El Salvador	Berlin	3	2006	44	Single Flash	LaGeo/Enel Green Power	General
	Berlin	4	2008	9.4	Binary	LaGeo/Enel Green Power	Enex
France	Soultz-sous-Forêts	1	2008	1.5	Binary	European EGS Interest Group	UTC/Turboden
Germany	Unterhaching	1	2008	3.4	Binary	Municipality	Siemens
	Lendau	1	2008	3	Binary	Municipality	ORMAT
Guatemala	Amatitlán	1	2007	24	Binary	ORMAT	ORMAT
Island	Hellisheidi I	1-2	2006	90	Single Flash	Orkuveita Reykjavikur	Mitsubishi
	Hellisheidi III	1-2	2008	90	Single Flash	Orkuveita Reykjavikur	Mitsubishi
	Reykjanes	1	2005	50	Single Flash	Hitaveita Sudurnesja	Fuji Electric
	Reykjanes	2	2006	50	Single Flash	Hitaveita Sudurnesja	Fuji Electric
	Hellisheidi II	1	2007	33	Single Flash	Orkuveita Reykjavikur	Toshiba
	Nesjavellir	4	2005	30	Single Flash	Orkuveita Reykjavikur	Mitsubishi
	Svartsengi	2	2005	30	Single Flash	Hitaveita Sudurnesja	Fuji Electric
Indonesia	Wayang Windu	2	2009	117	Single Flash	Star Energy Ltd	Fuji Electric
	Darajat	3	2008	110	Dry Steam	Chevron	Mitsubishi
	Kamojang	4	2007	60	Dry Steam	PLN	Fuji Electric
	Lahendong	2	2008	20	Single Flash	PLN	Fuji Electric
	Lahendong	3	2009	20	Single Flash	PLN	Fuji Electric
	Sibayak	2-3	2007	11	Single Flash	Pertamina Geothermal Energy	Harbin
Italy	Nuova San Martino	1	2005	40	Dry Steam	Enel Green Power	General
	Nuova Larderello	1	2005	20	Dry Steam	Enel Green Power	Ansaldo/Tori
	Sasso 2	1	2009	20	Dry Steam	Enel Green Power	GE/Nuovo
	Nuova Lagoni Rossi	1	2009	20	Dry Steam	Enel Green Power	GE/Nuovo
Japan	Hatchobaru	3	2006	2	Binary	Kyushu Electric Power	ORMAT
Kenya	Olkaria III	3	2008	36	Single Flash	ORMAT	Mitsubishi
	Oserian	2	2007	2	Single Flash	Oserian Flower co	Elliot
Mexico	Los Humeros	8	2007	5	Back Pressure	Comisión Federal de Electricidad	Mitsubishi
New Zealand	Kawerau	1	2008	100	Double Flash	Mighty River Power	Fuji Electric
	Mokai 2	1-5	2005	20	Binary	Tuaropaki Power Co	ORMAT
	Mokai 2	1	2005	19	Single Flash	Tuaropaki Power Co	Mitsubishi
	Mokai 1A	1	2007	17	Binary	Tuaropaki Power Co	ORMAT
	Ngawha 2	1	2008	15	Binary	Top Energy	ORMAT
	Wairakei	15-17	2005	14	Binary	Contact Energy	ORMAT
	KA24	1	2008	8.3	Binary	ORMAT	ORMAT
Nicaragua	San Jacinto-Tizate	1-2	2007	10	Back Pressure	Polaris	Alstom
Papua New Guinea	Lihir	2	2005	30	Single Flash	Lihir Gold Ltd mine	GE/Nuovo
	Lihir	3	2007	20	Single Flash	Lihir Gold Ltd mine	General
Philippines	Mambucal	1	2007	49	Single Flash	National Power Corporation	Fuji Electric
Portugal	Pico Vermelho	1	2006	13	Binary	Electricidade dos Açores	ORMAT
Rossia	Okeanskaya	1-2	2007	3.6	Single Flash	SC Geoterm	Kaluga Turbine Works
	Mendeleevskaya	1	2007	1.8	Single Flash	SC Geoterm	Kaluga Turbine Works
	Germencik	1	2009	47	Double Flash	GURMAT	Mitsubishi
Turkey	Dora	1	2006	7.4	Binary	MB	ORMAT
	Kizildere Binary	1	2008	6.8	Binary	BEREKET	ORMAT
USA	Bottle Rock	2	2007	55	Dry Steam	US Renewables	Fuji Electric
	Faulkner	1	2009	50	Binary	Nevada Geothermal	ORMAT
	North Brawley	1-7	2009	49	Binary	ORMAT	ORMAT
	Stillwater	1-2	2009	48	Binary	Enel Green Power	Mafi Trench
	Richard Burdett	1-2	2005	30	Binary	ORMAT	ORMAT
	Galena III	1	2008	30	Binary	ORMAT	ORMAT
	Salt Wells	1	2009	24	Binary	Enel Green Power	Mafi Trench
	Desert Peak II	1	2006	23	Binary	ORMAT	ORMAT
	Galena II	1	2007	13	Binary	ORMAT	ORMAT
	Raft River	1	2008	13	Binary	US Geothermal	ORMAT
	Blundell I	2	2007	11	Binary	Pacific Corporation	ORMAT
	Gould	1-2	2006	10	Binary	ORMAT	ORMAT
	Heber South	1	2008	10	Binary	ORMAT	ORMAT
	Thermo Hot Spring	1-50	2009	10	Binary	Raser Technologies	UTC/Turboden
Total				1,699.2			

Source : Study on trend of consulting business on geothermal power development, Institute of Energy Economics, Japan, 2011

CHAPTER IV

IV GEOTHERMAL RESOURCES IN INDIA

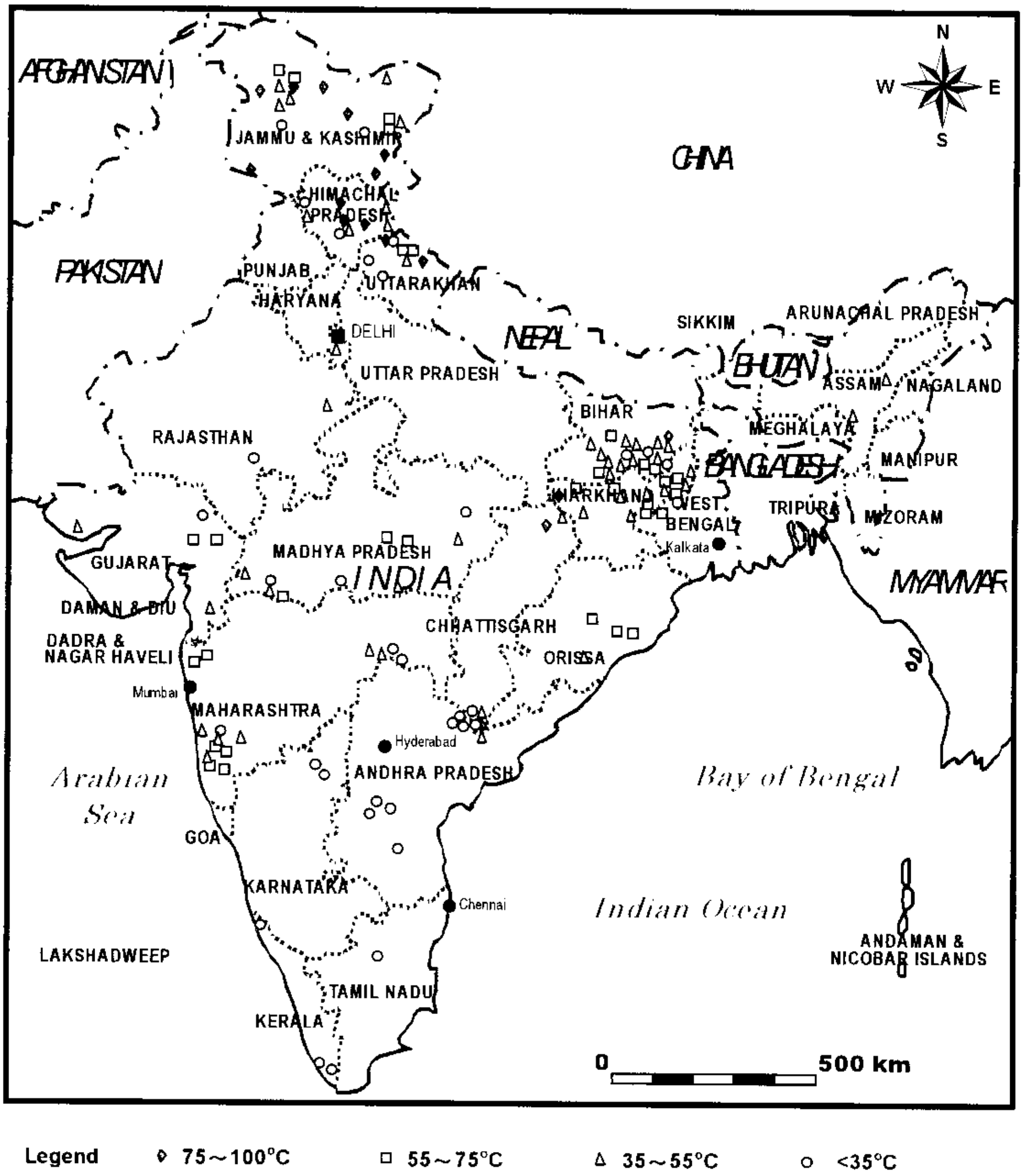
IV-1 Major Geothermal Areas in India

After the oil crises of the 1970s, the United Nations and the Geological Survey of India (GSI) carried out a reconnaissance survey of thermal springs, and the results were reported in the "Geothermal Atlas of India" by GSI, in 1991. Subsequently, geological and geochemical studies of thermal springs were conducted, and they suggest that some of thermal springs can be exploited for power generation or for direct utilization by industry. In addition, GSI and Atomic Minerals Division have drilled some shallow wells to a maximum depth of about 600 m. The major hot springs of India, summarized by GSI (2002), are shown in Fig. IV-1.

The following factors are regarded in Japan as criteria for selecting a prospective area (for a geothermal power plant of a conventional type):

- The presence of fumaroles with a discharge temperature around or exceeding boiling temperature
- The presence of a hot spring or shallow thermal well with a discharge temperature not lower than 60°C (not lower than 80°C for a Detailed Exploration)
- A temperature not lower than 150°C estimated through fluid chemistry geothermometry (not lower than 200°C for a Detailed Exploration)
- The presence of a Quaternary volcano in or around the area of which the last volcanic eruption is younger than 0.6 Ma
- The presence of altered ground of a certain extent younger than 0.3 Ma

For a binary system geothermal power plant, the criterion for estimated reservoir temperature can be reduced to 100°C. The volcanism criterion does not apply in India, as India is not a volcanic country. The altered ground criterion may be difficult to apply, because alteration age is usually uncertain. For these reasons, geothermal areas were selected where temperatures not lower than 60°C have already been confirmed and the chemical composition of the thermal water is known. 39 areas were selected from Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Gujarat, Maharashtra, Chhattisgarh, Andhra Pradesh, Jharkhand and West Bengal states,.

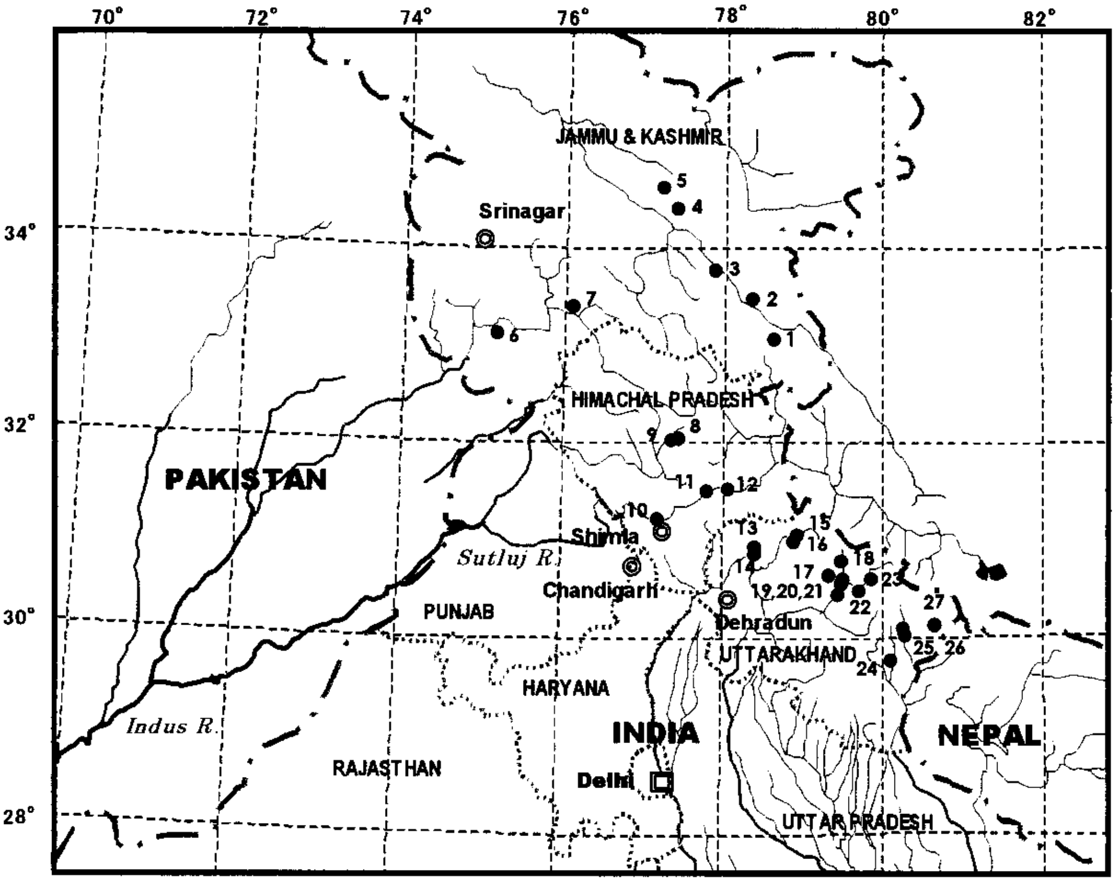


Source: GSI (2002), Geothermal energy resources of India

Fig. IV-1 Major Hot Springs in India

IV-1-1 Geothermal Resources in the Northern Region

There are many hot spring areas in the Northern Region (Jammu & Kashmir State, Himachal Pradesh State and Uttarakhand State). There are 27 hot spring areas in this region where there is a hot spring with a temperature not lower than 60°C and a known chemical composition: seven areas in Jammu & Kashmir State, five areas in Himachal Pradesh State and 15 areas in Uttarakhand State. Their locations and chemical data for the hot waters are given in Fig. IV-2 and Table IV-1, respectively. Hot spring areas with hot spring temperatures not lower than 80°C are Puga (63°C to 84°C, Jammu & Kashmir), Chhumathang (60°C to 83°C, Jammu & Kashmir), Manikaran-Kasol (72°C to 96°C, Himachal Pradesh), Yamnotri (90°C, Uttarakhand), Beda (94°C, Uttarakhand), Kanakar (81°C, Uttarakhand) and Tapovan (60°C to 94°C, Uttarakhand).



Legend ● Hot Springs (not lower than 60°C)

Jammu & Kashimir State

1: Puga (63～84°C) 2: Chhumathang (60～83°C) 3: Gaik (60°C) 4: Panamik (76°C) 5: Changlung (66°C)
6: Sidhu (65°C) 7: Galhar (60°C)

Himachal Pradesh State

8, 9: Manikaran-Kasol (72～96°C) 10: Tattapani (60～61°C) 11: Jeori (60°C) 12: Tapri (73°C)

Uttarakhand State

13: Yamnotri (90°C) 14: Banas (73°C) 15: Joti (65°C) 16: Gangnani (61°C) 17: Beda (94°C)
18: Khirao (60°C) 19: Loani (61°C) 20: Kanakar (81°C) 21: Gari (61°C) 22: Tapovan (60～94°C)
23: Juma (62°C) 24: Balati (68°C) 25: Nyu (72°C) 26: Dar (79°C) 27: Kalapani (62°C)

Source: GSI (2002), Geothermal energy resources of India

Fig. IV-2 Major Hot Springs in the Northern Region

Table IV-1 Chemical Composition of Hot Spring Waters in the Northern Region

Location	Temp. (°C)	ph	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	F (mg/l)	B (mg/l)	SiO_2 (mg/l)	Remarks	Reference
Jammu & Kashmir State														
Puga	84	8.9	600	90	5	1.5	468	172	799	5	155	237		1
	80	8.6	600	72	2	1	433	140	656	15	155	130		1
	70	8.3	530	68	15	tr	410	122	637	10	60	120		1
	80	7.6	580	80	54	1	400	118	830	15	123	113		1
	84	8.2	600	80	4	1.5	420	119	690	15	129	120		1
	67	8.1	540	72	16	2	398	129	708	12	129	165		1
	81	7 65	530	72	17	5	370	123	702	18	116	120	Drilled Hole	1
	80	8.4	640	76	2	2	424	140	686	15	140	130	Drilled Hole	1
	63	7.7	540	68	17	3	397	149	643	12	129	148	Drilled Hole	1
Chhumathang	83	8.8	355	21	3	0.2	113	258	290	2	38	152		1
	73	8.1	350	16	8	2	116	241	400	5	16	140		1
	60	7.8	340	45	10	2	110	221	376	5	15	120		1
	84	8.6	360	18	7	tr	122	241	368	10	16	100		1
	70	7.9	350	18	14	tr	108	224	396	5	15	100	Drilled Hole	1
	74	7.4	300	24	34	1	74	198	-	8	31	110	Drilled Hole	1
Gaik	60	7.8	94	3	8	1	21	91	129	20	4	80		1
Nubra(Panamik)	76	7.7	135	6	13	tr	13	99	254	12.5	2	101		1
Nubra(Changlung)	66	7.7	580	48	10	2	85	57	1610	10	8	130		1
Sidhu	65	7.3	350	70	114	16	606	45	495	2.5	tr	28		1
Galhar	60	6.95	56	4	14	1	30	72	112	6	1	35		1
Himachal Pradesh State														
Manikaran-Kasol	96	7.7	88	19	44	15	133	36	170	0.8	33	60		1
	77	6.7	30	10	59	13	56	57	175	-	24	30		1
	73	6.6	33	10	58	10	59	45	175	0.2	2	70		1
	82	7.5	17	6	60	6	30	52	170	0 4	19	40		1
	85	7.6	106	20	42	4.6	55	130	107			105		3
	86	6.4	78	17	38	4.6	51	140	104			104		3
	72	7.2	84	20	38	4.6	54	120	87			113		3
	73	7.3	88	21	42	6.9	53	160	126			117		3
	96	6.7	96	25	48	5.8	50	150	143			105		3
	78	7.6	75	15	70	10.4	70	200	117			86		3
	89	7.1	84.3	16.5	47.5	3.2	37.4	168	117	0.96	1.74	57.8		4
	87	6.8	62.8	12.9	43.1	5.07	37.1	171	80.2	0.96	1.76	56.6		4
Tattapani	61	7	2400	84	98	34	3865	108	296	1.7	4	38		1
	60	8	2000	100	81	40	108	215	3600	3		50		2
Jeori	60	7.6	920	40	116	22	1280	176	393	4	19	83		2
Tapri	73	7.9	240	23	28	2	145	117	288	11	6	160		2
Uttarakhand State														
Yamnotri	90	7.9	155	27	52	12	170	33	276	3	10	83		1
Banas	73	7.5	30	7	38	13	30	55	145	1	3	50		1
Joti	65	8.3	340	44	6	4	105	63	634	10	9	59		1
Gangnani	61	7.4	280	25	28	6	90	36	739	8	5	102		5
Beda	94	8.3	700	55	4	tr	139	109	1708	2.2	13	150		5
Khirao	60	8.2	54	5	2	4	12	38	118	4	2	80		1
Loani	61	8.4	39	8	13	3	15	58	192	4	1	46		1
Kanakar	81	8.1	30	5	34	3	15	30	117	1.6	-	22		1
Gari	61	8.4	366	38	7	12	141	43	639	8	5	45		1
Tapovan	94	7.5	16.7	8.33	80.9	27.6	6.77	24.7	375		0.39	78		6
	80	6.6	12.6	6.11	86.4	20.1	5.13	21.4	336		0.27	57		6
	67	6.5	12.8	6.79	95.6	23.1	4.67	21.7	381		0.25	59		6
	60	7.4	14.1	7.2	113	28.3	5.08	23.6	412		0.27	62		6
Juma	62	8	290	43	14	9	48	14	881	3	5	91		1
Balati	68	6.4	180	38	64	10	12	5	734	2	1	130		1
Nyu	72	7	22	38	174	118	10	32	1144	0.7	tr	56		1
Dar	79	7	89	10	13	2	2	63	221	4	2	99		1
Kalapani	62	6.8	270	14	36	5	30	29	751	8.6	3	88		1

Reference
1 Geological Survey of India (2002): Geothermal energy resources of India.
2 A. Absar, R. Shanker, B. L. Jangi, A. K. Bajaj, R. K. Aggarwal and G. K. Gupta (1996): Chemical variations in thermal discharges from Satluj and Spiti valleys, Himachal Pradesh, India - a conceptual geochemical model. GSI. Spl. Pub., (45), 169-182.
3 D. Chandrasekharam, M. A. Alam and A. Minissale (2005): Thermal discharges at Manikaran, Himachal Pradesh, India. Proc. W.G.C., 2005, 1-4.
4 D. Chinti, L. Pizzino, N. Voltattorni, F. Quattrocchi and V. Walia (2009): Geochemistry of thermal waters along fault segments in the Beas and Parvati valleys (north-west Himalaya, Himachal Pradesh) and in the Sohna town (Haryana), India. Geochemical Jour., vol. 43. 65-76.
5 R. Shanker, A. Absar and G. C. Sfuvastava (1999): Geochemistry and origin of geothermal systems of northwest Himalaya. 21st New Zealand Geothermal Workshop. 73-
6 SNC and JETRO (2010): Study on geothermal power development project at Uttarakhand State in India.

Source: GSI (2002), Geothermal energy resources of India

(1) Jammu & Kashmir State

The relation among major anions (Cl^-, $SO_4^{2-}$and HCO_3^-) dissolved in hot water samples from Jammu & Kashmir State is given in Fig. IV-3. The major anions in most of the hot waters are HCO_3^- and Cl^-. Hot waters from Chhumathang, Gaik, Panamik, Changlung and Galhar are classified as HCO_3 type water. Hot waters from Puga and Sidhu are classified into mixed type water and Cl-HCO_3 type water, respectively. Their B/Cl molar ratios are larger than 0.1 (see Fig. IV-4), indicating that these hot waters have been affected by sedimentary rocks or formations originating from sedimentary rocks.

The reservoir temperatures estimated from chemical geothermometry of the hot waters are given in Table IV-2. The validity of alkaline geothermometry depends on whether the chemical composition of the hot water reaches dissolution equilibrium under subsurface temperature conditions or not. As shown in Fig. IV-5, hot waters from Gaik, Changlung, Sidhu and Galhar do not reach equilibrium, remaining in an immature condition. Therefore, it should be kept in mind that temperatures calculated by alkaline geothermometry are uncertain. On the other hand, hot waters from Puga, Chhumathang and Panamik containing Mg in low concentrations can be regarded as having reached dissolution equilibrium. Since hot waters from Puga and Chhumathang in an immature condition yield a similar Na/K ratio, it is thought that the temperature calculated by alkaline geothermometry is reliable. From alkaline geothermometry, reservoir temperatures exceeding 200°C, around 210°C, and around 170°C will be expected in Puga, Chhumathang and Panamik, respectively. Consideration of the calculated temperatures shows that there is a possibility that hot waters with a temperature exceeding 100°C are present in Changlung and Sidhu.

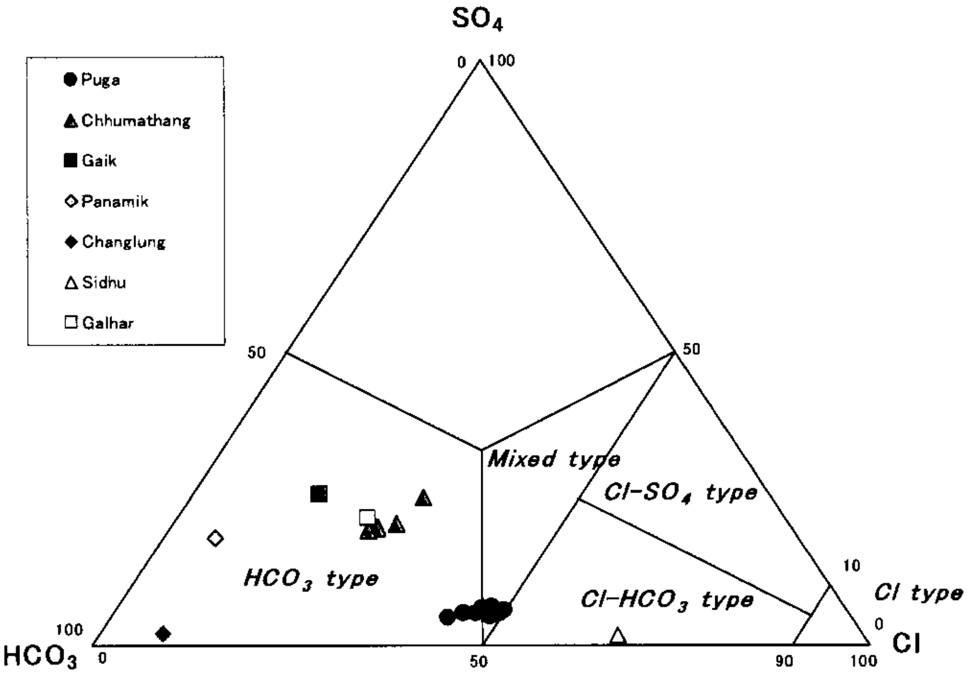


Fig. IV-3 Trilinear Plot of Major Anions in Hot Water from Jammu and Kashimir

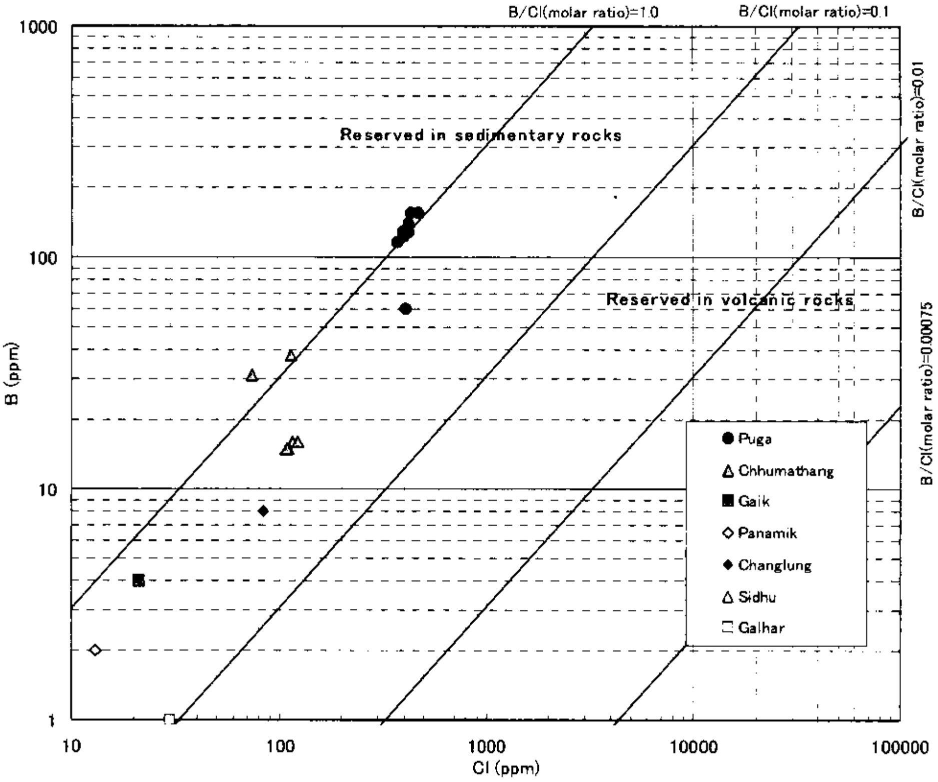


Fig. IV-4 Relation between B and Cl Concentrations in Hot Water from Jammu and Kashimir

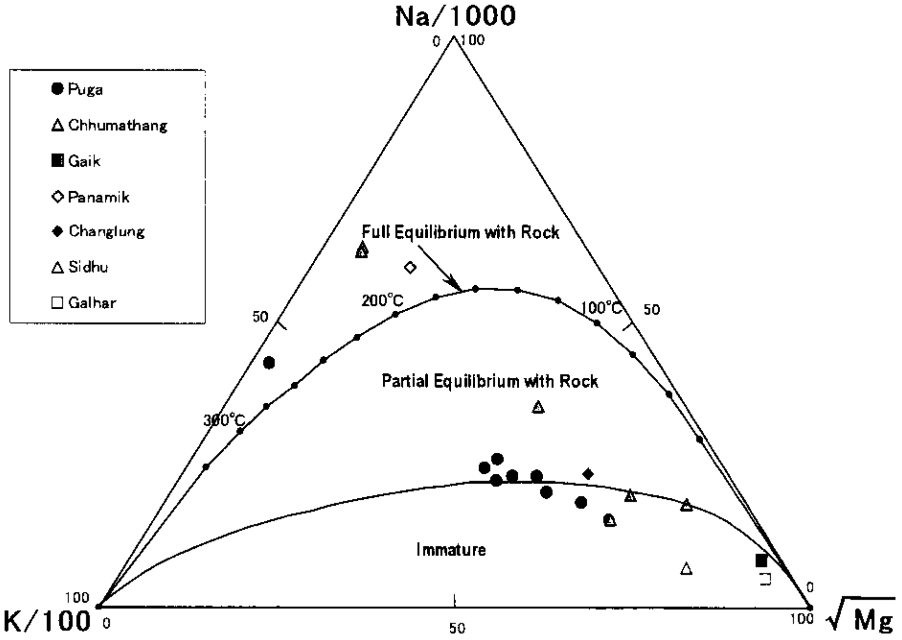
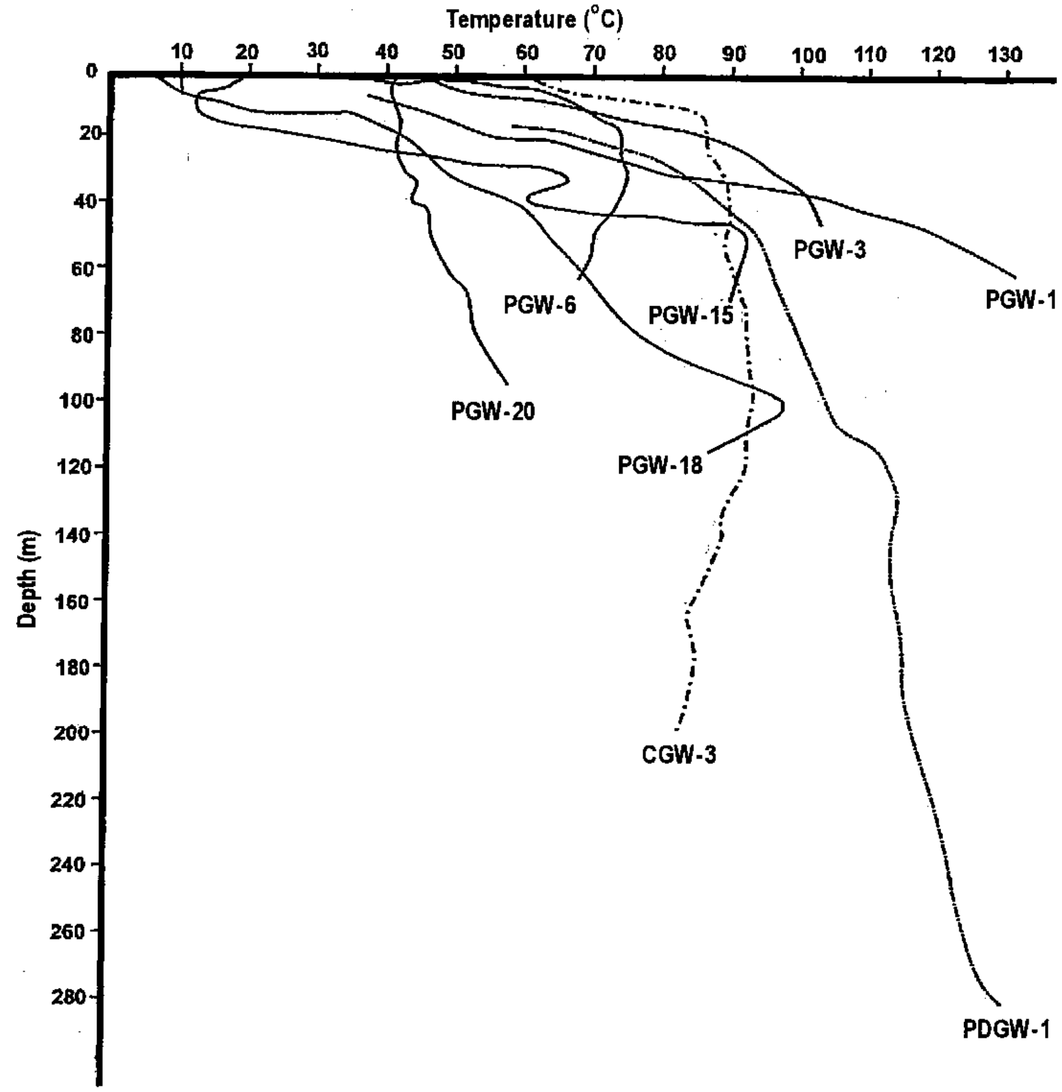


Fig. IV-5 Ternary Plot of Major Cations in Hot Water from Jammu and Kashimir

Table IV-2 Temperatures Estimated from Chemistry of Hot Water from Jammu and Kashmir

Location	Temp. (°C)	Geothermometer (°C)											
		$TSiO_2$						TNa-K			TNa-K-Ca	T(Na-K-Ca)-dMg	TK-Mg
		quartz (adiavatic)	quartz (conductive)	chalcedny	α cristobalite	β cristobalite	amorphous	Truesdell	Fournier	Giggenbach			
Puga	84	178	192	173	143	93	68	**236**	**254**	**267**	246	246	158
	80	145	152	127	102	53	31	**208**	**233**	**247**	241	241	158
	70	141	148	122	97	48	26	**216**	**239**	**253**	220	220	332
	80	139	144	118	94	45	23	**225**	**246**	**259**	213	213	162
	84	141	148	122	97	48	26	**221**	**243**	**256**	240	240	154
	67	158	167	144	117	68	44	**221**	**243**	**256**	223	223	145
	81	141	148	122	97	48	26	**223**	**245**	**258**	223	223	130
	80	145	152	127	102	53	31	**207**	**232**	**246**	242	242	147
	63	152	160	136	110	61	38	**214**	**238**	**251**	218	218	137
Chhumathang	83	153	162	138	112	62	39	**137**	**176**	**194**	182	182	143
	73	149	157	133	107	57	35	**116**	**158**	**177**	160	160	99
	77	141	148	122	97	48	26	**220**	**242**	**256**	213	213	130
	84	133	137	110	87	38	17	**123**	**164**	**182**	166	166	249
	70	133	137	110	87	38	17	**126**	**166**	**184**	152	152	249
	74	137	143	116	92	43	22	**165**	**199**	**215**	135	131	121
Gaik	60	122	125	97	74	26	6	90	135	155	78	53	66
Panamik	76	133	138	111	87	39	17	**114**	**156**	**175**	95	95	196
Changlung	66	145	152	127	102	53	31	168	201	218	199	199	132
Sidhu	65	81	77	45	27	-18	-35	277	285	294	150	150	112
Galhar	60	89	86	55	36	-10	-28	154	190	207	70	28	73

Some geothermal wells have been drilled in Puga and Chhumathang. Their temperature profiles are given in Fig. IV-6. The wells drilled in Puga are 28.5 m to 384.7 m deep. The highest temperature (130.37°C) was measured in well GW-1. Moreover, temperatures of 120°C at a depth of 92.5 m and 127°C at a depth of 280 m were measured in GW-18 and DGW-1. The six wells drilled in Chhumathang are 20 m to 221 m deep. Four of the wells are artesian, and the highest temperature of discharged hot water was 109°C.



Legend PGW, PDGW: Geothermal Well at Puga CGW: Geothermal Well at Chhumathang

Fig. IV-6 Temperature Profile of Geothermal Wells in Jammu and Kashmir

(2) Himachal Pradesh State

The relation among major anions (Cl^-, SO_4^{2-} and HCO_3^-) dissolved in hot water samples from Himachal Pradesh State is given in Fig. IV-7. Most of the hot waters from Manikaran-Kasol are classified as mixed type water. Hot water from Tapri is plotted around mixed type water, and hot waters from Tattapani are classified as Cl type water and HCO_3 type water. Hot water from Jeori is classified as Cl-HCO_3 type water.

B/Cl molar ratios in hot waters from Manikaran-Kasolare and Tapri are larger than 0.1 (see Fig. IV-8), indicating that these hot waters have been affected by sedimentary rocks or formations originating from sedimentary rocks. On the other hand, hot waters from Tattapani and Jeori, with a high concentration of Cl, have B/Cl ratios smaller than 0.1, indicating that these hot waters may have been affected by volcanic rocks or formations originating from volcanic rocks. However, volcanic rocks have not been identified in these areas. The relation between the Na concentration and Cl concentration suggests an effect of seawater, as data are plotted around the line connecting seawater (Na = 10,714 ppm, Cl = 19,000 ppm) and freshwater (Na = Cl = 0 ppm). It is known that there is a salty formation around Tattapani. Therefore, it is likely that the chemical composition of hot waters in Tattapani and Jeori has been affected by the salty formation extending underground.

Reservoir temperatures estimated by chemical geothermometry of hot waters are given in Table IV-3. Reservoir temperatures exceeding 100°C are estimated in Manikaran-Kasol, Tattapani, Jeori and Tapri. The validity of alkaline geothermometry depends on whether the chemical composition of the hot water reaches dissolution equilibrium under subsurface temperature conditions or not. As shown in Fig. IV-10, most of the hot waters from Himachal Pradesh do not reach equilibrium, and remain in an immature condition, though hot waters from Tattapani plot into a partial equilibrium region. Therefore, it should be kept in mind that temperatures calculated by alkaline geothermometry are uncertain.

Eight geothermal wells were drilled in Manikaran to depths varying from 90.3 m to 250 m. In addition, two geothermal wells (497.1 m deep and 706.9 m deep) were drilled, and a temperature of 101°C at a depth of 40 m was measured in the 497.1 m-deep well. Seven of the wells are artesian, with temperatures of the discharged hot waters ranging from 70°C to 94°C. Eight geothermal wells were drilled in Kasol to depths between 12.67 m and 309 m. Three of the wells are artesian, and the temperatures of the discharged hot waters ranged from 53°C to 72°C.

Temperature profiles of the drilled wells are given in Fig. IV-11. Most of the wells have a profile of the following kind: temperature increases up to a certain depth but decreases beyond that depth. These profiles (temperature profiles of lateral flow type) are identified in a area where thermal water does not come up from the deeper part of the drilled area but comes from a different place. Therefore, for geothermal development in Manikaran-Kasol, it will be necessary to identify the origin of the thermal water flowing into the drilled area.

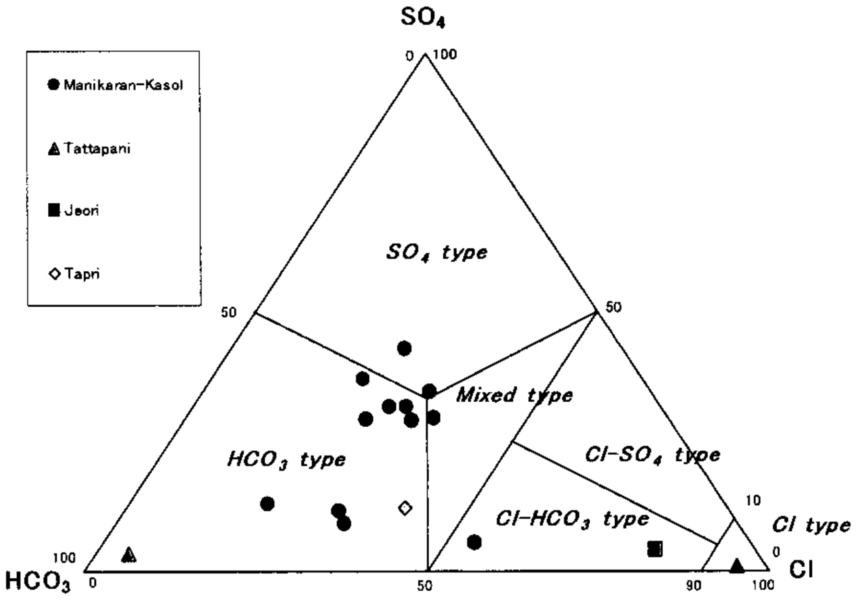


Fig. IV-7 Trilinear Plot of Major Anions of Hot Water from Himachal Pradesh

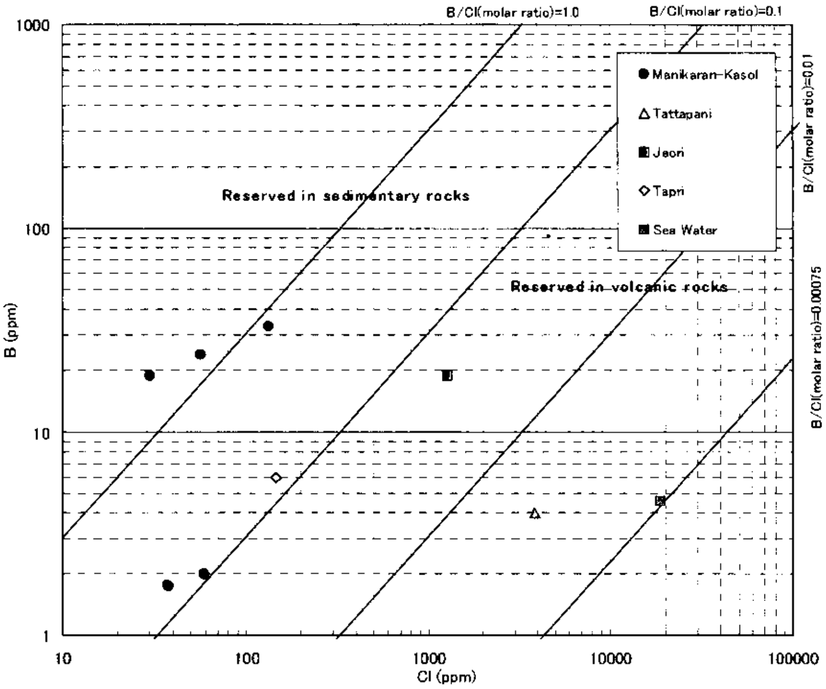


Fig. IV-8 Relation between B and Cl Concentrations in Hot Water from Himachal Pradesh

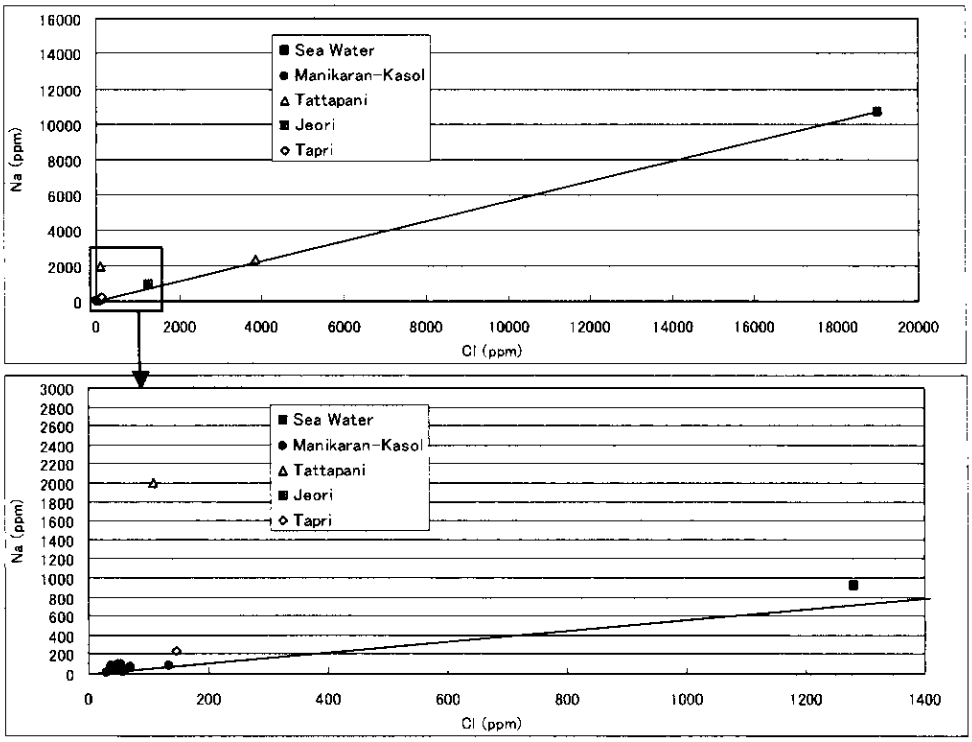


Fig. IV-9 Relation between Na and Cl Concentrations in Hot Water from Himachal Pradesh

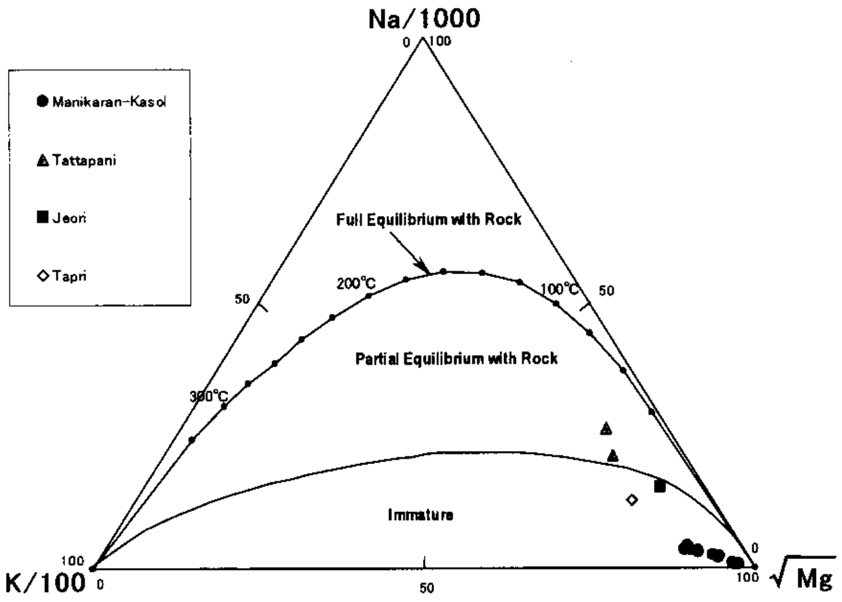


Fig. IV-10 Ternary Plot of Major Cations in Hot Water from Himachal Pradesh

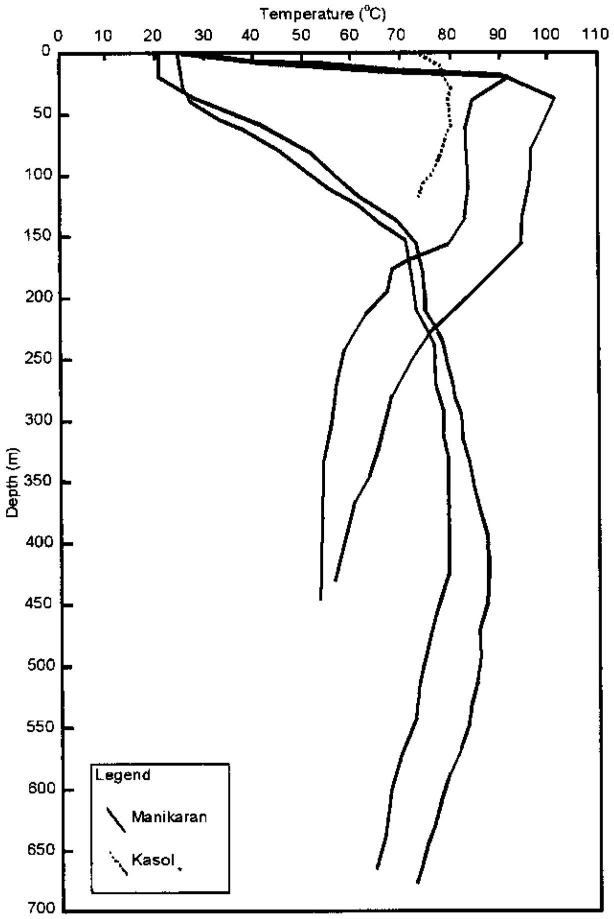


Fig. IV-11 Temperature Profile of Geothermal Wells in Manikaran and Kasol

Table IV-3 Temperatures Estimated from Chemistry of Hot Water from Himachal Pradesh

Location	Temp. (°C)	Geothermometer (°C)											
		$TSiO_2$						TNa-K			TNa-K-Ca	T(Na-K-Ca)-dMg	TK-Mg
		quartz (adiavatic)	quartz (conductive)	chalcedny	α cristobalite	β cristobalite	amorphous	Truesdell	Fournier	Giggenbach			
Manikaran-Kasol	96	110	111	81	60	13	-7	289	293	302	102	102	78
	77	83	79	48	30	-16	-33	368	348	351	63	38	64
	73	117	118	90	68	20	0	349	335	340	64	32	67
	82	94	92	61	42	-5	-23	380	356	358	43	43	62
	85	135	140	114	89	41	19	268	278	289	108	108	94
	86	135	139	113	89	40	19	290	294	303	100	97	90
	72	139	144	118	94	45	23	305	305	313	107	107	94
	73	140	146	120	96	47	25	305	305	313	107	107	90
	96	135	140	114	89	41	19	320	316	322	112	112	97
	78	126	129	101	78	30	10	277	285	294	81	67	76
	89	108	109	79	58	11	-8	273	282	292	95	74	94
	77	108	108	78	57	10	-9	281	288	297	85	67	82
Tattapani	61	92	89	59	39	-7	-25	97	141	160	158	158	106
	60	103	102	72	51	5	-14	123	164	182	175	175	109
Jeori	60	124	127	99	76	28	8	112	155	174	138	138	92
Tapri	73	156	165	142	115	66	42	183	213	229	136	136	109

(3) Uttarakhand State

The relation among major anions (Cl^-, $SO_4^{2-}$and HCO_3^-) dissolved in hot water samples from Uttarakhand State is given in Fig. IV-12. Hot water from Yamnotri has a relatively high concentration of Cl (170 ppm) and is classified as mixed type water. Hot waters from the other areas are classified as HCO_3 type water. However, hot waters from Beda and Gari have a relatively high concentration of Cl (139 ppm and 141 ppm, respectively). Their B/Cl molar ratios are larger than 0.1 (see Fig. IV-13), indicating that these hot water have been affected by sedimentary rocks or formations originating from sedimentary rocks.

Reservoir temperatures estimated from the chemical geothermometry of hot water are given in Table IV-4. The validity of alkaline geothermometry depends on whether the chemical composition of the hot water reaches dissolution equilibrium under subsurface temperature conditions or not. Hot waters from Uttarakhand, excepting Beda, do not reach equilibrium, but remain in an immature condition (see Fig. IV-14). Therefore, it should be kept in mind that temperatures calculated by alkaline geothermometry are uncertain, except for those from Beda. On the other hand, hot water from Beda can be regarded as being in dissolution equilibrium. From alkaline geothermometry, reservoir temperatures of around 200°C will be expected in Beda. Calculated Na-K-Ca temperatures suggest the possibility that there are hot waters with a temperature exceeding 100°C in Yamnotri, Gangnani, Khirao, Gari, Juma and Balati.

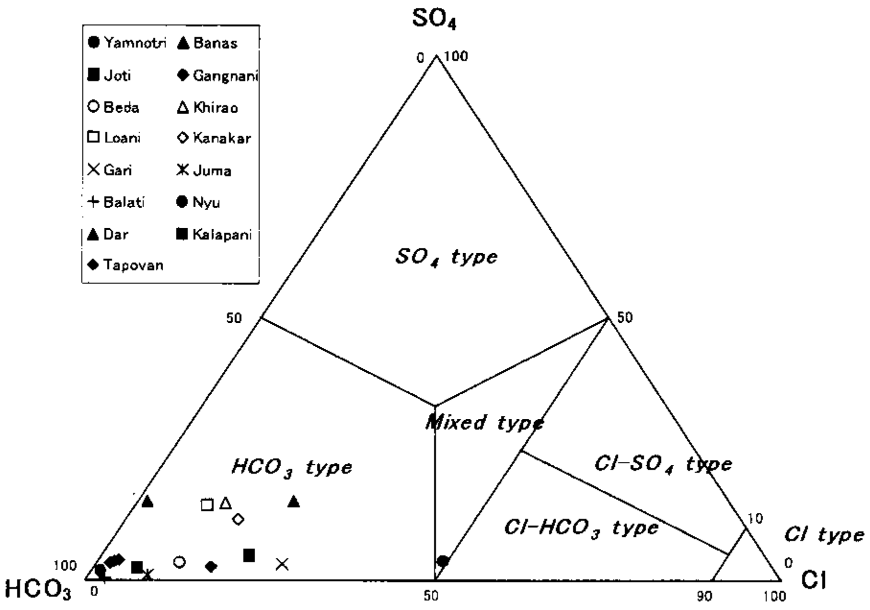


Fig. IV-12 Trilinear Plot of Major Anions in Hot Water from Uttarakhand

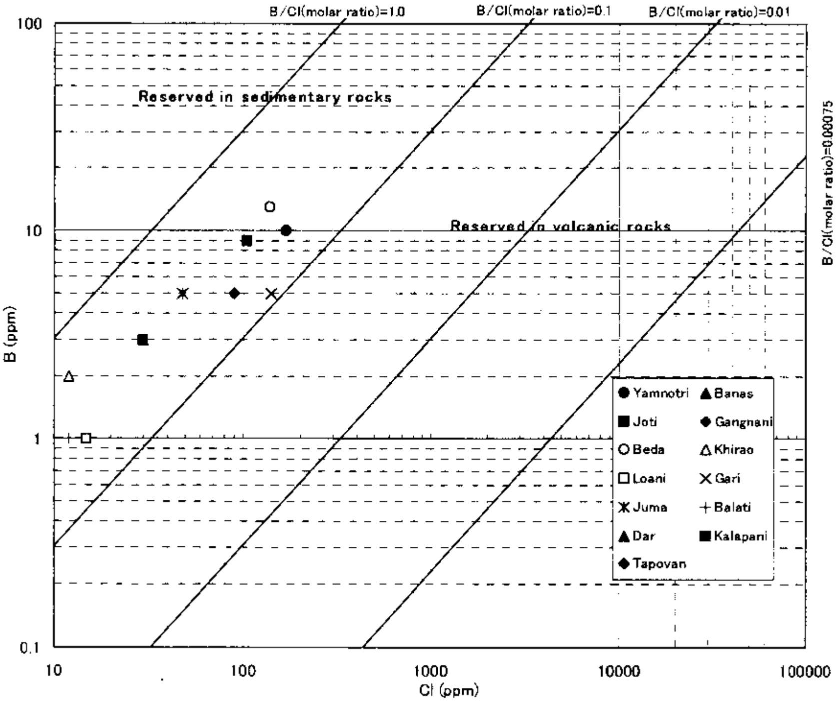


Fig. IV-13 Relation between B and Cl Concentrations in Hot Water from Uttarakhand

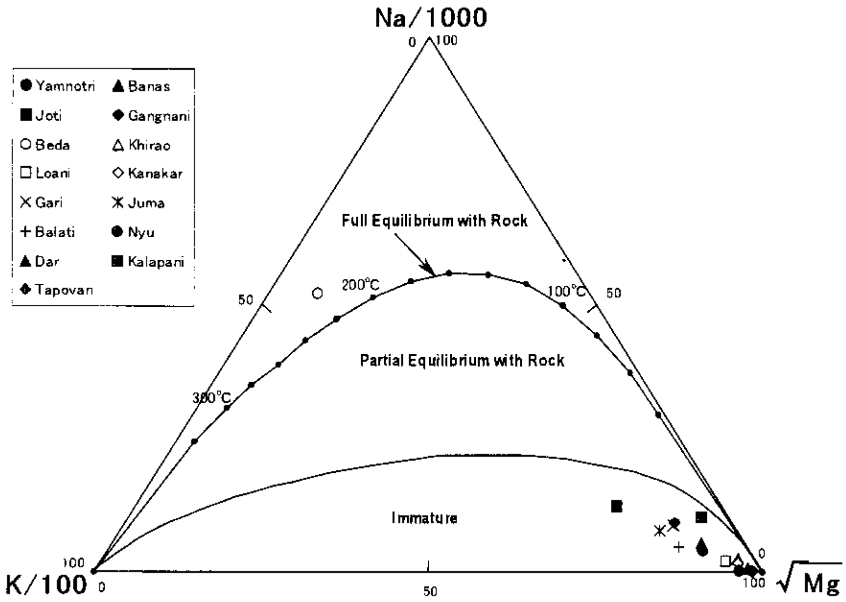


Fig. IV-14 Ternary Plot of Major Cations in Hot Water from Uttarakhand

Table IV-4 Estimated Geothermometric Temperature of Hot Water from Uttarakhand

Location	Temp. (°C)	Geothermometer (°C)											
		$TSiO_2$						TNa-K			TNa-K-Ca	T(Na-K-Ca)-dMg	TK-Mg
		quartz (adiavatic)	quartz (conductive)	chalcedny	α cristobalite	β cristobalite	amorphous	Truesdell	Fournier	Giggenbach			
Yamnotri	90	124	127	99	76	28	8	256	270	281	119	119	89
Banas	73	103	102	72	51	5	-14	301	302	310	61	52	57
Joti	65	109	110	80	59	12	-7	217	240	254	221	221	118
Gangnani	61	134	138	112	88	39	18	176	207	223	180	180	96
Beda	94	153	161	137	111	61	39	163	197	214	209	209	248
Khirao	60	122	125	97	74	26	6	179	210	226	125	125	62
Loani	61	99	98	68	48	1	-17	281	287	297	91	91	76
Kanakar	81	72	67	35	18	-27	-43	250	265	277	53	53	65
Gari	61	98	97	67	47	0	-18	192	220	235	207	207	98
Juma	62	128	132	105	81	33	12	234	253	266	194	194	106
Balati	68	145	152	127	102	53	31	285	291	300	130	130	101
Nyu	77	107	107	78	57	10	-9	1107	704	646	78	78	70
Dar	79	132	137	110	86	37	16	200	227	242	109	109	87
Kalapani	62	127	130	103	80	31	11	126	166	185	110	110	84
Tapovan	94	121	124	96	73	25	5	465	409	404	46	15	52
	80	108	108	79	58	10	-9	457	404	400	34	34	49
	67	109	110	80	59	12	-7	482	419	413	35	35	50
	60	111	112	83	62	14	-5	471	413	408	35	35	49

IV-1-2 Geothermal Resources in the Western Region

There are seven hot spring areas in the Western Region where there are hot springs with a temperature not lower than 60°C and whose chemical composition has been described: three areas in Gujarat State, three areas in Maharashtra State and one area in Chhattisgarh State. Their locations and chemical data for the hot waters are given in Fig. IV-15 and Table IV-5, respectively. Hot spring areas where there are hot springs with a temperature not lower than 80°C are Cambay (100°C, Gujarat) and Tattapani (62°C to 98°C, Chhattisgarh).

The three hot spring areas in Gujarat where there are hot springs with a temperature not lower than 60°C and whose chemical composition has been described are Tulsi Shyam, Cambay and Tuwa. The relation among the major anions (Cl^-, $SO_4^{2-}$and HCO_3^-) dissolved in hot water samples from Gujarat State is given in Fig. IV-16, though hot water from Tuwa is not included in this diagram because of its lack of an HCO_3 concentration. Hot waters from Tulsi Shyam and Cambay are classified as Cl-HCO_3 type water. Concentrations of Cl in these hot waters are quite high (Tulsi Shyam = 450 ppm, Cambay = 2,428 ppm). The relation between the Na concentration and Cl concentration suggests an effect of seawater, as data are plotted around the line connecting seawater and freshwater, and it is considered that the chemical composition of these hot waters is affected by seawater. Due to a lack of a concentration of K in the hot water, alkaline thermometry cannot be applied to the hot water from Tuwa. Hot waters from Tulsi Shyam and Cambay do not reach equilibrium, but remain in an immature condition (see Fig. IV-18). Therefore, it should be kept in mind that temperatures calculated by alkaline geothermometry are uncertain. However, it is possible that there are hot waters with a temperature exceeding 100°C in Tulsi Shyam, considering the calculated Na-K-Ca temperature. The chemical data on hot waters from Gujarat were not sufficient to evaluate reservoir temperature, and a supplemental geochemical survey of its hot springs will be required.

Three hot spring areas in Maharashtra where there are hot springs with a temperature not lower than 60°C and whose chemical composition has been described are Rajwadi, Tural and Khed. The relation among the major anions (Cl^-, $SO_4^{2-}$and HCO_3^-) dissolved in hot water samples from Maharashtra State is given in Fig. IV-16. Hot waters from Rajwadi and Tural are classified as Cl-SO_4 type water, and hot water from Khed is classified as Cl type water. Concentrations of Cl in these hot waters are quite high (Rajwadi = 376 ppm, Tural = 375 ppm and Khed = 1,065 ppm). The relation between Na concentration and Cl concentration suggests an effect of seawater, as data are plotted around the line connecting seawater and freshwater (see Fig. IV-17), and it is considered that the chemical composition of these hot waters is affected by seawater. These hot waters do not reach equilibrium, but remain on the boundary between an immature condition and a partial equilibrium condition (see Fig. IV-18). Therefore, it should be kept in mind that temperatures calculated by alkaline geothermometry are uncertain, The chemical data on hot waters from Maharashtra were not sufficient to evaluate reservoir temperature, and a supplemental geochemical survey of its hot springs will be required.

Hot spring waters from Tattapani, Chhattisgarh, have a relatively high concentration of HCO_3 (177 to 213 ppm) and are classified as HCO_3 type water (see Fig. IV-16). Their B/Cl molar ratios are around 0.024 (see Fig. IV-19), indicating that these hot waters have been affected by volcanic rocks or formations originating from volcanic rocks. As there is Proterozoic gneiss and granite in this area, relatively low B/Cl molar ratios will result from the effect of these rocks. One water sample from Tattapani is plotted around the equilibrium curve (see Fig. IV-18) and the other two samples have similar Na/K ratios to the sample in equilibrium condition. Therefore, a reservoir temperature of around 160°C will be expected in Tattapani (see Table IV-5). Temperature profiles of geothermal wells drilled this area are shown in Fig. IV-20. A temperature of 112°C at a depth of 480 m was measured in well No. 6 and a temperature of 110°C , around depths of 100 m and 300 m in well No. 4A.

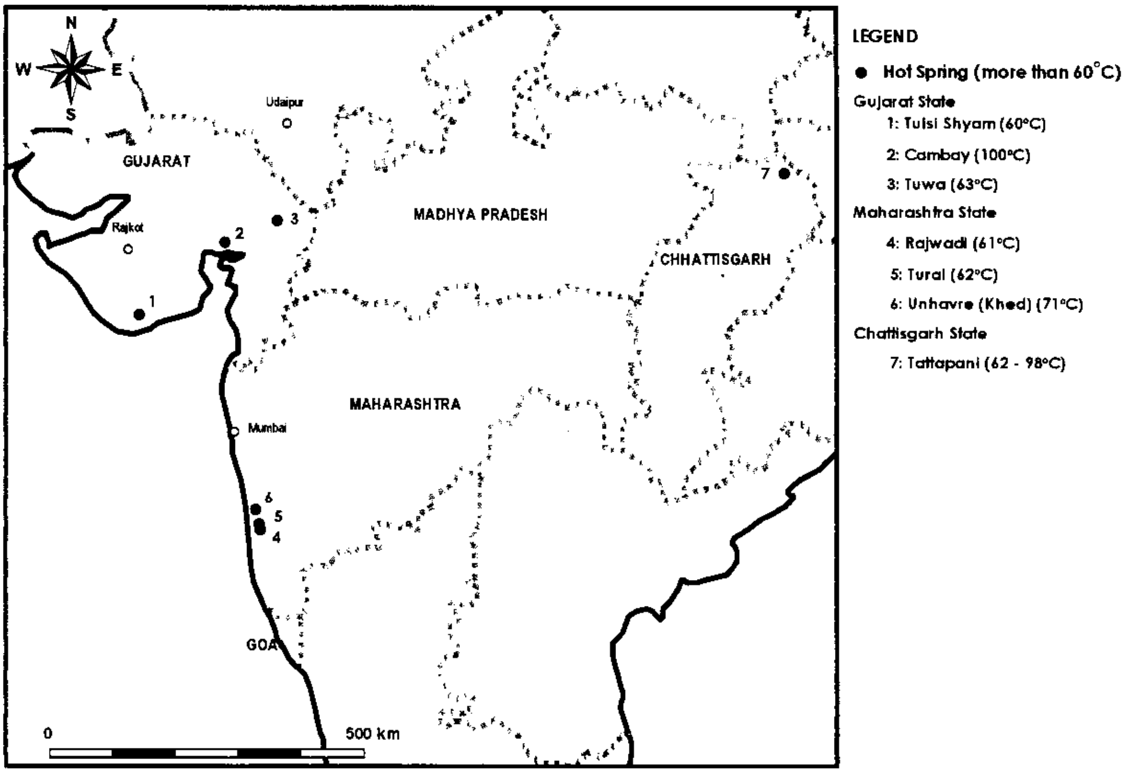


Fig. IV-15 Major Hot Springs in the Western Region

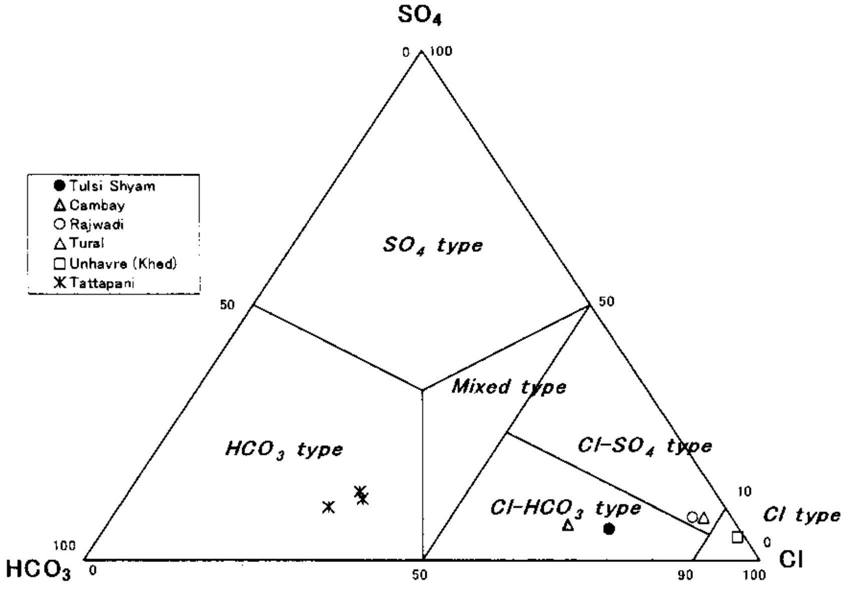


Fig. IV-16 Trilinear Plot of Major Anions in Hot Water from the Western Region

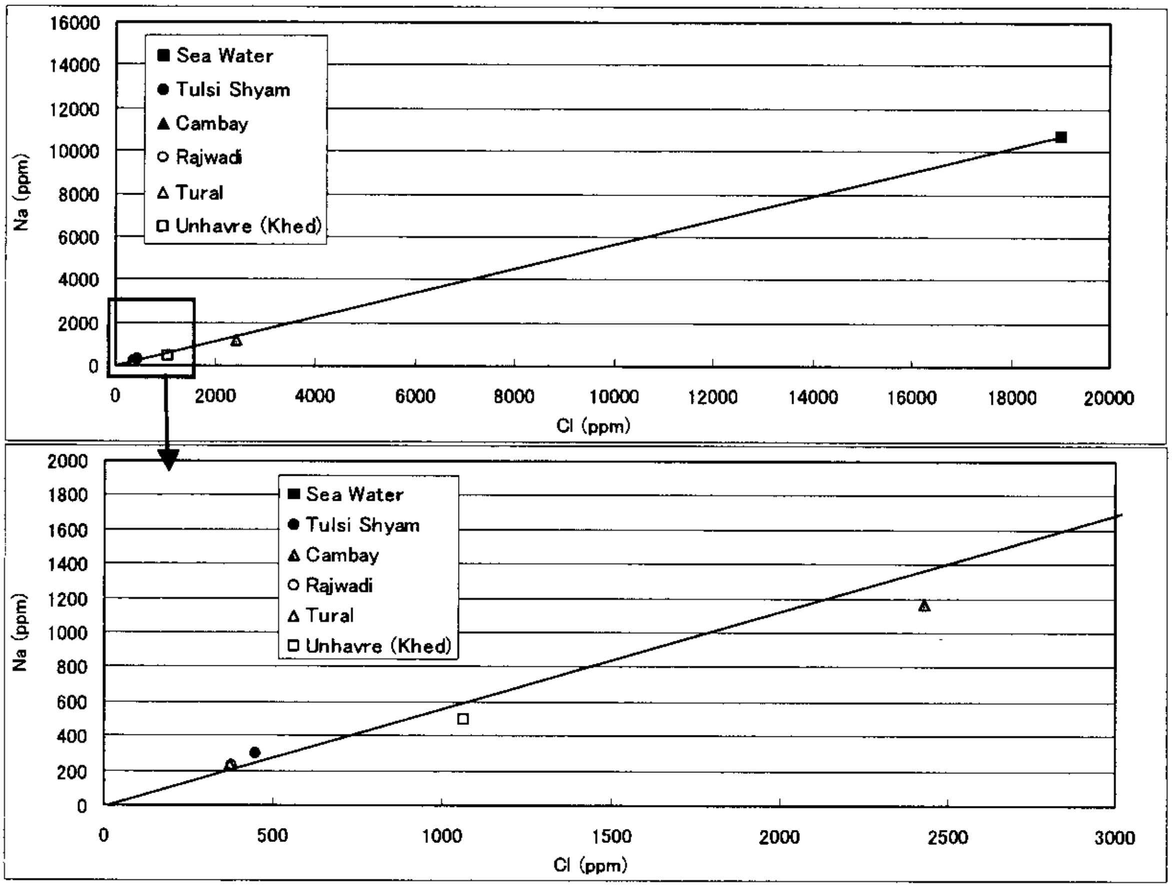


Fig. IV-17 Relation between Na and Cl Concentrations in Hot Water from Gujarat and Maharashtra

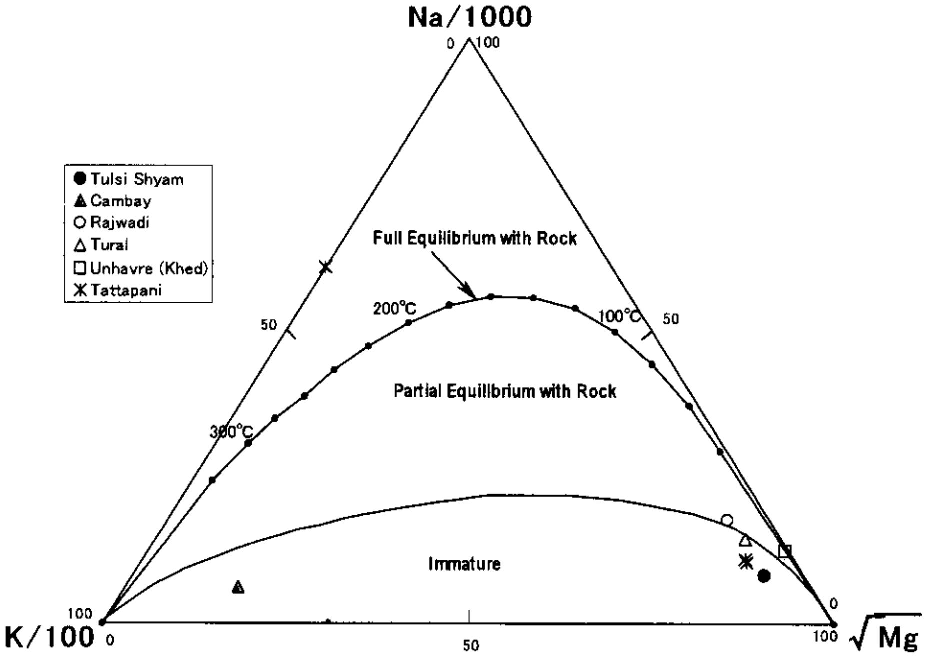


Fig. IV-18 Ternary Plot of Major Cations in Hot Water from the Western Region

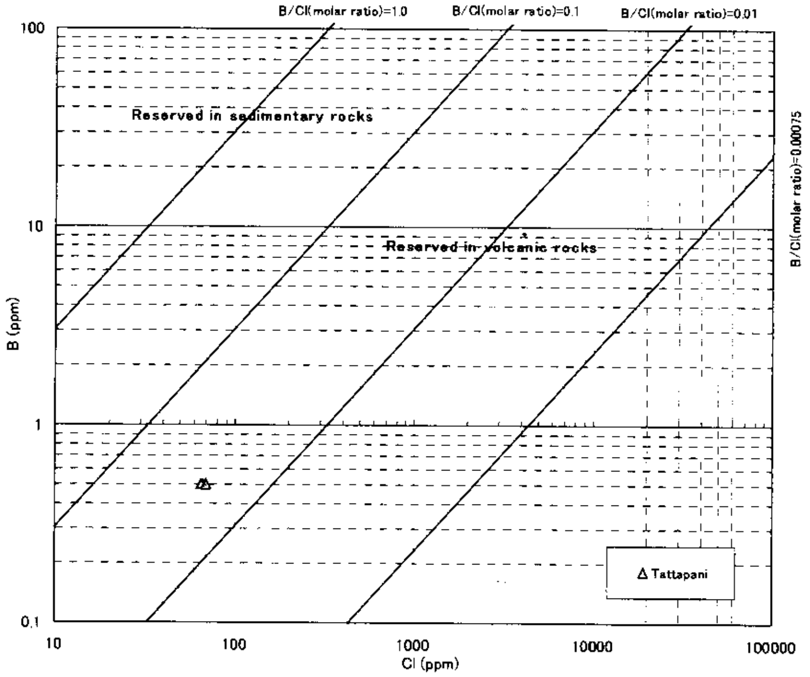


Fig. IV-19 Relation between B and Cl Concentrations in Hot Water from Tattapani

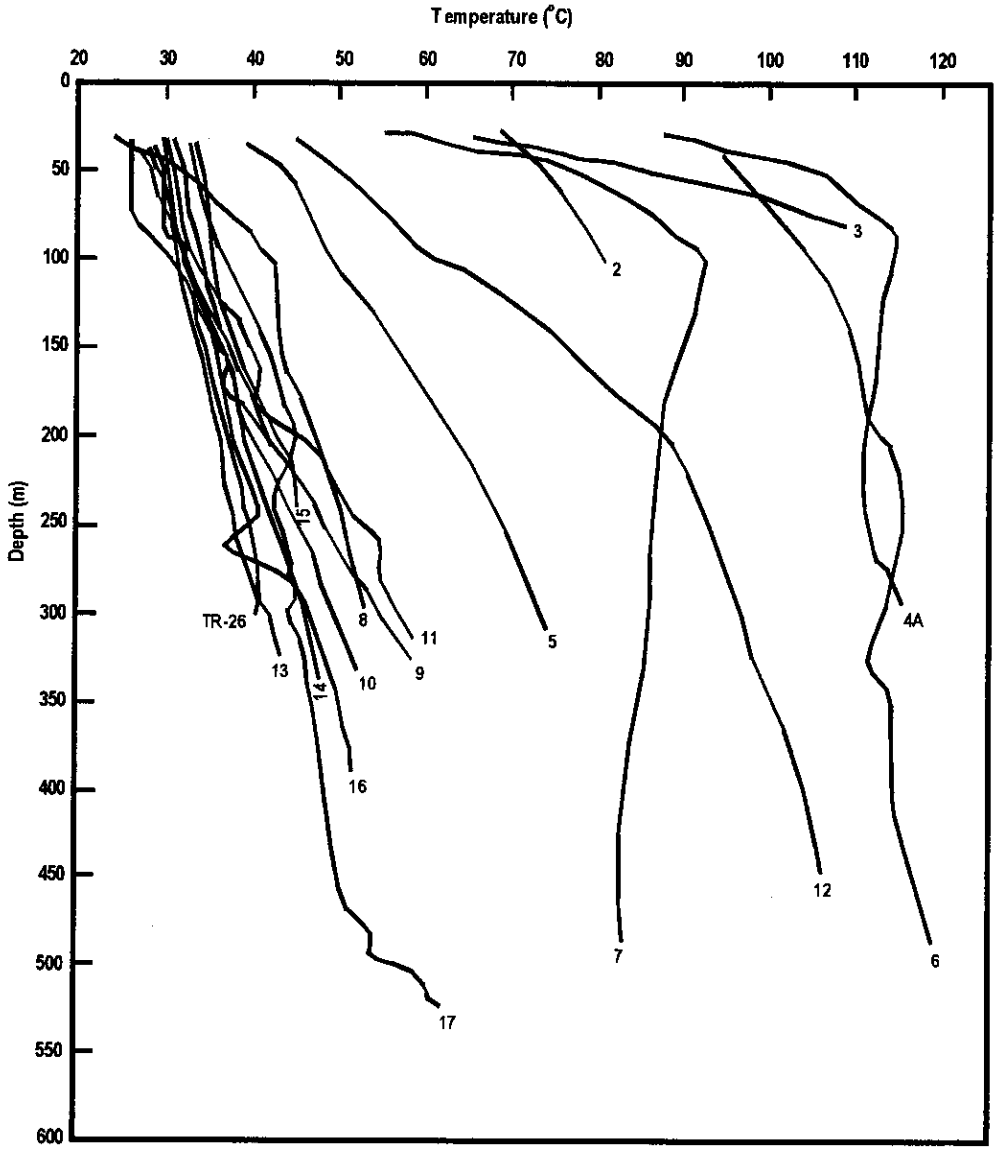


Fig. IV-20 Temperature Profile of Geothermal Wells in Tattapani

Table IV-5 Chemical Composition of Hot Spring Waters in the Western Region

Location	Temp. (°C)	ph	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	F (mg/l)	B (mg/l)	SiO_2 (mg/l)	Remarks	Reference
Gujarat State														
Tulsi Shyam	60	7	300	20	75	10	450	100	200	4	1	110		1
Cambay	100		1167	1451	9	8	2428	672	1534				Drilled Hole	1
Tuwa	63	7.6			505	14	2500	265				30		1
	63		126		508	13		188		0.8		78		1
Maharashtra State														
Rajwadi	61	7.7	238	7.6	52	1.05	376	100	43.7	4	<0.5	82		1
Tural	62	7.6	231	7.8	56	1.63	375	100	30.6	4	<0.5	122		1
Unhavre (Khed)	71	7.7	500	2	180	12	1065	136	20	2	<0.5	60		1
Chattisgarh State														
Tattapani	91		133	8	3	1	67	70	177	3	0.5	96		1
	62		126	8	3	1	65	60	213	3	0.5	60		1
	98		124	8	4	0	70	64	180	3	0.5	104		1

Reference

1 Geological Survey of India (2002): Geothermal energy resources of India.

Table IV-6 Estimated Geothermometric Temperature of Hot Water from the Western Region

Location	Temp. (°C)	Geothermometer (°C)											
		T_{SiO_2}						TNa-K			TNa-K-Ca	T(Na-K-Ca)-dMg	TK-Mg
		quartz (adiavatic)	quartz (conductive)	chalcedny	α cristobalite	β cristobalite	amorphous	Truesdell	Fournier	Giggenbach			
Tulsi Shyam	60	137	143	116	92	43	22	148	185	202	106	106	84
Cambay	100							849	603	567	476	476	244
Rajwadi	61	124	126	99	76	28	7	90	135	155	78	50	88
Tural	62	142	149	123	98	49	27	94	139	158	77	46	83
Unhavre (Khed)	71	110	111	81	60	13	-7	-10	40	62	25	25	33
Tattapani	91	131	135	108	84	36	15	139	177	195	166	166	90
Tattapani	62	110	111	81	60	13	-7	143	181	198	146	146	90
Tattapani	98	135	139	113	89	40	19	145	182	200	166		

IV-1-3 Geothermal Resources in the Southern and Eastern Regions

There are six hot spring areas in the Southern and Eastern Regions where there are hot springs with a temperature not lower than 60°C and whose chemical composition has been described; one area in Andhra Pradesh State, one area in Jharkhand State and four areas in West Bengali State. Their locations and chemical data for the hot waters are given in Fig. IV-21 and Table IV-7, respectively. There is no hot spring area with hot spring temperatures above 80°C.

The relation among the major anions (Cl^-, $SO_4^{2-}$and HCO_3^-) dissolved in hot water samples from the Southern and Eastern Regions is given in Fig. IV-22. Hot water from Agnigundala in Andhra Pradesh has a relatively high Cl concentration (430 ppm) and SO_4 concentration (146.5 ppm), and this water is classified as Cl-SO_4 type water. Hot water from Tatta in Jharkhand is classified as mixed type water. Hot waters from Agnikund, Kharkund and Bara Palasi in West Bengal have quite low SO_4 concentrations (0.01 to 0.04 ppm). Hot water from Agnikund has a relatively high Cl concentration (100 ppm), and is classified as Cl-HCO_3 type water. Hot water from Kharkund is also classified as Cl-HCO_3 type water, but hot water from Bara Palasi is classified as HCO_3 type water. On the other hand, hot water from Tantloi has a relatively high SO_4 concentration (39 ppm) and is classified as Cl-SO_4 type water.

Reservoir temperatures estimated by geothermometry are given in Table IV-8. The validity of alkaline geothermometry depends on whether the chemical composition of the hot water reaches dissolution equilibrium under subsurface temperature conditions or not. Hot waters from Agnigundala, Agnikund and Kharkund do not reach equilibrium, but are plotted around the boundary between an immature condition and a partial equilibrium condition (see Fig. IV-23). Therefore, it should be kept in mind that temperatures calculated by alkaline geothermometry are uncertain. As the Mg concentrations in hot waters from Tatta and Bara Palasi are described as "trace" (no numerical value is given), these hot waters cannot be plotted in Fig. IV-23. Considering the calculated Na-K-Ca temperature, it is possible that there are hot waters with a temperature exceeding 100°C in Agnigundala, Tatta and Agnikund.

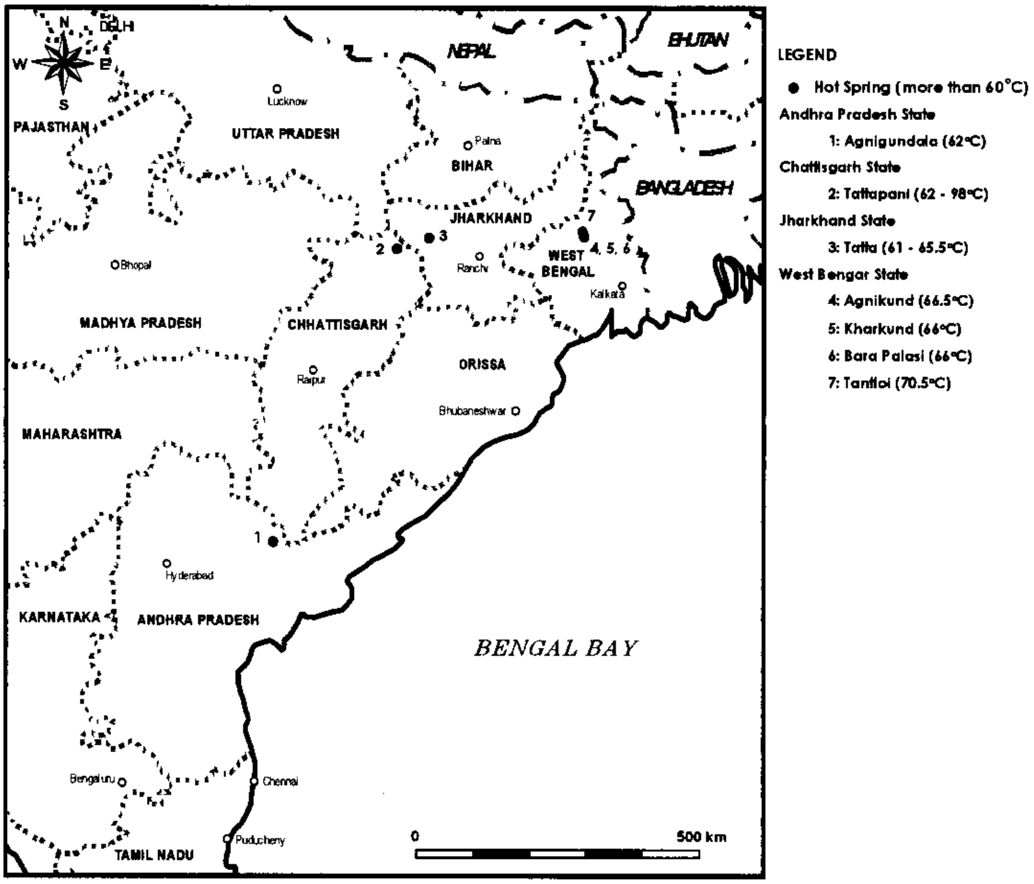


Fig. IV-21 Major Hot Springs in the Southern and Eastern Regions

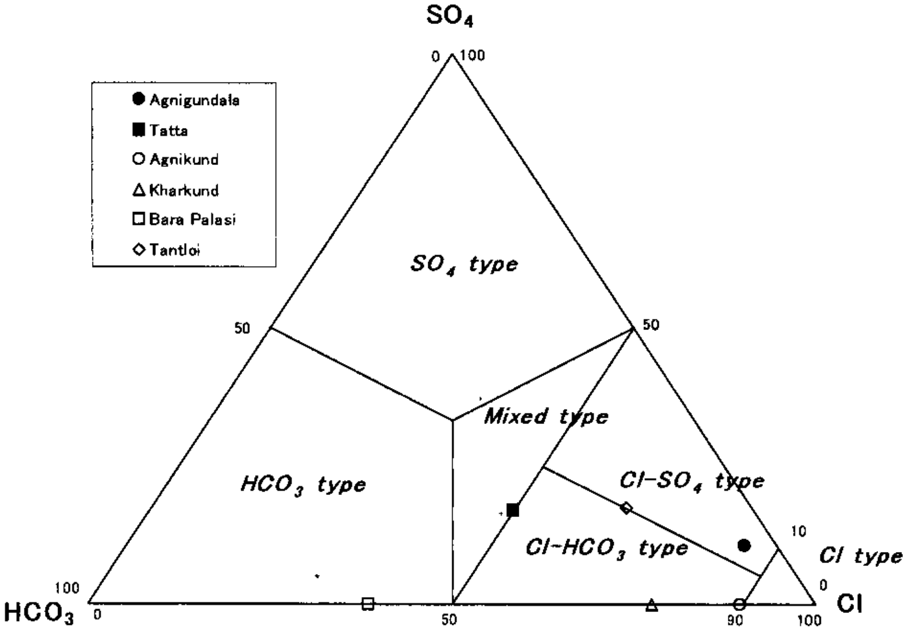


Fig. IV-22 Trilinear Plot of Major Anions in Hot Water from the Southern and Eastern Regions

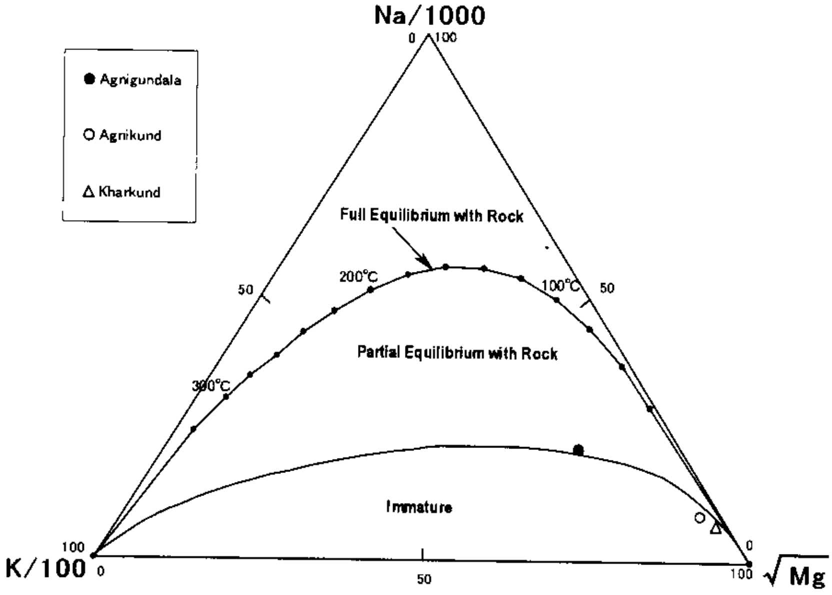


Fig. IV-23 Ternary Plot of Major Cations in Hot Water from the Southern and Eastern Regions

Table IV-7 Chemical Composition of Hot Spring Waters in the Southern and Eastern Regions

Location	Temp. (°C)	ph	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	F (mg/l)	B (mg/l)	SiO_2 (mg/l)	Remarks	Reference
Andhra Pradesh State														
Agnigundala	62	7.5	321	23.6	32.5	0.9	430	146.5	38	3.5		143		1
Jharkhand State														
Tatta	61- 65.5	7.62	162	5	8	tr	105	98	120			808		1
West Bengar State														
Agnikund	66.5	9.11	108	4.18	2	1.2	100	0.04	20	12		60		1
Kharkund	66	9.04	110	2.65	6	2	100	0.03	50	12		60		1
Bara Palasi	66	9.08	100	2	tr	tr	40	0.01	110	15		80		1
Tantloi	70.5	9.4	10	2	1	tr	53	39	24	11		275		1

Reference

1 Geological Survey of India (2002): Geothermal energy resources of India.

Table IV-8 Temperatures Estimated by Geothermometry for the Southern and Eastern Regions

Location	Temp. (°C)	Geothermometer (°C)											
		$TSiO_2$						TNa-K			TNa-K-Ca	T(Na-K-Ca)-dMg	TK-Mg
		quartz (adiavatic)	quartz (conductive)	chalcedny	α cristobalite	β cristobalite	amorphous	Truesdell	Fournier	Giggenbach			
Agnigundala	62	150	158	134	108	59	36	157	192	209	137	130	122
Tatta	61- 65.5	262	300	306	261	214	180	88	133	153	103	103	145
Agnikund	67	110	111	81	60	13	-7	104	147	166	127	127	72
Kharkund	66	110	111	81	60	13	-7	72	119	140	82	82	56
Bara Palasi	66	122	125	97	74	26	6	62	109	130			
Tantloi	71	187	203	185	154	104	78	277	285	294	86		

IV-1-4 Prospective Areas for Geothermal Power Development in India

(1) Proposed Prospective Areas

Prospective areas for geothermal power development in India were selected on the basis of identified temperatures, temperatures expected from the chemistry of thermal water and the present state of exploration of each field. It must be noted that the social and natural conditions affecting each field have not been considered in this selection. Social and natural conditions, however, are fundamental factors that need to be considered together with resource potential in evaluating the possibility of realizing a geothermal power project. Therefore, research on the social and natural conditions in the proposed prospective areas is required before the planning of geothermal exploration can be undertaken.

Among the 39 areas described in the sections above, the following nine areas can be regarded as the most prospective ones (where the highest temperatures are not lower than 80°C):

- Puga (Jammu & Kashmir State, 130.37°C)
- Tattapani (Chhattisgarh State, 112°C)
- Chhumathang (Jammu & Kashmir State, 109°C)
- Manikaran and Kasol (Himachal Pradesh State, 101°C)
- Cambay (Gujarat State, 100°C)
- Tapovan (Uttarakhand State, 94°C)
- Beda (Uttarakhand State, 94°C)
- Yamnotri (Uttarakhand State, 90 °C)
- Kanakar (Uttarakhand State, 81°C)

Among the areas where the highest identified temperatures are not lower than 60°C (though temperatures are lower than 80°C), a geothermal reservoir with a temperature exceeding 100°C will be expected in the following 17 areas:

- Joti (Uttarakhand State, 65°C, estimated temperature = about 240°C)
- Gari (Uttarakhand State, 61°C, estimated temperature = about 210°C)
- Changlung (Jammu & Kashmir State, 66°C, estimated temperature = about 200°C)
- Juma (Uttarakhand State, 62°C, estimated temperature = about 190°C)
- Gangnani (Uttarakhand State, 61°C, estimated temperature = about 180°C)
- Tattapani (Himachal Pradesh State, 60°C, estimated temperature = about 170°C)
- Sidhu (Jammu & Kashmir State, 65°C, estimated temperature = about 150°C)
- Jeori (Himachal Pradesh State, 60°C, estimated temperature = about 140°C)
- Agnigundala (Andhra Pradesh State, 62°C, estimated temperature = about 130°C)
- Tapri (Himachal Pradesh State, 73°C, estimated temperature = about 135°C)
- Balati (Uttarakhand State, 68°C, estimated temperature = about 130°C)
- Agnikund (West Bengar State, 66.5°C, estimated temperature = about 125°C)
- Khirao (Uttarakhand State, 60°C, estimated temperature = about 125°C)
- Kalapani (Uttarakhand State, 62°C, estimated temperature = about 110°C)
- Dar (Uttarakhand State, 79°C, estimated temperature = about 110°C)
- Tulsi Shyam (Gujarat State, 60°C, estimated temperature = about 105°C)
- Tatta (Jharkhand State, 65.5°C, estimated temperature = about 105°C)

From temperatures estimated by geothermometry, a geothermal reservoir with a temperature exceeding 200°C will be expected in the following five areas: Puga (about 240°C), Chhumathang (about 210°C), Beda (about 210°C), Joti (about 240°C) and Gari (about 210°C). It may be possible to achieve geothermal power generation in these five areas with a plant of a conventional type. On the other hand, geothermal power generation with a binary cycle type plant will be appropriate in the remaining 21 areas, as the expected reservoir temperatures are lower than 200°C.

Judging from the present situations of the above 26 areas, the following four areas can be regarded as being in the Resource Evaluation Phase (Phase 3) or Detailed Exploration Phase (Phase 2): Puga, Chhumathang, Tattapani (Chhattisgarh State) and Tapovan. And the following two areas can be regarded as being in the Detailed Exploration Phase (Phase 2): Manikaran & Kasol, and Cambay. The remaining 20 areas are in the Regional Exploration Phase (Phase 1). Taking into consideration the above-mentioned field exploration situations together with identified and estimated temperature conditions, proposed prospective areas for geothermal power development can be listed, as shown in Table IV-9. Although NGRI carried out MT surveying in Chhattisgarh State, Himachal Pradesh State, Jharkhand State and Uttarakhand State with the support of MNRE, the MT survey results are not considered in this study because the MT data were not made available for this study.

Table IV-9 Proposed Prospective Areas for Geothermal Power Development

Area	State	Present Status	Measured Maximum Temperature (°C)		Estimated Reservoir Tempemperature from Water Chemistry (°C)	Remarks
Puga	Jammu & Kashmir	Resource Evaluation Phase (Phase3) or Detailed Exploration Phase (Phase 2)	130.37	not lower than 80	213 - 246	
Chhumathang	Jammu & Kashmir		109		160 - 213	
Tattapani	Chhattisgarh		112		146 - 166	
Tapovan	Uttarakhand		94		Low accuracy of alkaline geothermometer, as low alkaline ions concentrations	
Manikaran Kasol	Himachal Pradesh	Detailed Exploration Phase (Phase 2)	101		43 -112	Relatively low alkaline ions concentrations = relatively low accuracy of alkaline geothermometer Drilled wells have temperature-profiles of lateral flow type
Cambay	Gujarat		100		not available	Data from 1 sample, additional survey will be required to check estimated temperature High salinity water, Alkaline ratio = water does not reach to resolved equilibrium
Beda	Uttarakhand	Regional Exploration Phase (Phase 1)	94		209	Data from 1 sample, additional survey will be required to check estimated temperature
Yamnotri	Uttarakhand		90		119	Data from 1 sample, additional survey will be required to check estimated temperature
Kanakar	Uttarakhand		81		Low accuracy of alkaline geothermometer, as low alkaline ions concentrations	Data from 1 sample Low alkaline ions concentrations = low accuracy of alkaline geothermometer Additional survey will be required to check estimated temperature
Joti	Uttarakhand		65	60 to 80	221	Data from 1 sample, additional survey will be required to check estimated temperature
Gari	Uttarakhand		61		207	Data from 1 sample, additional survey will be required to check estimated temperature
Changlung	Jammu & Kashmir		66		199	Data from 1 sample, additional survey will be required to check estimated temperature
Juma	Uttarakhand		62		194	Data from 1 sample, additional survey will be required to check estimated temperature
Gangnani	Uttarakhand		61		180	Data from 1 sample, additional survey will be required to check estimated temperature
Tattapani	Himachal Pradesh		60 - 61		158 - 175	High salinity water affected from salty formation Validity of alkaline geothermometer must be studied.
Sidhu	Jammu & Kashmir		65		150	Data from 1 sample, additional survey will be required to check estimated temperature
Jeori	Himachal Pradesh		60		138	Data from 1 sample, high salinity water affected from salty formation Validity of alkaline geothermometer must be studied.
Agnigundala	Andhra Pradesh		62		137	Data from 1 sample, additional survey will be required to check estimated temperature
Tapri	Himachal Pradesh		73		136	Data from 1 sample, additional survey will be required to check estimated temperature
Balati	Uttarakhand		68		130	Data from 1 sample, additional survey will be required to check estimated temperature
Agnikund	West Bengar		66.5		127	Data from 1 sample, additional survey will be required to check estimated temperature
Khirao	Uttarakhand		60		125	Data from 1 sample, additional survey will be required to check estimated temperature Low alkaline ions concentrations = low accuracy of alkaline geothermometer.
Kalapani	Uttarakhand		62		110	Data from 1 sample, additional survey will be required to check estimated temperature
Dar	Uttarakhand		79		109	Data from 1 sample, additional survey will be required to check estimated temperature
Tulsi Shyam	Gujarat		60		106	Data from 1 sample, additional survey will be required to check estimated temperature
Tatta	Jharkhand		61- 65.5		103	Data from 1 sample, additional survey will be required to check estimated temperature

☐	Area where temperature of 200°C or higher than 200°C will be expected.
☐	Area where temperature of 100°C to 200°C will be expected.

(2) Exploration required in proposed prospective areas

Areas in the Resource Evaluation Phase (Phase3) or Detailed Exploration Phase (Phase 2)

Puga (Jammu & Kashmir State)

Some geothermal exploration has been conducted, and slim holes (28.5 m to 384.7 m deep) were also drilled (maximum temperature = 130.37°C). A reservoir temperature of around 240°C will be expected from the alkaline geothermometry of the thermal water. Judging from these data, there is a geothermal reservoir with a temperature exceeding 200°C in a deeper portion of the field (deeper than bore hole bottoms of the previously drilled wells), though exactly how deep is still uncertain. It is possible that geothermal power generation with a conventional plant can be applied in this area. The following exploration and study will be proposed in preparation for the future geothermal power project. It must be noted that a supplementary survey will be required when previous survey data prove insufficient for the selection of drilling targets.

Review of previous survey data and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Chhumathang (Jammu & Kashmir State)

Some geothermal exploration has been conducted, and slim holes (20 m to 221 m deep) were also drilled (maximum temperature of discharging thermal water = 109°C). A reservoir temperature of around 210°C will be expected from alkaline geothermometry of the thermal water. Judging from these data, there is a geothermal reservoir with a temperature exceeding 200°C in a deeper portion of the field (deeper than bore hole bottoms of the previously drilled wells), though exactly how deep is still uncertain. It is possible that geothermal power generation with a conventional plant can be applied in this area. The following exploration and study will be proposed in preparation for the future geothermal power project. It must be noted that a supplementary survey will be required when previous survey data prove insufficient for the selection of drilling targets.

Review of previous survey data and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Tattapani (Chhattisgarh State)

Some geothermal exploration has been conducted, and a maximum temperature of 112°C was measured at a depth of 480 m in the drilled slim hole. A reservoir temperature of around 160°C will be expected from alkaline geothermometry of the thermal water. Judging from this temperature condition, geothermal power generation with a binary cycle type plant is appropriate in this area. The following exploration and study will be proposed in preparation for the future geothermal power project. It must be noted that a supplementary survey will be required when previous survey data prove insufficient for the selection of drilling targets.

Review of previous survey data and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Tapovan (Uttarakhand State)

This area will be considered in the next chapter.

Areas in the Detailed Exploration Phase (Phase 2)

Manikaran and Kasol (Himachal Pradesh State)

Some geothermal exploration has been conducted, and a maximum temperature of 101°C was measured at a depth of 40 m in the drilled slim hole. Although the concentration of cations dissolved in the thermal waters is rather low (meaning that the accuracy of the temperature estimated from alkaline geothermometry of the thermal water is relatively low), a reservoir temperature of at least around 110°C will be expected. Judging from this temperature condition, geothermal power generation with a binary cycle type plant is appropriate in this area. It must be noted that drilled wells give a temperature profile indicating that drilling sites are situated in an area where the lateral flow of thermal water is dominant (thermal water does not flow up from greater depth under the drilled hole bottoms). Therefore, the source supplying thermal water to the drilling sites must be situated in a different place from the drilling sites. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, supplementary surveying and selection of drilling targets/well specifications: about 8 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Cambay (Gujarat State)

The temperature of discharging thermal water is reported to be 100°C (boiling temperature). The considerably high salinity of this water indicates a contribution of seawater, but effects of boiling (steam loss, enriching) must also be considered. It is difficult to estimate the reservoir temperature from the chemical composition of this water. Considering the high salinity, a study of scaling and erosion/corrosion problems will be required as a part of future resource evaluation. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, supplementary surveying and selection of drilling targets/well specifications: about 8 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 27 months

Feasibility study: about 4 months

Areas in the Regional Exploration Phase (Phase 1)

Beda (Uttarakhand State)

The temperature of discharging thermal water in Beda is reported to be 94°C. A reservoir temperature of around 210°C will be expected from alkaline geothermometry of the thermal water. Judging from this temperature condition, it is possible that geothermal power generation with a conventional type plant will be appropriate in this area. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, the estimate must be re-examined in the light of chemical data from more thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Yamnotri (Uttarakhand State)

The temperature of discharging thermal water is reported to be 90°C. A reservoir temperature of around 120°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from more thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Kanakar (Uttarakhand State)

The temperature of discharging thermal water is reported to be 81°C. As the concentration of cations dissolved in the thermal water is low, and the reported data consists of the chemical composition of a single water sample, it is difficult to estimate reservoir temperature from the chemical composition of this water with sufficient accuracy. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Joti (Uttarakhand State)

The temperature of discharging thermal water is reported to be 65°C. A reservoir temperature of around 240°C will be expected from alkaline geothermometry of the thermal water. Judging from this temperature condition, it is possible that geothermal power generation with a conventional type of plant will be appropriate in this area. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Gari (Uttarakhand State)

The temperature of discharging thermal water is reported to be 61°C. A reservoir temperature of around 210°C will be expected from alkaline geothermometry of the thermal water. Judging from this temperature condition, it is possible that geothermal power generation with a conventional type of plant will be appropriate in this area. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Changlung (Jammu & Kashmir State)

The temperature of discharging thermal water is reported to be 66°C. A reservoir temperature of around 200°C will be expected from alkaline geothermometry of the thermal water. Judging from this temperature condition, it is possible that geothermal power generation with a conventional type of plant will be appropriate in this area. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Juma (Uttarakhand State)

The temperature of discharging thermal water is reported to be 62°C. A reservoir temperature of around 190°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Gangnani (Uttarakhand State)

The temperature of discharging thermal water is reported to be 61°C. A reservoir temperature of around 180°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimation is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming 3 wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Tattapani (Himachal Pradesh State)

The maximum temperature of discharging thermal waters is reported to be 60°C. A reservoir temperature of around 170°C was estimated from alkaline geothermometry of the thermal water. However, it must be noted that the chemical composition of thermal waters in this area is affected not only by subsurface temperature but also by a salty formation extending underground. Therefore, this estimate lacks certainty, and more detailed study will be required. Moreover, since it is required to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. Considering the high salinity of the thermal waters, a study of scaling and erosion/corrosion problems will be required as part of a future resource evaluation. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming 3 wells), discharge testing and resource evaluation: about 27 months

Feasibility study: about 4 months

Sidhu (Jammu & Kashmir State)

The temperature of discharging thermal water is reported to be 65°C. A reservoir temperature of around 150°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Jeori (Himachal Pradesh State)

The temperature of discharging thermal water is reported to be 60°C. A reservoir temperature of around 140°C was estimated from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Moreover, the chemical composition of the thermal water in this area is affected not only by subsurface temperature but also by a salty formation extending underground. Therefore, this estimate lacks certainty, and more detailed study will be required. Moreover, since it is required to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. Considering the high salinity of the thermal waters, a study of scaling and erosion/corrosion problems will be required as part of a future resource evaluation. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 27 months

Feasibility study: about 4 months

Agnigundala (Andhra Pradesh State)

The temperature of discharging thermal water is reported to be 62°C. A reservoir temperature of around 130°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Tapri (Himachal Pradesh State)

The temperature of discharging thermal water is reported to be 73°C. A reservoir temperature of around 135°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is required to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. Considering the high salinity of the thermal water, a study of scaling and erosion/corrosion problems will be required as part of a future resource evaluation. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 27 months

Feasibility study: about 4 months

Balati (Uttarakhand State)

The temperature of discharging thermal water is reported to be 68°C. A reservoir temperature of around 130°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Agnikund (West Bengali State)

The temperature of discharging thermal water is reported to be 66.5°C. A reservoir temperature of around 125°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Khirao (Uttarakhand State)

The temperature of discharging thermal water is reported to be 60°C. A reservoir temperature of around 125°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples in this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Kalapani (Uttarakhand State)

The temperature of discharging thermal water is reported to be 62°C. A reservoir temperature of around 110°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Dar (Uttarakhand State)

The temperature of discharging thermal water is reported to be 79°C. A reservoir temperature of around 110°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Tulsi Shyam (Gujarat State)

The temperature of discharging thermal water is reported to be 60°C. A reservoir temperature of around 105°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

Tatta (Jharkhand State)

The temperature of discharging thermal water is reported to be 65.5°C. A reservoir temperature of around 105°C will be expected from alkaline geothermometry of the thermal water. However, it must be noted that this estimate is based on the reported chemical composition of a single water sample. Therefore, this estimate must be re-examined in the light of chemical data from additional thermal water samples from this area. Moreover, since it is necessary to ascertain the extent of the geothermal anomaly area, regional exploration (phase 1) should be conducted. The following exploration and study will be proposed as preparatory work for a future geothermal power project.

Review of previous survey data, regional exploration (geological survey and geochemical survey) and selection of a prospective area: about 6 months

Detailed exploration (MT survey) and selection of drilling targets/well specifications: about 4 months

Drilling of exploratory wells (assuming three wells), discharge testing and resource evaluation: about 25 months

Feasibility study: about 4 months

IV-2 Indian Private Companies and Institutes Concerned with Geothermal Power Development

For geothermal power development, exploration of geothermal resources, well drilling and well testing are essential requirements. The remaining sections of this chapter consider which private companies or institutes in India could suitably undertake this exploration, drilling and testing.

IV-2-1 Geophysical Survey (MT Survey)

The only institutes or companies in India which are able to carry out MT surveying for geothermal resource exploration are national institutes such as NGRI and GSI. NGRI owns three sets of MT data acquisition systems produced by Metronix, Germany. IIT Bombay (Indian Institute of Technology Bombay) owns one MT data acquisition system produced by Metronics. One set, however, is not enough to carry out geothermal MT surveying efficiently.

IV-2-2 Institutions/Firms that can Undertake Geothermal Well-drilling

In India, there are no drilling contractors with experience in drilling actual geothermal wells (except for hot spring wells). However, since large-scale development of oil and gas has been carried out, there are several companies with large-scale drilling equipment that will be available for geothermal drilling in India. Among them, it is considered that the following companies have the ability to drill a deep geothermal well, based on a survey of the IADC (International Association of Drilling Contractors, http://www.iadc.org/) website and local information. As a part of the actual bidding process, it will be necessary to carry out a detailed survey of these companies, considering the availability of their drilling equipment etc.

- Shiv-Vani Universal, Ltd. http://www.shiv-vani.co.in/
- John Energy Limited. http://www.johnenergy.com/
- Essar Oilfield Services India, Ltd. http://www.essar.com
- Oil & Natural Gas Corporation Limited. http://www.ongcindia.com/

IV-2-3 Well Testing, Production Testing and Chemical Analysis of Geothermal Fluid

NGRI and GSI have laboratories for chemical analysis. It is also possible to carry out chemical analysis at IIT Bombay through its Department of Earth Sciences. Although India has experience in well drilling and well testing in oil and gas fields, this experience is not directly applicable to geothermal exploration. Therefore, outside technical advice and support is thought to be necessary to enable the well drilling, well testing, production testing and chemical analysis required in geothermal exploration.

CHAPTER V

V TAPOVAN FIELD

V-1 Review of Previous Studies of Tapovan Geothermal Field

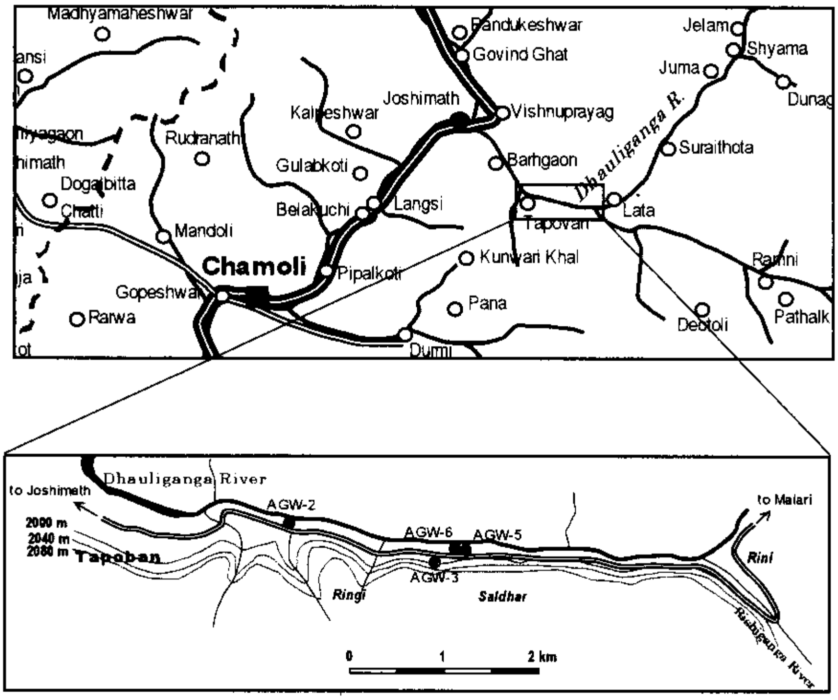
V-1-1 Outline of Previous Studies

Geothermal resource study in the Tapovan area including geological, geochemical and geophysical surveys and the drilling of shallow thermal gradient holes was conducted by the Geological Survey of India (GSI) from the 1970s through the 1990s. In the first stage of exploration, five 50 m holes were drilled, and a downhole temperature of 60°C was measured. Subsequently, four exploratory wells (AGW-2, AGW-3, AGW-5 and AGW-6), with depths of 291 to 728.1 m, have been drilled. Figure V-1 shows the location of these wells.

Exploratory well AGW-2, drilled to a depth of 291 m, struck artesian conditions at a depth of 79 m. It discharged 80°C hot water at a rate of 665 LPM. After about 15 years of production, the well continues to discharge 80°C hot water at a rate of 300-400 LPM. AGW-3, drilled to a depth of 431 m, struck artesian conditions at a depth of 350 m. On reaching a depth of around 430 m, 90°C. hot water discharged at a rate of 800 LPM. With the passage of time, a thick mound of spring deposit has formed around the wellhead, and the discharge has fallen to 300-400 LPM. During field reconnaissance for this study in September, 2009, the well continued to discharge 93.9°C hot water at a rate of 300-400 LPM. AGW-5, drilled to a depth of 412.5 m, struck artesian conditions at a depth of 350 m with a temperature of 92°C. It had been planned to drill the well to a depth of 900 m, but due to the drilling difficulties, it was completed only to a depth of 412.5 m. AGW-6, drilled to a depth of 728.1 m, struck artesian conditions at a depth of 510 m. 68.5°C hot water discharged at a rate of 950 LPM after the drilling proceeded to a depth of 728.1 m (Sharma et al., 1995; GSI, 2002; Table 3-3). On the basis of exploratory well drilling results, multi-purpose utilization of hot water in the Tapovan area was proposed by GSI researchers in a published paper (S. C. Sharma and A.B. Dhaulakhundi, 1995), but this proposal has not been put into effect.

Two hydroelectric power plant construction projects are in progress near Tapovan geothermal field: the Tapovan Vishnugad H.E. Project is downstream of the Tapovan area, and the other, the Lata-Tapovan H.E. Project, is located upstream of the area. Geological and geophysical surveying has been conducted in and around the Tapovan area as part of the hydroelectric power plant construction projects in the area.

SNC and JETRO (2010) reviewed the results of geoscientific study of Tapovan. The estimation of geothermal potential and a geothermal resource development plan were also considered. A summary of the results of SNC and JETRO (2010) follows.



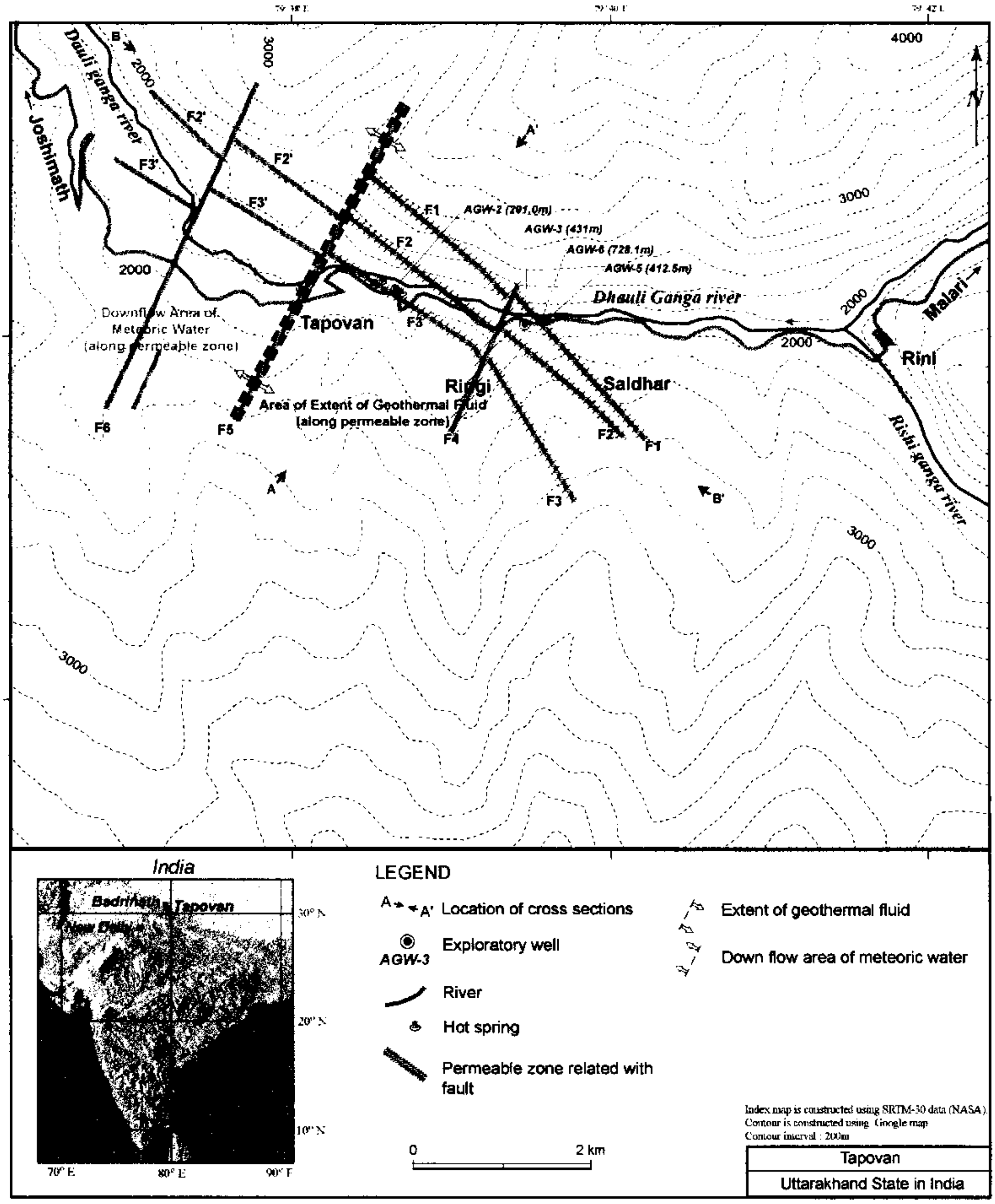
(Source: JETRO and SNC, 2010)

Fig. V-1 Location of Tapovan Field and Existing Wells in Tapovan

V-1-2 Geothermal Resources in Tapovan

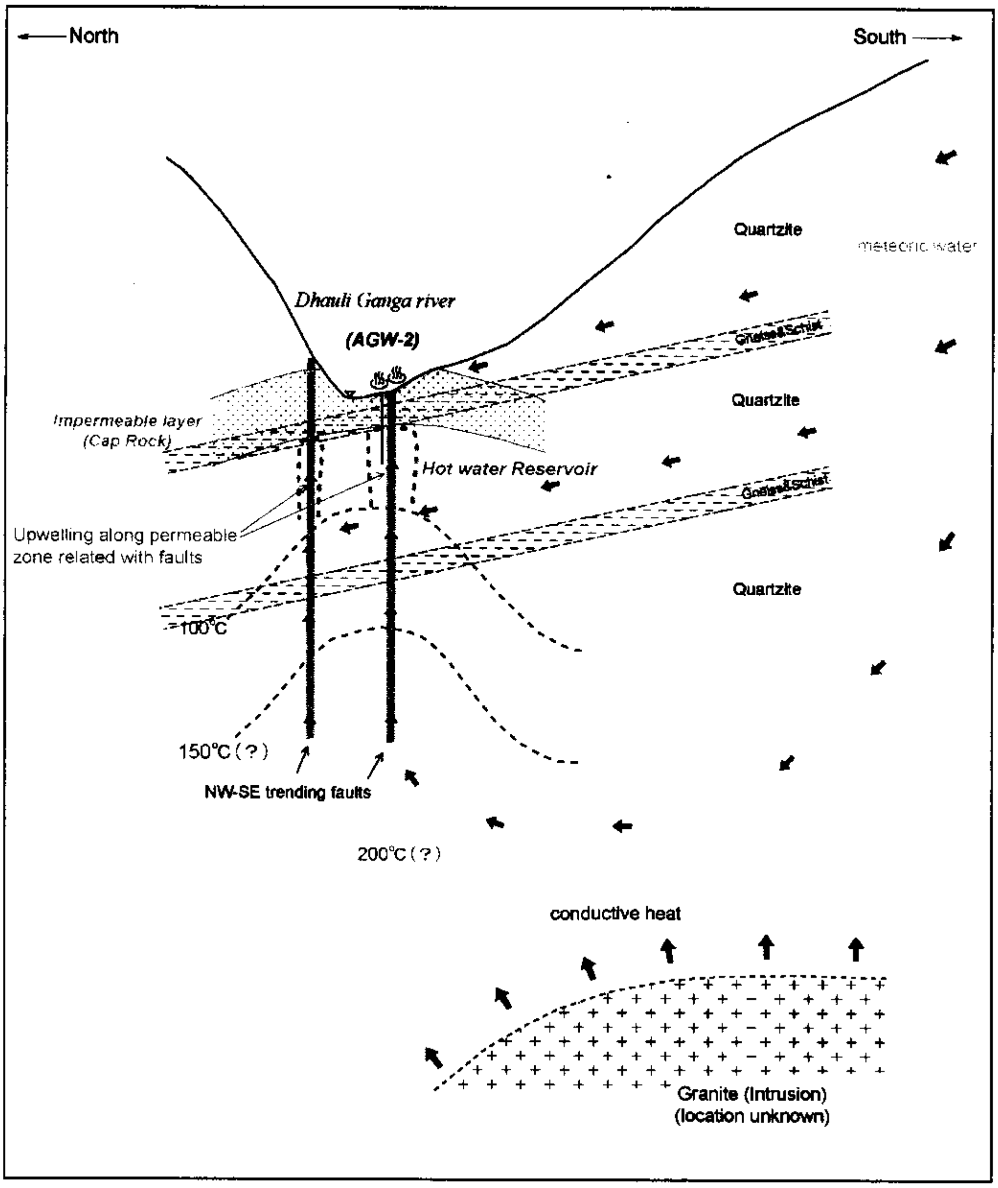
The following description is based on the geothermal model of Tapovan constructed in SNC and JETRO (2010) (see Figs. V-2 and V-3). Hot water with temperature of around 100°C is stored in the permeable zones of F1, F2, F3 and F4 developed along the faults east of F5 and mainly south of the river. The cap rock formed due to hydrothermal alteration at a depth shallower than 200 m prevents cold groundwater from flowing into the geothermal reservoir. The heat source for the geothermal system in this area is considered to be the conductive heat of the Tertiary to Quaternary granite intrusion. Although it is still not clear, the heat source driving the geothermal system may lie in the deeper part of the southern or southwestern part of Tapovan field.

Meteoric water penetrating into deep levels in the mountainous area higher than the Tapovan area is heated by the conductive heat from an intrusive body. Hot fluids are stored in permeable zones F1, F2, F3 and F4, which are the fractures associated with faults below the impermeable zone (cap rock). The geothermometry for spring water suggests that the reservoir temperature is around 100°C. The hot fluid ascending along the fractures drives the hot springs (Tapovan-1, -2 and -3). The geochemistry of hot spring water and discharged water from AGW-3 imply that hot water flows and is stored mainly in quartzite. As shown in Figs. 3-12 and 3-13, it is possible that a geothermal reservoir of a higher temperature may extend below the bands of schist or gneiss in quartzite at depth. Based on the thermal gradient in this area, the temperature of the geothermal reservoir assumed in the deeper region is estimated to be 160°C at a depth of approximately 2,000 m. However, it is still uncertain whether a geothermal reservoir in the deeper region is likely or not. In general, geothermometers based on geochemistry are powerful tools for estimating reservoir temperatures at depth. However, it is difficult to estimate reservoir temperature at depth because of the small amount of chemical constituents in the hot water in this area. They originate from the rock hosting the hot water, which is mainly quartzite. Therefore, further detailed geoscientific study is required to examine the possible presence of a deeper reservoir and to consider its temperature.



(Source: JETRO and SNC, 2010)

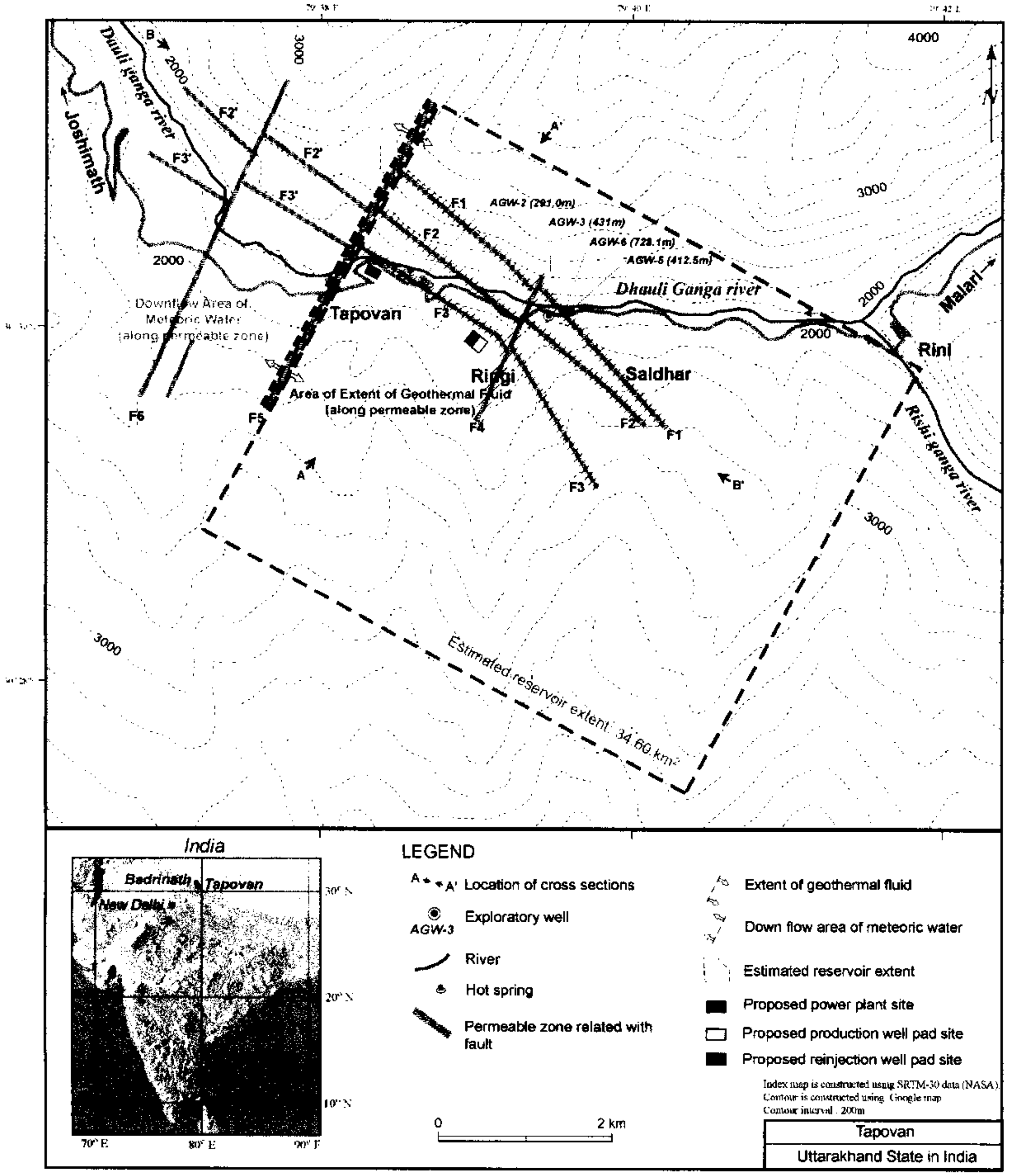
Fig. V-2 Estimated Area of Extent of Geothermal Fluid and Area of Meteoric Water Downflow



(Source: JETRO and SNC, 2010)

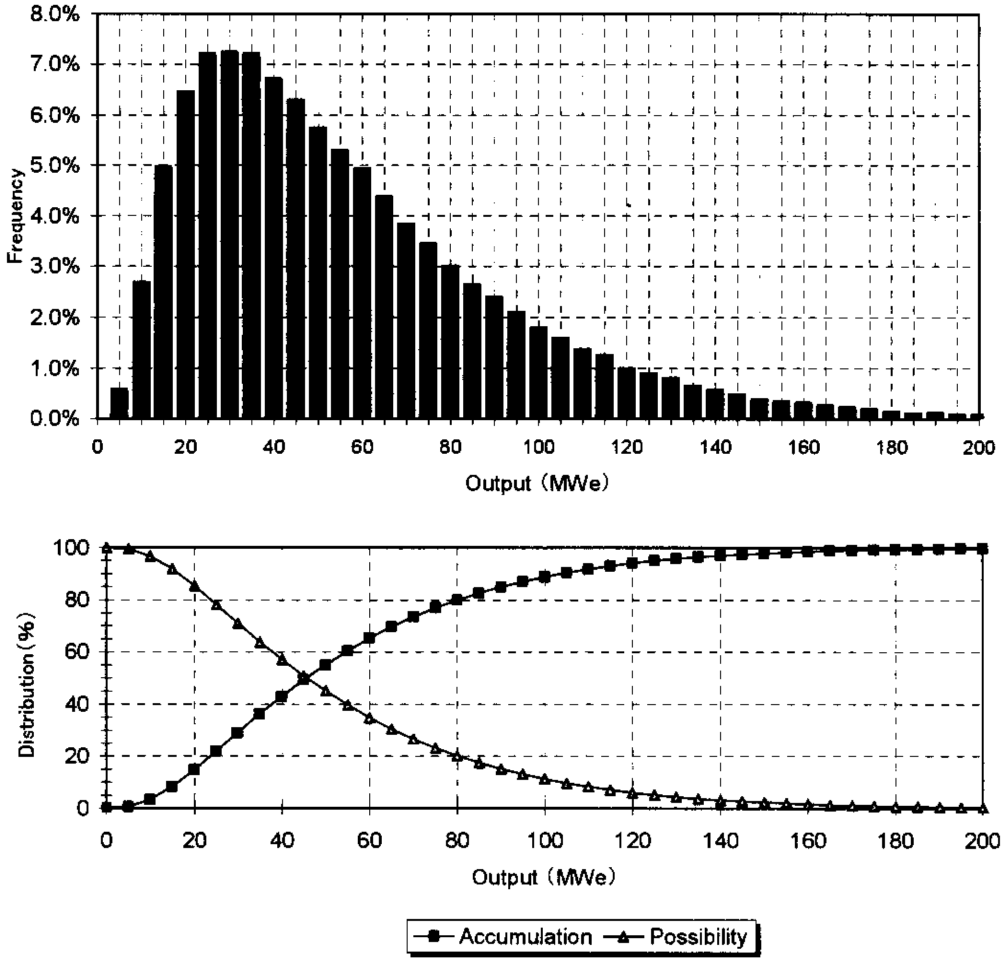
Fig. V-3 Conceptual Model of Geothermal System in Tapovan (N-S cross section)

Although the available data are very limited at present, the potential of the geothermal resource in the Tapovan field has been estimated in SNC and JETRO (2010) using a volumetric method applying Monte Carlo Analysis. From this analysis, a potential of more than 23.7 MWe has been estimated with a probability of 80% (Figs. V-4 and V-5).



(Source: JETRO and SNC, 2010)

Fig. V-4 Estimated Reservoir Extent in Tapovan



(Source: JETRO and SNC, 2010)

Fig. V-5 Probability Distribution and Cumulative Probability shown by Monte Carlo Analysis

V-1-3 Review of the Outline of the Project Plan

A description of the project plan for Tapovan formulated in SNC and JETRO (2010) follows. The project plan should be revised and updated after a resource feasibility study including exploratory well drillings. In the current study, this project plan is partly revised based on the results of a field reconnaissance survey. A description of the revised points is given in Chapter V-2.

As the Tapovan field is topograpically characterized by a steep wall valley, there are not so many sites suitable for a plant. Given these field conditions, ten wells can be drilled with rather easy site preparation (construction). Assuming that the ten wells will consist of 5 production wells and 5 reinjection wells and that the productivity of a production well will be 2 MW per well, the expected output will be 10 MWe. On this basis, a project plan targeting the geothermal development of 10 MW was recommended in SNC and JETRO (2010).

As the geothermal resource in the Tapovan field is considered to be hot water between 100°C and 200°C, a binary system power plant is recommended as a suitable system for generating geothermal power in this field. Although it is difficult to specify the detailed design of the power plant, the following geothermal project will be proposed.

<Geothermal resource development>

- Site preparation for production well pads, reinjection well pads and power plant site
- Construction of access road
- Drilling of production wells and reinjection wells

<Piping to transport produced hot water (fluid collection and reinjection system)>

<Construction of a 10 MW binary geothermal power plant>

(1) Geothermal resource development

a. Proposed Site for Power Plant and Well Pads

The Tapovan geothermal field is characterized by a steep topography, thus there are few suitable sites for a power plant and well drilling pads. The first candidate site is located approximately 1 km west of well AGW-3, on the left bank of Dhauliganga River, where there is a terrace that consists of relatively gently sloping terrain. The elevation there is 150 m higher than the public road and there are some private houses and an elementary school there. Therefore, land for the well drilling and power plant needs to be acquired in advance of geothermal field development. The secondary candidate site is located about 1.5 km northwest of the first candidate site, at a lower elevation than the first candidate site. However, the secondary candidate site is not available as the site of a power plant and well pads because the area is used by the Indian army.

A detailed topographic survey should be carried out prior to earthwork on the production drilling pads (7,000 m^2), reinjection drilling pads (7,000 m^2) and the power plant site (12,000 m^2).

b. Access road

For the civil engineering work that will be necessary in the course of the geothermal development of Tapovan field, it is possible to hire contractors and to purchase materials for the work in Deheradun city, which is the capital of Uttarakhand state.

The road between Dehradun and Joshimath on national highway 58 is mostly paved with asphalt and runs via Devapurayag, Rudraprayag and Chamoli. From Joshimath to Tapovan, a less substantial road runs through the steep topography of the river valley.

A new access road should be constructed where there are only steep footpaths at present to allow access to the proposed power plant and drilling site from the existing public road. The route of the access road from the existing public road to the power plant site is reviewed in this study and described in Section V-2.

Fresh water for well drilling and power plant operation can be obtained from the Dhauliganga River flowing through the northern part of the site by installing an 8-inch steel pipeline to transport the water.

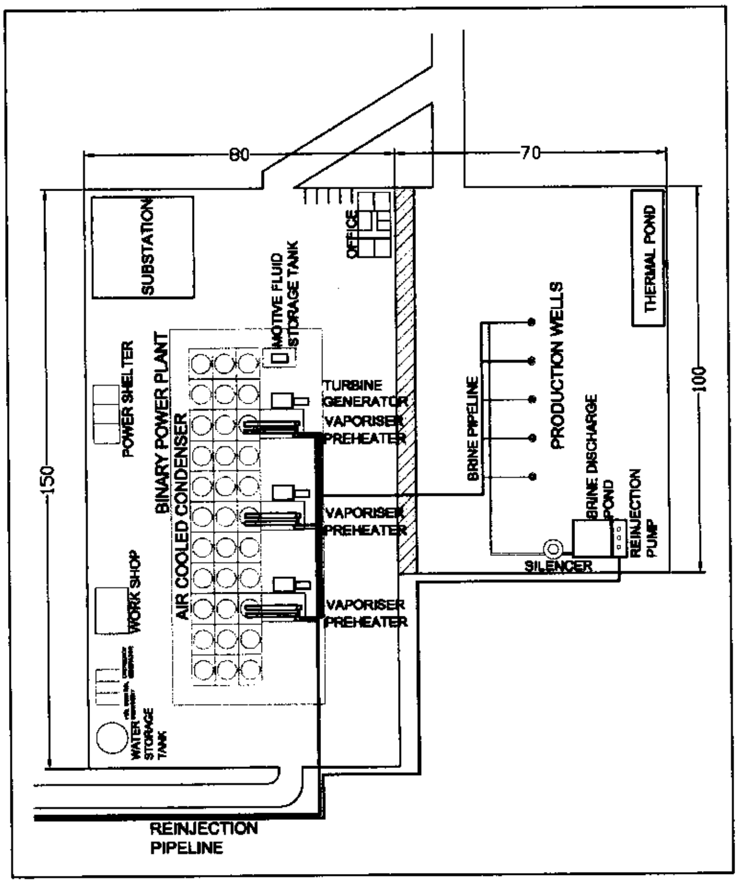
c. Production and Reinjection Well Drilling

It is recommended that the Drilling Rig should have an output of more than 800-1,000 HP for exploratory well drilling to an average depth of 1,000-2,000 m. It is important to conduct a detailed investigation concerning drilling rig mobilization and demobilization and the costs of drilling equipments and materials.

Production wells and reinjection wells should take advantage of directional drilling so that multiple targets can be drilled from the planned pads.

(2) Layout of FCRS and pipeline route

Figure V-6 shows the layout of the Tapovan field site. A production pipeline will be constructed from the production wells to the binary power plant, and a reinjection pipeline will link the power plant to the reinjection well pads.



(Source: JETRO and SNC, 2010)

Fig. V-6 Layout of FCRS and Pipeline Route

Production well pumps are installed in every production well to bring geothermal water at the reservoir temperature to the surface. There are two types of production well pumps: line shaft turbine pumps and submersible pumps. Pumps are selected in consideration of the depth at which they will be set, the type of well casing used, temperature capability, purchase price, etc.

Wellhead silencers will be installed at the production pads for use in production testing, and to discharge brine in a plant emergency situation. A brine discharge pond made of reinforced concrete will be constructed at the production pad to store the discharged brine temporarily. Reinjection pumps will be installed adjacent to the brine discharge pond. Water held in the pond is pumped out and delivered to the reinjection wells through the pipeline.

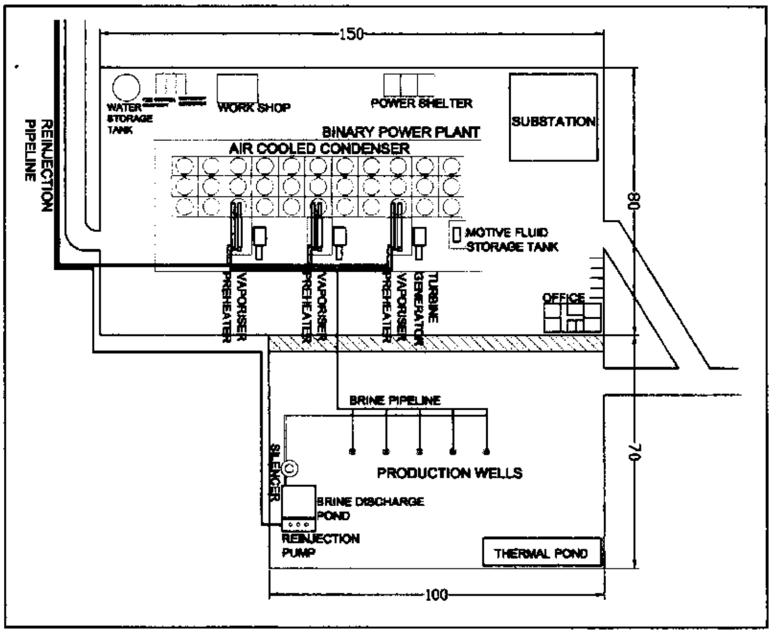
(3) Plan for the geothermal power plant

According to SNC and JETRO (2010), the geo-science shows that the geothermal resource in this field is water-dominated and of medium temperature. A binary cycle plant is able to exploit the energy in geothermal water of this temperature. Therefore, a binary power plant is recommendable for power generation for this project. Plans for the geothermal power plant will be re-examined after detailed geothermal resource study including exploratory well drilling.

a. Layout of the power plant

Generally, the following points must be considered when planning the layout of a geothermal power plant: (a) Direction of steam piping from steam field, (b) Direction of transmission lines, (c) Wind direction for optimum placement of the cooling tower

A production well pad of about 70 x 100 m will be located approximately 1 km west of well AGW3. Five (5) production wells will be drilled from the pad. The plant site, which is about 80 m x 150 m, will be located next to the production well pad. The plant site will accommodate three (3) 3.5 MW binary units with air-cooled condensers, which will be located in the center of the plant site. The Substation, water storage tank and appurtenant buildings will be placed around the generation units. The air-cooled condensers will be located downwind of the switchyard and power shelter so that air-cooled condenser exhaust with corrosive non-condensable gas and mist will not affect electrical equipment. The main transformer will be installed in the substation. Figure V-7 shows the Layout of a Binary Power Plant.



(Source: JETRO and SNC, 2010)

Fig. V-7 Layout of a Binary Power Plant

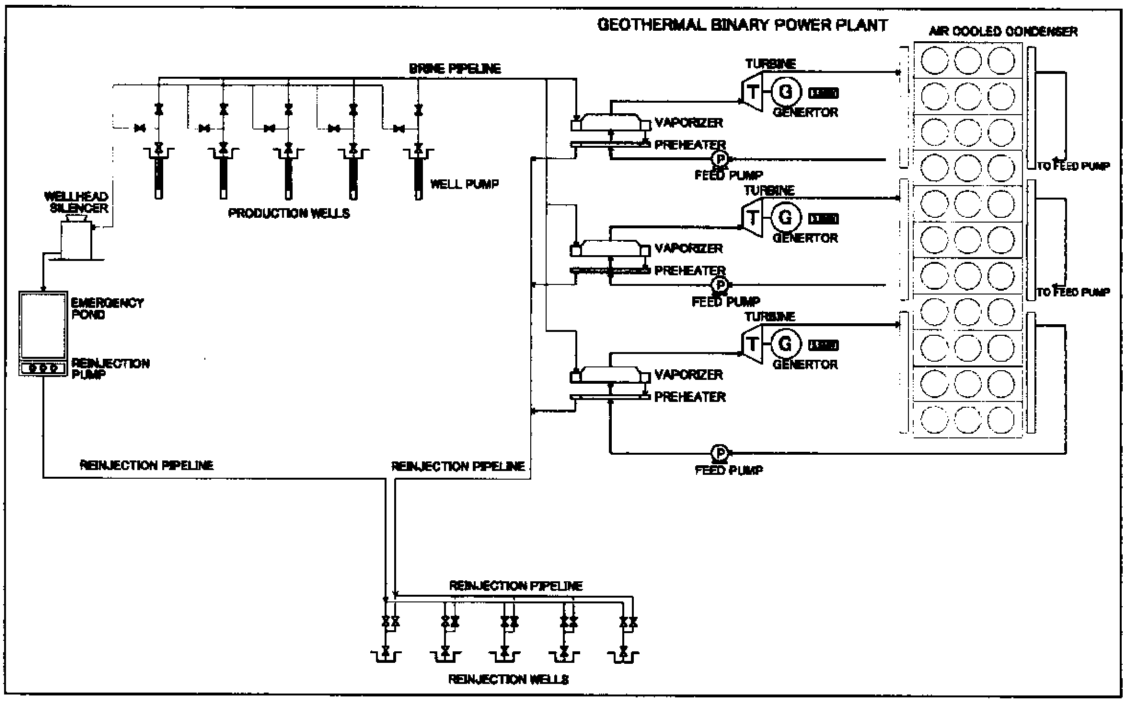
b. Outline of Binary Plant Process

Figure V-8 shows Process Flow Diagram for a binary power plant. The total brine production of five production wells using well pumps is assumed to be 2,400 t/h. The 10.5 MW power plant will consist of three 3.5 MW binary module generating units with all required ancillary equipment.

There are two kinds of heat source and working fluid cycles in a binary power plant. In the primary cycle, geothermal brine produced from production wells by means of well pumps is delivered to a heat exchanger (primary vaporizer, secondary preheater). After passing through the preheater, the brine is transported to the reinjection wells and injected underground.

In the secondary cycle, a working fluid with a low boiling point is pumped at fairly high pressure through the heat exchanger, where it is vaporized and then directed through a turbine. The vapor exiting the turbine is then condensed by an air-cooled condenser and cycled back to the heat exchanger by a feed pump.

In a plant emergency situation, the produced brine is discharged into the brine pond through the wellhead silencer. Brine in the pond is sent to the reinjection wells by means of the reinjection pump.



(Source: JETRO and SNC, 2010)

Fig. V-8 Process Flow Diagram for a Binary Power Plant

c. Power generating facilities

Essentially, power plant design requires a grasp of the steam conditions of production wells and the meteorological conditions in the field. Little of this data is available to the designer at present, because this field is not under geothermal development. A trial design of the geothermal power plant for Tapovan field is shown below.

Main specifications of facilities

Turbine

☐	Type	Single flow, condensing
☐	Rated Output	3.5 MW
☐	No. of units	3 units
☐	Speed	1,500 rpm

Generator

☐ Type	Cylindrical Revolving- field Rotor Type, Totally Enclosed, Air Cooled, Three- phase Synchronous Generator
☐ Rated Voltage	11 kV
☐ Frequency	50 Hz
☐ Power Factor	0.9 lagging
☐ Excitation System	Brushless Exciter

Vaporizer

☐ Type	Shell & Tube type 1 set/unit
☐ Heat source	brine
☐ Inlet temperature	150°C
☐ Flow rate	400 t/h /unit

Preheater

☐ Type	Shell & Tube type 1 set/unit
☐ Outlet temperature	80°C
☐ Flow rate	400 t/h /unit

Feed pump

☐ Type	Multi-stage centrifugal pump	1 set/unit

Condenser

☐ Type	Mechanical draft air-cooled Fan tower and fin tube 1 set/unit

There are basically only two types of condenser for cooling the working fluid vapor of a binary power plant, water-cooled, or air-cooled.

The choice to be made between air-cooled or water-cooled condensers is an important one. Water-cooled binary plants generate higher average power outputs, both because they are not as subject to daily and seasonal oscillations in ambient temperature, and also because they do not have the parasitic load needed to run the fans on air-cooled condensers. The key to the use of water-cooled condensers is the availability of a constant supply of cooling water. However, there is no information about the availability of surface water that could be used or restrictions on the use of that water.

Therefore, SNC and JETRO (2010) assume conservatively that the cooling cycle will use more costly air-cooled condensers.

Selection of working fluid

The performance of a binary plant is affected by the working fluid. The selection of working fluid must satisfy the following conditions.

- ☐ It should be thermodynamically superior and thermally stable.
- ☐ It should be non-toxic and not corrosive to plant construction materials
- ☐ It should be cheap and easy to procure

Working fluids used in the past in low-temperature binary plants were CFC (Freon type) refrigerants. Binary plants currently use hydrocarbons (propane, butane, pentane etc) as HFC type refrigerants, with the specific fluid chosen to match the geothermal resource temperature. The following table shows the characteristics of normal-pentane as a typical working fluid.

Table V-1 Characteristics of Normal- Pentane

Molecular formula	C_5H_{12}
Molecular weight	72.151
Melting point (1 atm.)	- 129.73°C
Boiling point (1 atm.)	36.06°C
Critical temperature	197.2°C
Critical pressure	33.68bar
Hydro specific gravity (15.4℃)	0.6309
Gas specific gravity (15.4℃, 1 atm.)	2.6073
Explosion limit	1.4～8.3vol%
Ignition temperature	40°C

(Source: JETRO and SNC, 2010)

d. Ancillary facilities

Water Supply and Storage Facilities

A raw water storage tank will be constructed at the plant site to store intake water from Dhauli Ganga River.

Fire control Equipment

Hydrants and/or fire monitor nozzles will be installed outdoors around the binary plant and flammable materials warehouse. Diesel and motor-driven fire pumps will supply water from the raw water storage tank to the hydrants and monitor nozzles. Deluge systems will be provided for the main transformers. Portable dry-chemical extinguishers will be placed in the buildings.

Air compressor

An air compressor will be installed as a source of power for air-driven valves

Emergency generator

Emergency power will be supplied by battery backup system to the power plant, in case of failure of the power system.

Maintenance Facilities

A maintenance shop and a storage area for spare parts and tools will be provided.

Air Conditioning System

An air conditioning system will be installed for the control room, electrical rooms, and the administration office.

Communication system

A microwave communication system will be used for communication between the grid and the power plant.

e. Unloading and inland transportation of power plant equipment

Equipment and materials for Tapovan power plant, including those for the transmission line and switchyard, can be unloaded at the port of Calcutta. They will be transported from the port overland to Tapovan via Kanpur city in Uttar Pradesh State and Dehradun city in Uttarakhand State.

It must be noted that the above specifications for a binary power plant are based on many uncertain factors which remain to be examined. Moreover, this field is presently in the Regional Exploration Phase, and it is very difficult from the existing data to deduce the locations of drilling targets that will clarify the presence of a geothermal resource available for power generation. The present situation of this field requires detailed exploration (Detailed Exploration Phase). For this reason, further resource study prior to exploratory well drilling was proposed in SNC and JETRO (2010).

V-1-4 Review of Environmental and Social impacts

The results of the review of environmental and social impacts in SNC and JETRO (2010) are as follows.

The study area is located in a steep-walled valley with limited flatlands far from the residential area of Tapovan village. The study area is characterized by shrubbery, grassland, farmland and rocky areas. There is no power plant facility, but two hydro power plant projects were under construction near the study area. The Tapovan Vishnugad H.E. Project (520 MW) and Lata-Tapovan H.E. Project (171 MW) were to start operation in 2011 and in 2014, respectively. Except for the environmental impact of these ongoing projects, there was no other source of significant impact in the study area. There were few vehicular emissions and little noise from the small amount of traffic. There was dust in the air from road repair work, but it was temporary. No source of water pollution could be recognized in the study area.

Based on the site survey results and the project characteristics, survey items that must be addressed before project implementation have been identified to ensure appropriate attention to environmental and social considerations.

Subsequent study of environmental and social impacts should consider the following:

1. Flora and fauna found within the geothermal field, including the current status of precious species
2. Ecosystems in and around the geothermal field
3. Hydrogen sulfide (H_2S)
4. Noise & vibration
5. Water Quality
6. River flow/groundwater level
7. Influence on local livelihoods

V-1-5 Results of MT Survey

According to the report "MAGNETOTELLURIC INVESTIGATION IN GEOTHERMAL FIELDS OF TAPOVAN UTTARAKHAND, INDIA" (hereafter NGRI (2008)), an MT survey making use of 25 stations has been carried out in the area surrounding the Tapovan field, and an analysis of the 2-dimensional resistivity structure of three sections (Profile-1, Profile-2 and Profile-3) has been carried out (Fig. V-9). Among these analytical profiles of the areas sampled in and around the Tapovan field, Profile-3 is the one that is located in Tapovan geothermal field.

A hydrothermal alteration zone has been confirmed at the surface in the vicinity of MT stations T04, T02 and T03, which are located near the central portion of analytical Profile-3. In addition, well AGW-3 (drilling depth 431m) producing hot water of about 94°C and well AGW-2 (drilling depth 291m) producing hot water of about 80°C have been drilled between stations T04 and T02. Between stations T04 and T02, a relatively low resistivity zone of 30～60ohm-m lies near the surface. At the same time, a high resistivity zone with resistivity greater than 500ohm-m extends near the surface to the west in the area between station T11 and T10 and in the east between station T05 and T20. The relatively low resistivity zone extending near the surface between stations T04 and T02 is distributed in a configuration such that it appears to slide under the underside of the high-resistivity zone found near the surface between stations T05 and T20. This zone showing relatively low-resistivity can be understood as follows.

In geothermal areas generally, low resistivity zones corresponding to hydrothermal alteration zones show resistivity values of less than 10ohm-m. However, in Tapovan field, this kind of low resistivity zone has not been recognized, and the resistivity values for the relatively low resistivity zones are around 30～60ohm-m. It is possible that the distribution of pre-Cambrian metamorphic rock in the Tapovan field is responsible for this. That is to say, it is possible that a resistivity anomaly of less than 10ohm-m has not been detected because the rock itself is difficult for fluid to pass through and the conditions are not present to allow hot water to seep in and alter the rock over a relatively wide area (so that alteration occurs only in the vicinity of passages through which hot water flows). Consequently, although it is not a low resistivity anomaly of the kind recognized in ordinary geothermal systems, the relatively low resistivity zone of about 30～60ohm-m recognized near the surface may reflect the influence of the activity of hot water at subsurface. However, taking into consideration such things as the temperature data for the wells drilled so far in Tapovan field, together with the subsurface temperatures estimated on the basis of upwelling fluid and hot water discharging at the surface, it is unlikely that a high-temperature geothermal system of the kind recognized in volcanic areas has developed in this field.

In addition, it is thought that the high resistivity zone of greater than 1,000ohm-m which is distributed around 0m a.s.l. and deeper reflects a stratum in which there are few fissures/fractures. The depth of the top of this high resistivity zone increases as we move east of the central portion of the analytical profile, and it is also possible that the top of this high resistivity zone corresponds to the thrust fault inclined at a slight angle. Moreover, a low resistivity zone has been recognized at depths greater than 4 km in the vicinity of stations T20 and T25. However, when the observed apparent resistivity is considered, although indications of low resistivity are recognized in the low frequencies of the apparent resistivity profile in the east-west direction (TM mode), there are no indications of low resistivity in the apparent resistivity profile in a north-south direction (TE mode). Consequently, there is a high probability that this is a false image (of an anomalous area that does not actually exist). This type of false image is frequently recognized in the analysis of 2D resistivity structure.

2D resistivity structure analysis has been employed in this report, but when compared with 3D resistivity structure analysis, which is the latest analytic technique, there are times when it shows less analytical precision, particularly at depth. In order to carry out 3D resistivity structure analysis with good precision, it is necessary to lay out the MT stations in a planar distribution rather than linearly, and such a distribution is difficult to achieve in the Tapovan field due the restrictive topography.

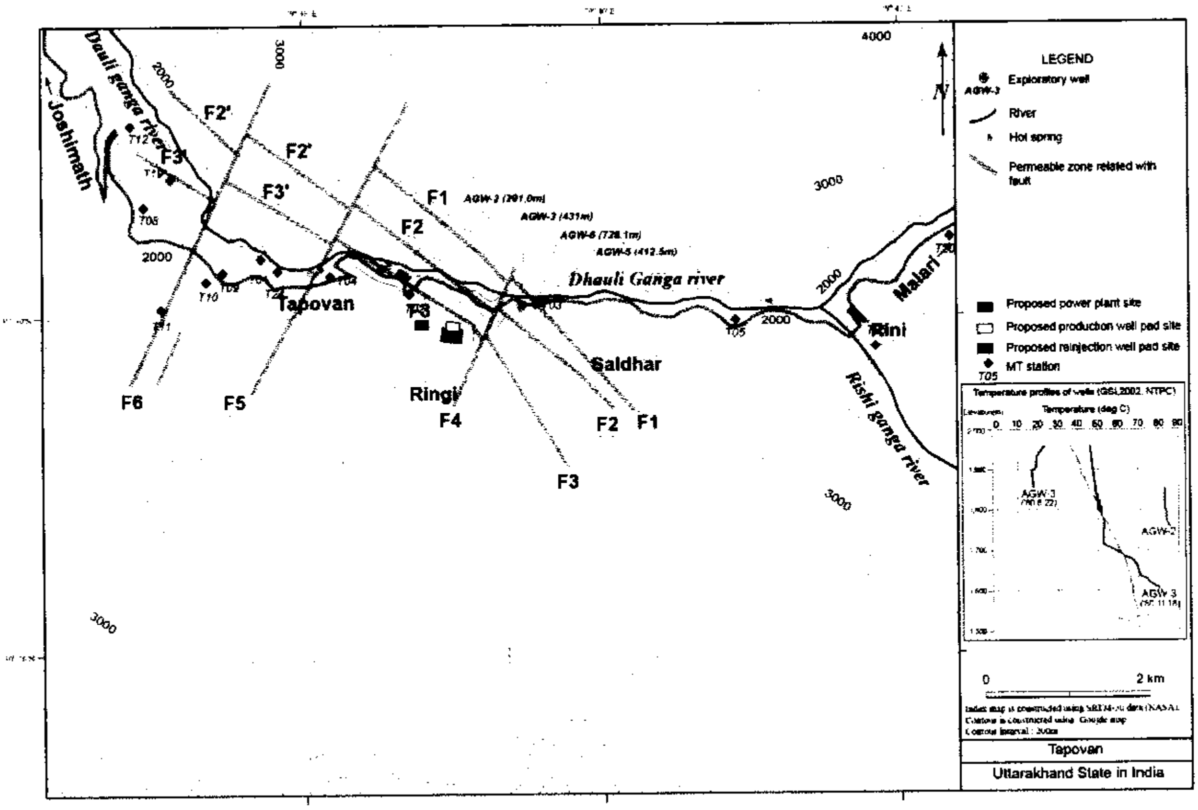


Fig. V-9 Location Map for MT Survey Stations and Existing Exploratory Wells

V-2 Present Situation of Tapovan Field

V-2-1 Project Status and Procedures Required for Further Development

As described in Section II-4, the government is currently preparing guidelines and policy to support the exploration of geothermal energy resources mainly by the private sector. In addition, considering the high risk and capital cost involved in geothermal energy generation, the government is evaluating the possibility of assisting the private sector by formulating a clear geothermal policy, preferably with a single window for obtaining all the clearances necessary for the execution of a geothermal project, and some monetary support in the form of tariff support or capital incentives. The guidelines under which geothermal energy development will be carried out in the country are being prepared by the Ministry of New and Renewable Energy (MNRE), and draft versions are currently available. However, until the guidelines come in force, prospecting licenses are granted by the relevant State Government, and this is the case for the geothermal development project at Tapovan in Uttarakhand.

NTPC requested approval to carry out a detailed survey for development of the geothermal project at Tapovan from the State Government of Uttarakhand in November 2008, and the approval was granted in March 2009. The procedures which NTPC should follow for the further progress of the project are described below on the basis of the results of interviews with representatives of the State Government.

After completing resource exploration, NTPC should submit a final report to the State Government with detailed survey results and a drilling plan, which should include a map of the area, a contour map of drilling sites, a statement of the drilling budget, and a statement of the methodology and budget proposed for elaboration of the Detailed Project Report (DPR) after the completion of drilling. Upon receipt of the report from NTPC, the State Government will take approximately two months to review it before granting permission for the drilling. At that point, the state Government will sign an MOU with NTPC, which will be a preliminary agreement between two parties on the expected potential of geothermal power generation at Tapovan in the future. After NTPC completes the drilling activities and the elaboration of the DPR, the DPR is submitted to the State Government requesting their permission for power plant construction (permission for utilization of the natural resources within the State). At this point, the State Government and NTPC will sign a power sales agreement at mutually agreed rates. An authorization of the Environmental Impact Assessment by the Ministry of Environment and Forests will be also required prior to power plant construction.

The State Government says that it does not require an authorization of the EIA by the Ministry of Environment and Forests for the drilling of geothermal wells. Actually, geothermal exploration is not listed as one of the projects requiring EIA authorization by MoEF. However, it is assumed that this is because no geothermal wells have yet been drilled in the country and it is reasonable to think that EIA authorization will be required for geothermal exploration, as is the case already for oil and gas field exploration in the country.

V-2-2 Geological Conditions in Tapovan Field

The Tapovan area and adjacent areas are covered by Proterozoic rocks of the Central Crystalline Group. These have been classified into three formations in the Tapovan area: the Helang Formation, Bilagarh Formation and Joshimath Formation, in ascending order (S. C. Sharma et al., 1995, GSI, 2002). The Helang Formation is mainly comprised of quartzite with occasional schistose bands, a thick sequence of gneiss with marble bands. The Helang Formation is overlain by the Bilagarh Formation, which is subdivided into Tapovan, Dhak and Garh members, in ascending order. The Tapovan member consists of quartzite, the Dhak member, of gneiss and schist, and the Garh member, of quartzite with schist bands. The Joshimath Formation is comprised of schist with bands of gneiss and occasional quartzite. Exploratory wells AGW-3 and AGW-6 reached the Helang Formation at a depth of 400 m, and 510 m, respectively. The rocks in the Tapovan area generally trend NW-SE to WNW-ESE and dip to the north. Strike/dip measured during the field survey was N25-65W/30-40N. The Central Crystalline Group features many intrusions of Tertiary to Quaternary granite. Granite is not exposed in the Tapovan area, but there are outcrops 25 km southwest and 25 km northwest of the Tapovan area (GSI, 2005).

Tapovan field is located in a mountainous region, and its topography is characterized by steep slopes and a deep valley. Rocks crop out on the steep slopes, which are covered by thin soil. Gently sloping or flat areas are very limited in the Tapovan field, and these are covered by soil. However, the soil is presumed to be thin on gently sloping and flat land because rocks directly crop out at the surface over some portion of these areas. Some areas are characterized by altered rocks of soft to medium hardness.

V-2-3 Social and Environmental Conditions in Tapovan Field

(1) Present Environmental and Social Conditions

a. Location

The Tapovan geothermal field lies at 79°39' east longitude and 30°29' north latitude. It is located in Ringi Village, Joshimath Tehsil (County), Chamoli District, Uttarakhand State.

b. Natural environment

1) Meteorology and Climatology

The climatic conditions in the study area and its surroundings vary with elevation. The variations in exposure to sunlight and to rain-bearing winds produce a very intricate pattern of local climate in the project area. In summer months (March–June), valley areas experience hot climatic conditions, while high mountain areas experience a cold climate. During the summer season, local thunderstorms are frequent and are often accompanied by heavy rain. The monsoon or rainy season extends from June to September. The majority of annual rainfall is received during the period from June to September. The winter season in the local Garhwal Himalayas mountain ranges, lasts from November to March, and at higher reaches snowfall is common during the winter months.

The temperature rises sharply after March, and the month of June is the hottest month of the year, with a daily maximum temperature going up to 26°C With the withdrawal of monsoons, by the end of September there is a decrease in temperatures. The months of December and January are the coldest months of the year, with a mean daily minimum temperature as low as 2°C.

The average annual rainfall is about 1200 mm, with the maximum rainfall being received under the influence of southwest monsoons during the months of July and September.

Table V-2 Monthly Mean Maximum & Minimum Temperature and Total Rainfall based on 1958 to 1987 Data

Month	Mean Daily Temperature (°C)		Rainfall (mm)
	Max	Min	
January	11.4	2.1	65.3
February	12.4	3.2	98.0
March	17.6	6.6	114.3
April	21.8	10.8	64
May	24.6	13.9	71.3
June	25.9	16.6	132.3
July	24.1	16.9	247.4
August	23.6	16.9	222.4
September	22.9	14.8	104.8
October	20.6	10.5	45.1
November	16.8	6.2	15.4
December	13.6	3.8	25.0

(Source: IMD data http://imd.gov.jp)

2) Flora

The dominant forest types in the project area are Himalayan moist temperate forest and Himalayan dry temperate forest. Chir pine (Pinus roxburghii) is the dominant tree species 750-1,600 m above sea level. Above 1,500 m above sea level, Chir pine grows in association with species such as Banj, Buransh, Anyar, and Kaphal. A floristic survey of the area found 191 plant species before the monsoon and 155 species after the monsoon, dominated by herb and shrub species. The main local forest reserves are Dasoli, Dunagiri, and Paikhadalla.

In the lower altitudes of the project area, the vegetation is comprised of mixed temperate coniferous forests. In the upper reaches, sub-alpine and alpine scrubs and pastures are prevalent. The entire area is covered at the lower altitudes by mixed forest with some tall trees, whereas the cold areas of the upper reaches are devoid of tree cover and characterized by stunted species of shrubs and herbs. The major forest types found in this catchment are discussed below.

Moist deodar forest is a more or less pure forest of deodar (Cedrus deodara) with a small proportion of other species. Such forest is found near the Hanuman Chatti area between elevations of 2500-2600 m. Some important tree associates found in the forests are Abies pindrow, Hippophae rhamnoides and Populus ciliata. Climbers and epiphytes are absent.

Western mixed coniferous forest is found in the Lambagar and Hanuman Chatti areas between altitudes of 2300 m and 2800 m. This is a mixed coniferous forest of fir, deodar, blue pine and Taxus, but it lacks Picea smithiana in this area. Important shrubs include Berberis aristata, Cotoneaster microphyllus, Elsholtzia fruticosa, Hippophae rhamnoides, Prinsepia utilis, Sarcococca salingna, Sorbaria tomentosa, Spiraea canescens, etc. Herbs and grasses are represented by Adiantum lunulatum, Anaphalis triplinervis, Anemone obtusiloba, Agrostis stolonifera, Calamagrostis emodensis, Circium wallichii, Fragaria nubicola, Geranium robertianum, Impatiens sulcata, etc.

3) Fauna

Wildlife in the area is reported to include leopards, jungle cats, civets, wild dogs, and Indian foxes, and at higher elevations bharals (Himalayan blue sheep), thars (a kind of wild goat), musk deer, snow leopards, and brown bears. Local bird species include partridge, pheasants, pigeons, woodpeckers, and cuckoos. Five species of fish are known to occur in the Dhauliganga River: spotted snow trout (Schizothorax richardsonii), Neomacheilus montanas, sucker head (Garra gotyla), torrent minnow (Barilius sps.), and point-snouted snow trout (Schizothorax progastus). The fish-catch survey conducted by the National Research Centre was dominated by Schizothorax species, which composed 90–95% of the catch on the Alaknanda River and 60% on the Dhauliganga River. The planktonic population in the Dhauliganga River is low. Benthic microfauna and microflora have an important role in the propagation of benthic fauna and fish life.Precious species

4) Land Cover

The major land cover categories are agricultural land and exposed rocks. The land cover pattern of the study areas is shown in Table V-3 below.

Table V-3 Land Cover Pattern of the Study Area

Land Cover	Area (%)
Dense vegetation	8.4%
Discrete vegetation	18.1%
Water bodies/ River bed	1.1%
Barren land and rocky areas	23.2%
Agriculture land (cropping and grazing)	24.6%
Grass land	3.8%
Scrub	13.3%
Snow	7.5%

(Source: EIA Report, Lata-Tapovan Hydroelectric Project (2006))

c. Social environment

1) Economic Development

Livestock grazing and cultivation are the dominant land-use activities in the area. The two cropping seasons are the monsoon season, from April to October and winter, from October to April. The major monsoon crops are maize and pulses, while the main winter crops are wheat, barley, mustard, and peas. Dryland cultivation is the dominant form of cropping, accounting for 85% of cultivated land in the area. Irrigation is practiced on terraced fields, where water is available. Fruit is also grown in small orchards in the area, as well as home garden crops.

Forest products harvested in the area include wood for construction, furniture, and implements; fodder; fuel wood; fruits and berries; medicines; and essential oils. Fishing is only a part-time activity; some of the catch is sold locally.

2) Social and Cultural Resources

The local settlement pattern is characterized by the 14 small rural villages, plus the town of Joshimath. The major town of Joshimath is on National Highway (NH) 58. This town is the local service center, providing a base station for pilgrims/tourists visiting Shri Badrinathji, Hemkunt Sahib, and the Valley of Flowers.

There are no historic or religious sites in the project area. Apart from village temples, the nearest site of historic and religious importance is Badrinath Temple, on the Alaknanda River 3,133 m above mean sea level. This site is 55 km from the barrage site on NH 58. Badrinath shrine was established as a pilgrimage site in the 8th century. A temple was first built in the 9th century, and the current structure is around 400 years old. About 600,000 pilgrims visit the temple every year between May and October. Additionally, the Joshimath Temple, established 1,200 years ago in Joshimath, is a notable pilgrimage site in the vicinity of the·Project.

3) Demographic Profile of the Villages in the Study Area

Information concerning the 14 villages in the study area was collected. The demographic profile is given in Table V-4 below. The total population of the area as per the 2001 census was 3,830. The number of females per 1,000 males is 1,034. The average family consists of 4.5 members. The latest data are from the 2011 census, but those figures had still not been released as of April 2012.

The 2011 census shows a population of 391,114 for Chamoli District and 10,116,752 for Uttarkhand State. The decadal population growth from 2001 to 2011 of Chamoli District and Uttarakhand State were 5.6% and 19.7%, respectively.

Table V-4 Demographic Profile of the Villages in the Study Area

Village Name	No. of households	Total population	Male population	Female population	SC population	ST Population
Barhgaon	176	825	408	417	164	0
Payaichormi	27	134	69	65	0	0
Dhak	85	369	182	187	178	0
Kundikhola	45	233	111	122	24	0
Bilagar	27	121	60	61	5	0
Chamtoli	17	78	36	42	0	0
Topovan	173	793	404	389	224	29
Gahar	11	51	25	26	0	0
Bhangul	42	195	107	88	18	6
Lata	75	342	150	192	59	277
Raini Chak Lata	41	153	82	71	0	141
Pang Chak Lata	29	105	44	61	1	103
Raini Chak Subhai	39	153	71	82	0	148
Ringi	61	278	134	144	9	6
Total	848	3830	1883	1947	682	709

(Source: EIA Report, Lata-Tapovan Hydroelectric Project (2006), Census of India 2001)

Out of the total population, Scheduled Tribes (ST) comprise 18.5%, Scheduled Casts (SC) comprise 17.8%, and the remainder of the population accounts for 63.7% of the total. However, it is to be noted that the distribution is quite diverse. Some of the villages, such as Raini Chak Lata and Paing Chak Lata, have a large population belonging to a Scheduled Tribe.

The overall literacy rate in the area is 66%; 78.7% for men and 53.3% for women. The highest literacy rate was observed in Bilagar village (76.9%). Lata village had the lowest literacy rate of 51.2%.

Table V-5 Literacy Rate of Villages in the Study Area

Village Name	Total Literacy	Literacy rate (%)	Male literates	Male literacy rate (%)	Female literates	Female literacy rate (%)
Barhgaon	569	69.0	346	60.8	223	39.2
Payaichormi	81	60.4	53	65.4	28	34.6
Dhak	220	59.6	137	62.3	83	37.7
Kundikhola	148	66.5	85	57.4	63	42.6
Bilagar	93	76.9	45	48.4	48	51.6
Chamtoli	51	65.4	29	56.9	22	43.1
Topovan	554	69.9	323	58.3	231	41.7
Gahar	31	60.8	19	61.3	12	38.7
Bhangul	132	67.7	88	66.7	44	33.3
Lata	175	51.2	86	49.1	89	50.9
Raini Chak Lata	116	75.8	66	56.9	50	43.1
Pang Chak Lata	71	67.6	39	54.9	32	45.1
Raini Chak Subhai	104	68.0	57	54.8	47	45.2
Ringi	175	62.9	109	62.3	66	37.7
Total	2520	65.8	1482	78.7	1038	53.3

(Source: EIA Report, Lata-Tapovan Hydroelectric Project (2006), Census of India 2001)

The percentage of main workers (who worked for more than six months of the previous year) in the total population is 36.4%. Marginal workers (who worked for less than six months of the previous year) account for 8.3%, and non-workers account for 55.3%.

Table V-6 Occupational Profile in the Study Area

Village Name	Workers	Marginal workers	Non Workers
Barhgaon	228	13	597
Payaichormi	37	9	97
Dhak	110	13	259
Kundikhola	107	57	126
Bilagar	35	24	86
Chamtoli	45	5	33
Topovan	290	35	503
Gahar	16	0	35
Bhangul	101	33	94
Lata	170	3	172
Raini Chak Lata	80	49	73
Pang Chak Lata	54	19	51
Raini Chak Subhai	82	65	71
Ringi	151	6	127
Total	1506	331	2324

(Source: EIA Report, Lata-Tapovan Hydroelectric Project (2006), Census of India 2001)

The major occupation in the villages of the study area is agriculture. Most of the working population is involved in this occupation. The common occupations prevalent in the study villages are work in construction, transportation and communications etc.

4) Local Infrastructure

Buses are the only community transport available in the study area. The study area has no railway service. The nearest railway stations are at Haridwar and Dehradun, located respectively about 290 km and 360 km away.

Medical facilities are poor in the study area villages. Hospital facilities are available only at Tapovan village. Child welfare Centers and Maternity and Childcare Centers are available in the villages of Tapovan, Lata and Barhgaon.

Information on educational facilities is summarized in the table below.

No high schools, colleges, or other vocational training centers are available.

Table V-7 Educational Facilities in the Study Area

Village Name	Primary School	Middle School	High School
Barhgaon	1	1	-
Payaichormi	1	-	-
Dhak	1	1	-
Kundikhola	-	-	-
Bilagar	-	-	-
Chamtoli	-	-	-
Topovan	1	1	-
Gahar	-	-	-
Bhangul	1	-	-
Lata	1	-	-
Raini Chak Lata	1	1	-
Pang Chak Lata	1	-	-
Raini Chak Subhai	1	1	-
Ringi	1	-	-

(Source: EIA Report, Lata-Tapovan Hydroelectric Project (2006), Census of India 2001)

5) Housing

Houses are built in traditional fashion with brick and mortar and also using traditional utilities. About 25-30% of houses are pucca houses (built of more permanent materials like stone, brick or cement), 2-3% of houses are kutcha houses (with mud or dry masonry walls), whereas a large majority of 68-73% are semi-pucca houses (pucca houses roofed with traditional materials). Most of the houses are two-storied with an average of four to five rooms, and most of them (about 75-80%) are electrified. Natural sources, such as springs are often used directly as a source of drinking water, though tap water is used by about 80% of the people. Local people depend largely on fossil fuels, including dung cake and forest wood (about 60-70% of them), while about 22-25% use LPG, and the rest use other fuels such as kerosene and bio-gas.

(2) Present Condition of the Project Area

The project area is located in a steep-walled valley with little flatland which is included in the Nanda Devi Biosphere Reserve. There is shrubbery, grassland, farmland, rocky areas and residential areas in the project area. The farmland and residential areas are held privately, while the rest is public land. There is no power plant facility, but two hydro power plant projects are located near the project area. The Tapovan Vishnugad H.E. Project (520 MW) is progressing slowly and will start operation in 2014. The Lata-Tapovan H.E. Project (171 MW) is stalled for the moment. The candidate drilling site for exploratory wells is located in Ringi village, where flatland is occupied by residences, farm land, schools and an army base. The drilling site is located 250 m away from the two schools, 300 m away from the residential area and 500 m away from the army base in Ringi village. The population of the Ringi Village is about 600, according to the village people. They obtain their drinking water from tributaries of Dhauli Ganga River at higher elevations. There are some mountain trails from the main road to Ringi village, which are community roads of Ringi Village, but are narrow and unpaved, so they are covered by debris and landslides in the rainy season from July to September and by snow in the winter season from December to March.

(3) Environmental and Social Impacts Associated with Project Implementation

Environmental and Social Considerations

On the basis of the site survey and the project characteristics, study items requiring assessment before project implementation were selected to ensure that environmental and social considerations are given appropriate weight. Table V-8 shows the rationale for selecting items for which impact is anticipated. This table should be viewed in the light of the following considerations.

The schools and residential area in Ringi village are located 250 m away from the candidate drilling site for exploratory wells. The A-weighted sound pressure level of well drilling generally ranges from 100 to 110 dB(A), and drilling is a 24-hour operation. Thus a negative impact is expected on the elementary school in the daytime and on residences at night. Measures to muffle the drilling noise and/or relocation of the elementary school are desirable.

Residents in Ringi village use drinking water from tributaries of the Dhauli Ganga River at higher elevations. The water for exploratory well drilling is pumped up from the mainstream at lower elevations. Thus no negative impact is expected on drinking water, but the monitoring of drinking water quality is recommended to ease the anxiety of residents.

The possibility of hydrogen sulfide exposure from exploratory wells is low, but monitoring during production testing is recommended.

To create an access road from the main road to the exploratory well drilling site, it is planned to refurbish the mountain trail which is a community road of Ringani Village. After refurbishment, the amount of construction traffic will increase, and the provision of an alternative community road might be necessary, if requested by the local residents.

Table V-8 Estimation of Environmental Impacts

Items		Exploration/Implementation Period	Operation Period
Air Quality	Hydrogen sulfide (H_2S)	Production testing conducted for reservoir evaluation will involve emissions of gas containing H_2S, which will temporarily affect the surrounding areas.	As geothermal fluid containing H_2S will be used as steam for generating electricity, H_2S will be emitted with the steam through the cooling tower into the atmosphere, which will affect the environment near the power plant.

	Nitrogen oxide (NOx)	Transportation of equipment and materials during construction will not affect an extensive area. However, there may be private homes near the transportation route which will be temporarily affected.	-
	Dust, etc.	Vehicles transporting equipment and materials during construction will raise dirt and dust clouds, but the affected area will be limited. However, there may be private homes near the transportation route which will be affected.	-
Noise & vibration		Noise and vibration will be emitted by the drilling and operation of geothermal wells, and also by the construction equipment used during exploration and construction. Such noise and vibration are only temporary, but will affect the ambient environment near the project site.	During plant operation, noise and vibration will be generated from the cooling towers, steam turbines, generators and other such equipment, which will affect the ambient environment near the power plant.
Water Quality		Muddy water will be generated during drilling.	During operation, the effluent from the power plant may adversely affect the surrounding hydrological environment.
Soil Contamination		The risk of soil contamination resulting from geothermal fluid leaking into the surroundings must be considered in the design of the FCRS,	-
Waste	Industrial waste	During construction, industrial waste (excavation sludge, and construction waste and debris) will be generated.	During operation, industrial waste (such as sludge and waste oil) will be generated.
	Civil engineering work waste soil	Civil engineering work will generate waste soil. Measures to reduce its volume and appropriate disposal to the spoil bank must be studied.	-

Subsidence		-	As geothermal fluid will be extracted from deep underground and hot water will be returned to deep underground, ground subsidence is expected in the neighborhood of the power plant.
Odor		The unpleasant, foul odors of H2S generated in the well-discharge tests are projected to temporarily affect the neighboring areas.	Unpleasant or foul odors of H2S generated during the in-service period are projected to affect the areas neighbouring the power-plant.
Natural environment	Water use	Construction will use surface water /groundwater, which may affect the river flow /groundwater level. However, this water intake will be temporary and the amount is so limited that only a slight impact is expected.	During operation, surface water /groundwater will be used for power generation. There is a concern about the water intake affecting the river flow /groundwater level, as well as swamps and bogs.
	Topography and Geology	It is anticipated that surveying, drilling of production wells and power plant construction work could cause some changes to the topography.	-
Natural environment	Flora & Fauna	Flora and fauna may be temporarily affected during the project implementation period.	Modification of the land and the presence of plant facilities will affect the distribution and habitat of the animals and the important plant species and their communities.
	Ecological Systems	There may be some temporary influence during the project implementation period.	Modification of the land and the presence of plant facilities will presumably change the distribution of the animals and plants, and their habitat and breeding environment.
Social Environment	Local economy such as employment and livelihood etc.	An increase in employment opportunities, surveys, local procurement of construction materials and equipment, and local purchase of food for workers are expected to have a positive effect on the local economy and residents' livelihood.	An increase in employment opportunities, local procurement of materials and equipment for power plant management and maintenance, and local purchase of food for power plant workers are expected to have a positive effect on the local economy and residents' livelihood.

	Land use and utilization of local resources	Setting up the survey and construction work bases and construction of access roads will involve the use of land and local resources.	The operation of the power plant and relevant facilities will involve the use of land and local resources.
	Existing social infrastructure and services	Social infrastructure can be expected to improve with the construction and improvement of roads during the survey and project implementation period.	Positive effects, such as construction, maintenance and management of the roads and the supply of electric energy to the local residents, can be expected from the presence of a power plant and other relevant facilities.
Others	Global Warming	Vehicles and machines used in transport and construction will emit greenhouse gases. However, such emissions are only temporary during the project implementation period.	A large number of positive effects can be expected, as the replacement of diesel power plants will lead to dramatic reductions in greenhouse gas emissions. Also, geothermal power generation involves far lower greenhouse gas emissions than other types of steam-power generation.

(4) Outline of Laws and Regulations relevant to Environmental and Social Considerations

a. Laws and Regulations for Environment Protection during Geothermal Development

The following are the laws and regulations regarding environmental protection that are relevant to geothermal development. All laws and regulations can be found at the Indian government website http://moef.nic.in/modules/rules-and-regulations/environment-protction/ (sic).

Environmental Protection

☐ No. 29 of 1986, [23/5/1986] - The Environment (Protection) Act, 1986, amended 1991
☐ S.O.844(E), [19/11/1986] - The Environment (Protection) Rules, 1986
☐ S.O.1533(E), [14/09/2006] - Environmental Impact Assessment Notification-2006

Air Pollution

☐ No. 14 of 1981, [29/3/1981] - The Air (Prevention and Control of Pollution) Act 1981, amended 1987
☐ G.S.R.6(E), [21/12/1983] - The Air (Prevention and Control of Pollution) (Union Territories) Rules, 1983
☐ G.S.R.712(E), [18/11/1982] - The Air (Prevention and Control of Pollution) Rules, 1982

Water

☐ No. 36 of 1977, [7/12/1977] - The Water (Prevention and Control of Pollution) Cess Act, 1977, amended 1992 ,
☐ No. 19 of 2003, [17/3/2003] - The Water (Prevention and Control of Pollution) Cess (Amendment) Act, 2003.
☐ No. 6 of 1974, [23/3/1974] - The Water (Prevention and Control of Pollution) Act, 1974,

amended 1988

- □ G.S.R.830(E), [24/11/2011] - The Water (Prevention and Control of Pollution) Amendment Rules, 2011.
- □ G.S.R.378(E), [24/7/1978] - The Water (Prevention and Control of Pollution) Cess Rules, 1978
- □ G.S.R.58(E), [27/2/1975] - The Water (Prevention and Control of Pollution) Rules, 1975
- □ Central Board for the Prevention and Control of Water Pollution (Procedure for Transaction of Business) Rules, 1975 amended 1976

Noise

- □ The noise pollution (Regulation and control) (Amendment) Rules,
- □ S.O.123(E), [14/2/2000] - Noise Pollution (Regulation and Control) Rules, 2000

Forest Conservation

- □ State/Union Territory Minor Forest Produce (Ownership of Forest Dependent Community) Act, 2005 - Draft
- □ Forest (Conservation) Act, 1980, amended 1988.
- □ The Indian Forest Act, 1927.
- □ G.S.R.23(E) - Forest (Conservation) Rules, 2003.
- □ G.S.R.719 - Forest (Conservation) Rules, 1981, amended 1992.

b) Environmental Assessment System in India

In India, many development projects prior to the 1980s were implemented with very little or no environmental precautions. Later on, these issues were formally addressed by the Department of Environment, which was established in 1980. This was then upgraded to the Ministry of Environment and Forests in 1985. In 1980, the clearance of large projects from the environmental point of view became an administrative requirement to the extent that the planning commission and the central investment board sought proof of such clearance before approving financing.

Five years later, in 1985, the Ministry of Environment and Forests issued guidelines for the Environmental Assessment of river valley projects. These guidelines require various studies, such as an assessment of the impacts on forests and wildlife in the submergence zone, on the potential for waterlogging, on upstream and downstream aquatic ecosystems and fisheries, as well as on water-borne diseases, climatic changes and seismicity. Major legislative measures affecting environmental clearance were taken in 1994, when a specific notification requiring environmental clearances was issued under section 3 and rule 5 of the environment protection Act, 1986. This is known as the "Environment impact Assessment Notification 1994".

Environmental clearance for development projects can be obtained either at the state level or at the central level depending on the characteristics of the project. However (and regardless of where the final environmental clearance is obtained), for most projects, the consent must first be sought from the relevant state pollution control board or pollution control committees, in the case of union territories.

The project proponent is responsible for preparing the EIA statement with the help of an external consultant or institution.

Ideally, the EIA should provide information to decision-makers at an early stage in the project planning cycle. It should be initiated as early as possible before the commencement of a project. If the project secures approval, the EIA should include a provision to cover the audit of the project.

Geothermal power plants are not listed in the "List of Projects or Activities Requiring Prior Environmental Clearance", but "geothermal power plants" could be construed as belonging to the category of "thermal power plants". A thermal power plant of more than 50 MW is classified as Category "A", while plants of lesser capacity fall into Category"B".

The Ministry of Environment and Forests (MOEF) is the agency charged with the environmental clearance of Category"A" projects, while the State (or Union territory) Environmental Impact Assessment Authority (SEIAA) is the agency responsible for the environmental clearance of Category"B" projects.

V-2-4 Condition of Infrastructure in Tapovan Field

Access Conditions

The Tapovan area is situated in Chamoli district of Uttarakhand State. The area is located at an altitude of approximately 2,000 m above sea level in the valley of the Dhauliganga river, a major tributary of the Alaknanda River. The distance from Dehradun, the state capital of Uttarakhand State, to Joshimath is about 280 km via public roads which are all paved, presenting few issues for the transportation of heavy equipment such as drilling equipment. The distance from Joshimath to Tapovan is about 15 km and the road condition is generally good, though some repairs and improvements to the existing road will be required in several places. In addition, there are rock wall protrusions overhanging the road in several places, which may interfere with the transportation of heavy equipment. It is strongly recommended that these overhangs should be removed.

The distance from Tapovan to the site is about 3 km. However, it is impossible to create a new access from the nearest point on the existing road due to the very steep conditions. Thus, it is imperative that large-scale improvements should be made in the existing road from Tapovan village to the site. A road map covering a wide area is shown in Fig. V-10.

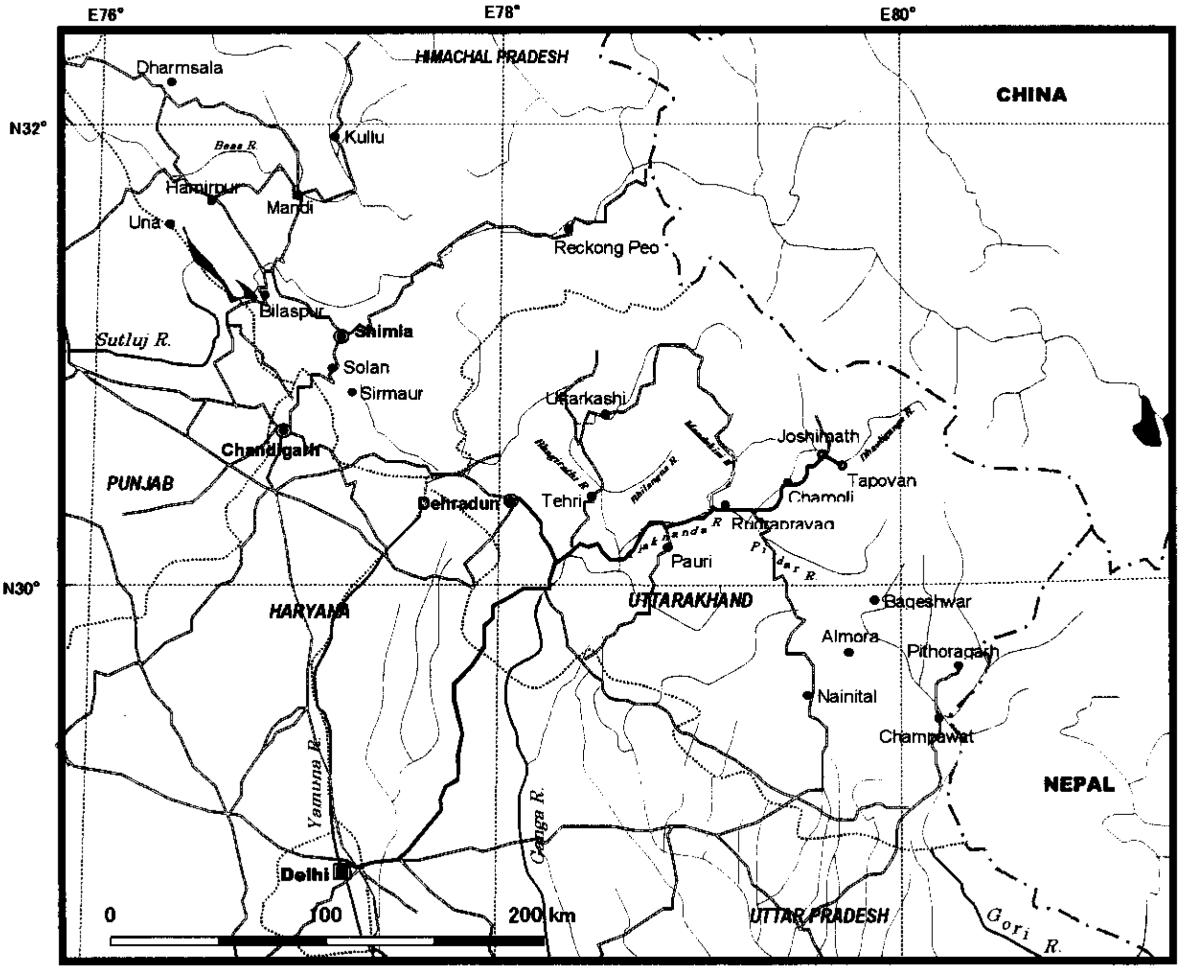


Fig. V-10 Route Map

Status of rivers

There are no rivers running through the Tapovan area other than the Dhauli Ganga River. The flow rate of the river is abundant, so several hydro power plant projects are in progress in this area, and also some of river water is used to supply Tapovan village.

In the village in the vicinity of the candidate site for the drilling and eventual power plant, the residents generally use meteoric water flowing through the valley in the vicinity as drinking water and for agriculture, with no direct intake from the Dhauli Ganga River. Therefore, even if there is direct intake from the river for drilling and power generation, the possible impact on the surrounding environment will be very small.

The candidate site for the drilling pad and the power plant

The Tapovan area is characterized by a steep topography, thus there are few candidate sites for the power plant and drilling pad. The only candidate site is located approximately 1 km west of well AGW-3 on the left bank of Dhauliganga River, where the terrace spreads out into a relatively gently sloping topography. The elevation of the site is 190 m higher than the existing public road and there are many private houses and an elementary school. Therefore the possibility should be carefully considered in advance of the project that these residents must be transferred elsewhere or appropriate environmental impact mitigations must be put in place. The photograph of candidate site and the tentative site layout are shown in Figs. V-11and V-12, and the site conditions are presented in Table V-9.

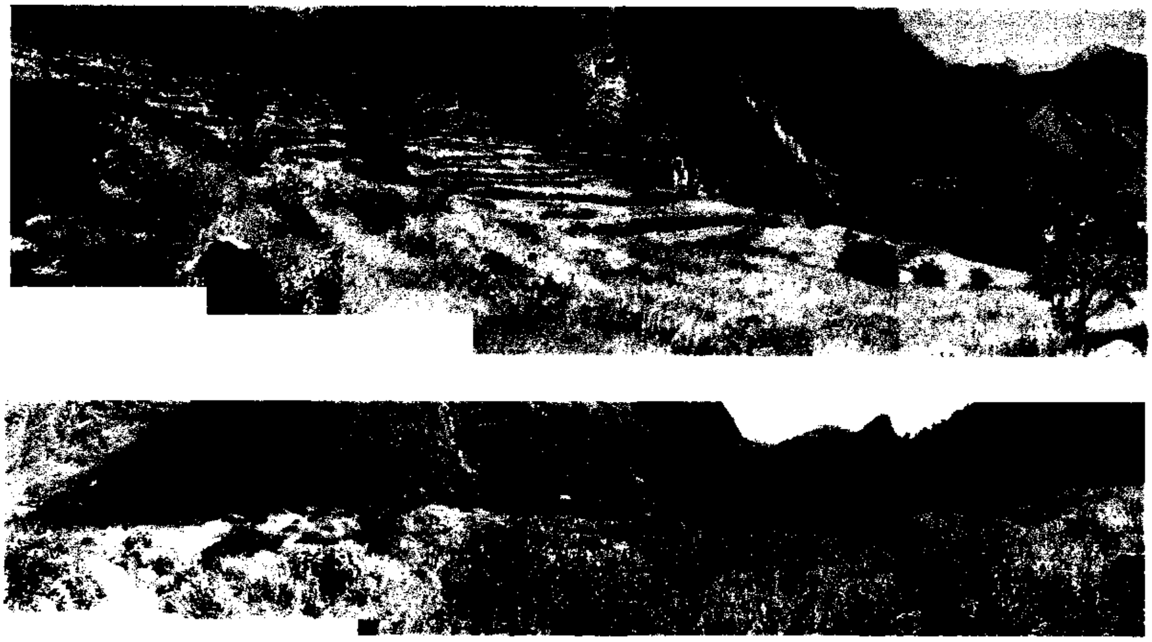


Fig. V-11 Proposed Site for Power Plant and Geothermal Wells

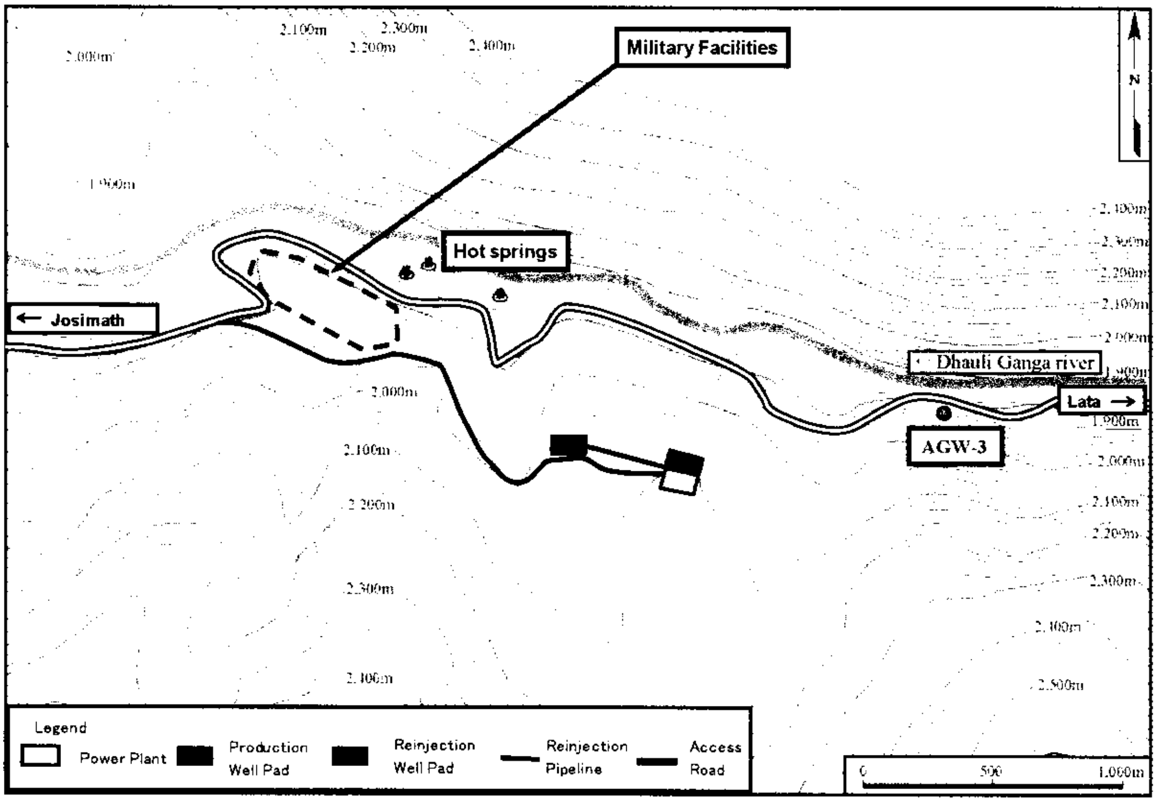


Fig. V-12 Site Layout in the Tapovan Area

Table V-9 Site Conditions

Location	Around 3km from Tapovan, around 18km from Joshimath
Elevation	2,044m - 2,133m
Access Conditions	Dehradun - Joshimath : Good Joshimath - Tapovan : generally good, but some road repair and improvements are required in several places [There are several overhanging rock walls along the road] Tapovan - Candidate site : None, a new access road will be required (2km)
Site Overview	There are four (4) shallow wells (AGW-2、3、5、6)
	Around 600 residents live near the site, and there is an elementary school
	In a generally steep-walled valley, the candidate sites are located on relatively mildly sloping terrain .
Status of Candidate Site	The site is covered by soil, with some outcrops of very hard sedimentary rock There are some cultivated areas, which are privately owned There is some forest area, which is State-owned A big river (Dhauli ganga River) flows near the site
Weather Conditions	The rainy season runs from July - September The snow season runs from the end of December - March [Max. depth of snow is around 30cm}
*Remarks 1. Drilling site a. Production well	
Candidate 1	ELV. 2,056m On a relatively mild slope in the cultivated area; Good, but a huge volume of civil work will be required
Candidate 2	ELV. 2,112m In a flat area where there is an elementary school; Can be considered
Candidate 3	ELV. 2,133m In a flat area where there are many houses; Impossible
b. Reinjection well	The candidate site selected in an earlier JETRO survey is on the Indian Army Base, so it is impossible to access. However, flat locations are very lmited in the Tapovan area, so the reinjection well site should be located close to the production well site.
2. Access	There is no access road to the candidate site. Around 2km of new access road should be constructed from Tapovan Village. It will be necessary for potential drilling contractors to carry out a detailed transportation survey of the route from their base of operations to the drilling site.
3. Water supply	Water will be taken from a river running through a very steep-walled valley. The necessary water volume (Max.1,000 liters/minute) can be secured. However, it will be quite difficult to maintain this water supply for the following reasons. * A high-pressure pump will be required (More than 25KSC at 1,000LPM) due to difference in elevation between the river and the site. * It will be quite difficult to maintain the water in-take point due to the constant changes in the water level of the river through the seasons (Dry/ Rainy/Snow) *Water pump installation will be quite difficult (The difference in elevation between the water level or the river and the existing road is around 70m)
4. Weather conditions	The senior manager of the NTPC Tapovan Hydro Power Project made it clear during a meeting at his project office that it is quite difficult to maintain an effective work regime in the rainy season and in the snow season. In the rainy season, landslides and rock-falls can occur, while in the snow season, transportation work is difficult.

Transmission Line

On Dhauriganga River in the area surrounding Tapovan, NTPC has two hydroelectric power plant projects under construction. Downstream on the Dhauriganga River, the private sector (including GVK with a 330 MW plant) also has several hydroelectric power plant projects under construction or in the planning stage. However, according to local information from the NTPC Tapovan Project Office, construction has been suspended on the Lata-Tapovan hydro plant and is to resume with the prospect of not standing.

□ Tapovan-Vishnugad Hydro Project

Output: 520 MW (130 MW x 3)

Location: 16 km northwest of Tapovan geothermal project site

Start of operation: 2014

□ Lata-Tapovan Hydro Project

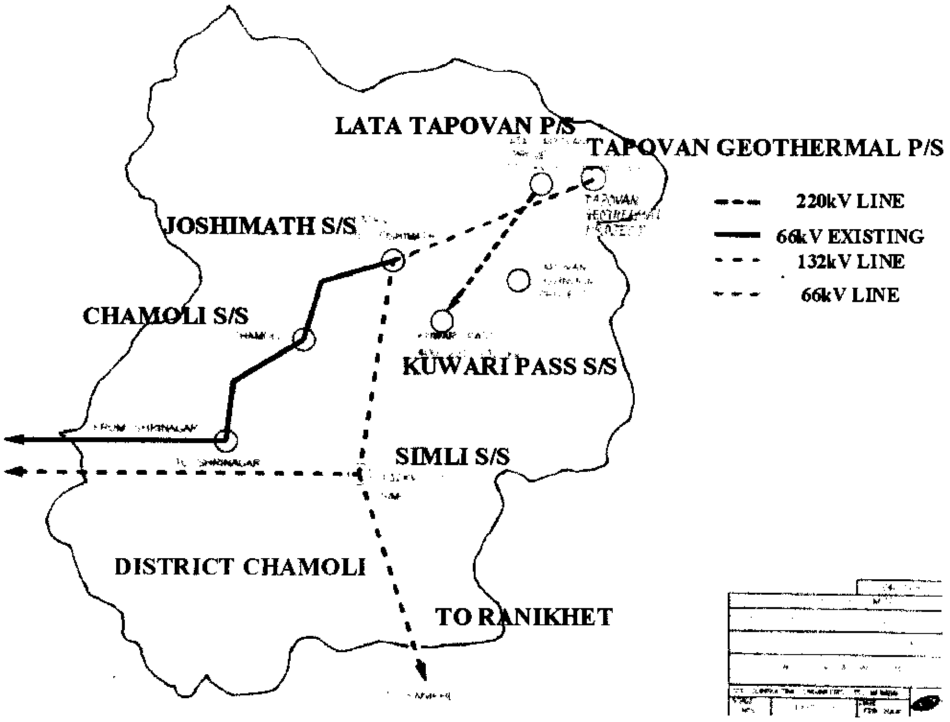
Output: 171 MW (57 MW x 3)

Location: 1.3 km northwest of Tapovan geothermal project site

Start of operation: currently suspended

The power system of Uttarakand in the northern region has been shown already in Fig. II-3, and the power system of Chamoli District including the Tapovan geothermal area is shown in Fig. V-13. As can be seen from this figure, the Tapovan geothermal plant site is pretty close to Lata-Tapovan hydro power station, which is a possible connection point for the power plant. The existing Joshimath substation is an alternative connecting point. Figure V-14 shows the hydro power projects in the Tapovan area planned by NTPC.

It may be possible to use a 220 kV transmission line to connect the new Tapovan geothermal power plant to the nearest Lata-Tapovan hydro power station, which is within 2 km of the geothermal plant. Such a connection would require very little land, but would involve considerably high costs because 220 kV Gas Insulated Switch Gear (GIS) has been adopted at the Lata-Tapovan power station. Therefore, a 66kV transmission line to the existing Joshimath substation would be the best option, since the output of the geothermal power plant will be small, maybe around 10 MW, and construction on the Lata-Tapovan hydro plant has been suspended. This 66 kV transmission line would be about 10 km in length, and would provide onward connection to Chamoli substation and Shirinagar substation. On the other hand, construction of a 132 kV power transmission line from Joshimath substation is in the planning stages.



(Source : NTPC Hydro Limited)

Fig. V-13 Power System of Chamoli District

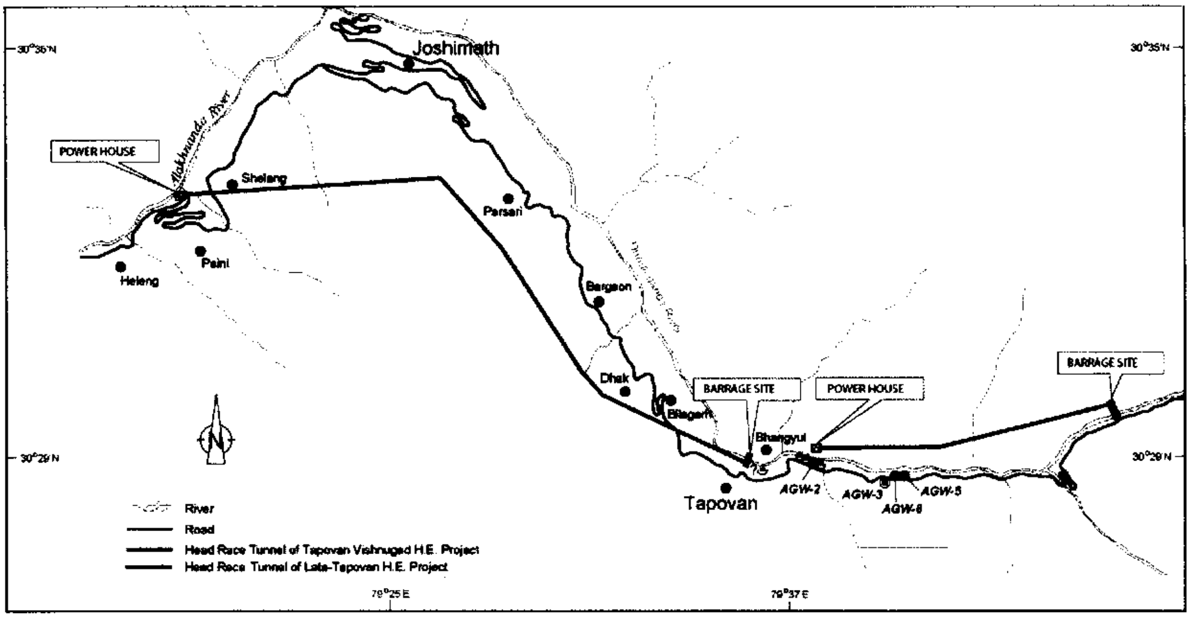


Fig. V-14 Hydro Power Projects in the Tapovan Area

CHAPTER VI

VI IMPLEMENTATION PLAN OF TAPOVAN GEOTHERMAL POWER PLANT PROJECT

This study has clarified a number of factors arguing against geothermal power development in the Tapovan field. The main negative factors are the following site conditions, which restrict land use for the geothermal project.

- The field is situated along the Dhauli Ganga River (in a steep-walled valley) and possible areas for civil work (flat to moderate slopes) are quite limited around Ringi village. In addition, the western part of this area is already utilized as an army base, and the remaining part is also utilized as cultivated land or residential areas. Therefore, negotiations with local people for land use will be required.
- This field has rather difficult weather conditions. Heavy rainfall occurs from July to September and landslides frequently occur in this season. December to March is the snow season. In these periods, civil work will be very difficult.
- Steam-field development risk remains, since the capacity of geothermal resources (suitable steam and thermal water production to obtain sustainable power generation) in the Tapovan field is still unknown.

If the first factor and the second factor do not rule out geothermal power development, the following steps can lead to successful geothermal power development in this field. In addition, drilling targets of exploratory wells were examined based on MT survey data provided from NTPC.

VI-1 Resource Evaluation

VI-1-1 Exploratory Well Drilling

(1) Drilling targets

Apparent resistivity section Profile-3 suggests the possible presence of a thrust fault (low-angle reverse fault) in and around Tapovan field. The thrust fault presumed from the MT survey data slopes gently to the east from the vicinity of MT station T04, and passes at an elevation of between 500m and 0m near stations T02 and T03, which are near the drilling pad candidate site, before passing near station T20 at an elevation of between 0m and -500m. However, in the surface topographical and geological data there is nothing corresponding to the thrust fault seen in the MT data. Although a consideration of the regional geological structure of the Himalayan mountain range does not rule out the possibility of a thrust fault being present in this area, it is judged that the precision of the MT survey data suggesting a thrust fault is not, on its own, a sufficient basis for the determination of drilling targets. The surface geological data suggests the presence of high-angle faults F1, F2 and F3 trending in a NW-SE direction and high-angle fault F4 trending in a NE-SW direction. The problem is that it has not been possible to ascertain the distribution of faults underground with great precision in the field. Therefore, exploratory wells should be program to penetrate both inferred faults estimated from geological data and MT survey data. In addition, exploratory wells are planned to cross MT survey line, because location of thrust fault is anticipated only along this MT survey line.

Drilling program of exploratory wells were examined considering above mentioned geological conditions. The main objective of exploratory well drilling is to confirm the existence of geothermal reservoir. Therefore, although exploratory well No. 2 is tentatively planned as exploratory reinjection well, well No. 2 is planned to drill the area where has possibility of existence of geothermal reservoir. If well No. 2 confirms geothermal reservoir, well No. 2 will be converted to production well. Future drilling plan and resource development plan will be examined and formulated based on the results of exploratory well drillings and testing, if further resource development is planned.

Figures VI-1 to VI-3 show drilling program considering uncertainty of existing of drilling targets. Exploratory well No. 1 (exploratory production well) will be drilled from the production well pad site. And exploratory well No. 2 (exploratory reinjection well) will be drilled from the reinjection well pad site. For consideration of the possible throw, the following drilling conditions were assumed. Maximum drift angle of exploratory wells is planned as 40° to obtain long distance of the deviation in order to penetrate some permeable structures. It is recommended that drilling contractor should carefully consider the geological condition and drilling techniques to drill as planned drift angle.

Exploratory well No. 1 (exploratory production well)

Kick off point	200 m
Buildup rate	1°./10 m
Maximum drift angle	40°.
Direction	N65°E

Exploratory well No. 2 (exploratory reinjection well)

Kick off point	200 m
Buildup rate	1°./10 m
Maximum drift angle	40°.
Direction	N20°W

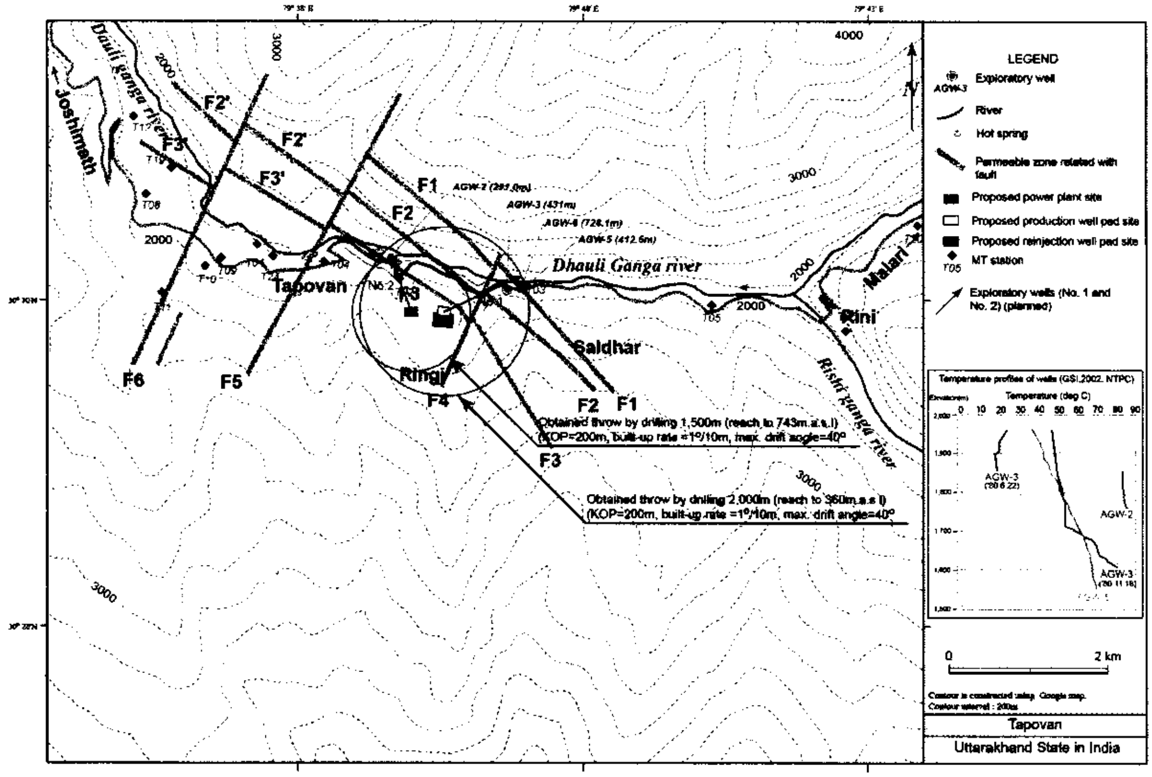


Fig. VI-1 Drilling Targets in Tapovan Field (plane view)

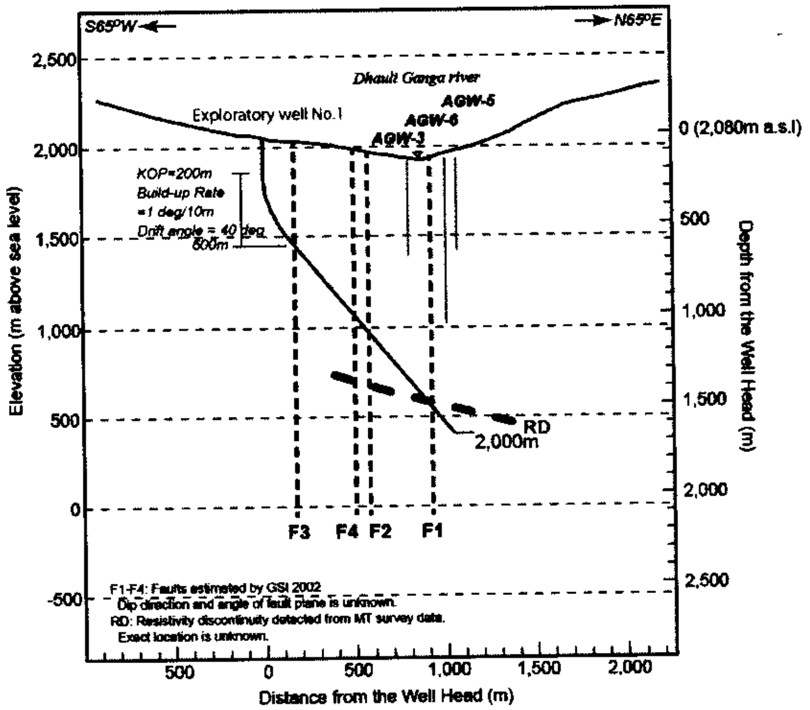


Fig. VI-2 Drilling Targets of Exploratory Production Well (Well No. 1)

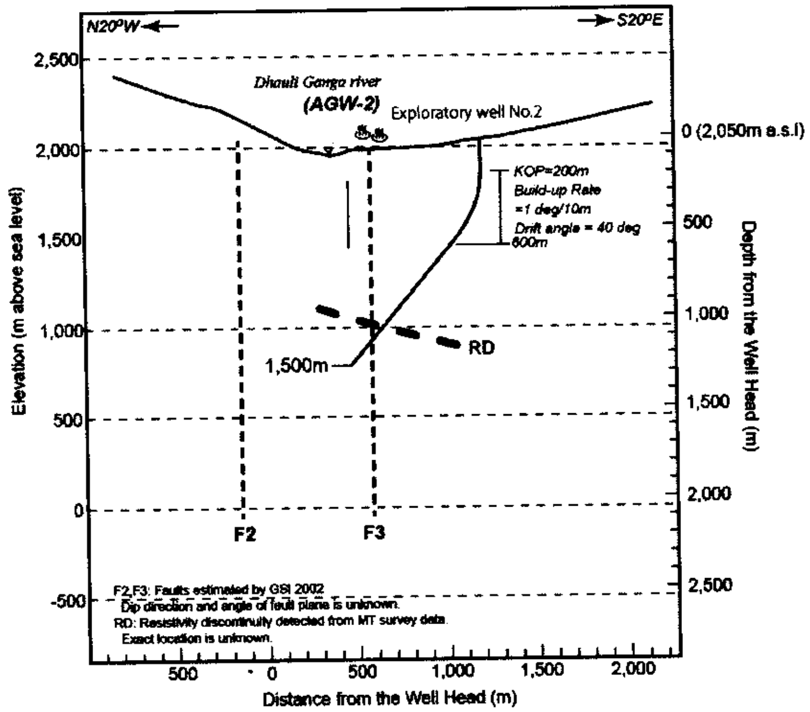


Fig. VI-3 Drilling Targets of Exploratory Reinjection Well (Well No. 2)

(2) Exploratory well drilling

Existence of geothermal reservoir will be examined by exploratory well drillings. Two (2) exploratory wells will be drilled to the above mentioned drilling targets (inferred fault structures). One is for production well, the other is for reinjection well. The following civil work is also included in the drilling work.

- Construction of an access road
- Construction of a drilling pad
- Setup of water supply facilities for the drilling work
- Two exploratory well drillings

a. Access Road Construction

As mentioned earlier, there is no access road permitting large vehicles to access the drilling site. The existing pavement from Tapovan village to the site will require extensive upgrading. For the future transportation of large drilling and power generation equipment, the width of the road should be about 6m, and its length will be approximately 2km.

b. Drilling pad Construction

Possible areas for civil work (flat to moderate slopes) are quite limited around Ringi village. The western part of this area is already utilized as an army base. Therefore, the remaining part is only one candidate site for the construction of well drilling pad. This area is utilized as cultivated land or residential areas. Well pad of exploratory well No. 1 will be constructed at this area. Well pad of exploratory well No. 2 (reinjection well) must be located at a lower level than the well pad of exploratory well No. 1 in order to enable gravity transport of reinjection water from production wells to reinjection wells.

A detailed topographic survey should be carried out prior to the civil work for the drilling pad and access road. In addition, a geotechnical investigation, including but not limited to a field investigation, laboratory testing, analysis and recommendations, should be conducted to understand the subsurface conditions impacting the design and construction plan for the site. Figure VI-4 shows a typical rig layout for drilling five wells.

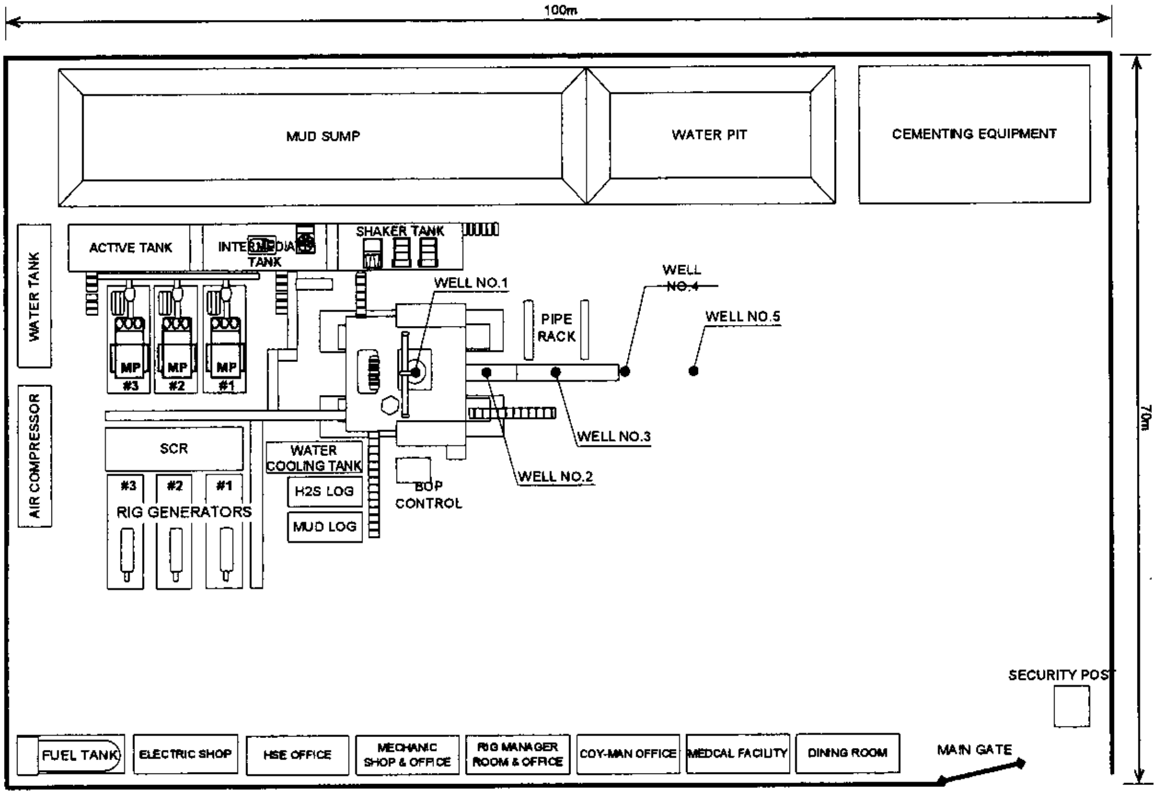


Fig. VI-4 Typical Rig Layout

c. Setup of water supply facilities for drilling work

Fresh water for drilling can be obtained from the Dhauliganga River through a pipeline to the drilling site. However, it will be necessary to consider the following technical points affecting the location of the water intake point:

- The difference in elevation between the water level of the river and the site is around 260 m, requiring a high-pressure pump to feed water to the site
- Variations in the river flow rate are quite large, making it difficult to install water intake facilities
- The difference in elevation between the water level of the river and existing road is around 70 m, which will also make it difficult to install water intake facilities

d. Well drilling

It is recommended that a drilling rig should have an output of around 800-1,000 HP for drilling of a exploratory production well and a exploratory reinjection well to an average depth of 1,500 to 2,000 m. Directional drilling will be applied for both production and reinjection drilling in order to drill multiple targets from a single well pad.

A typical well casing program of exploratory production and reinjection wells are shown in Figs. VI-5 and VI-6. It must be noted that the designation "production well" and "reinjection well" is not intended to fix the future utility of a well, but is only used as a temporary designation for planning purposes. Utilization of exploratory wells will be decided based on the results of drilling.

Typical well-head equipments during drilling works and on operation is shown in Fig. VI-7.

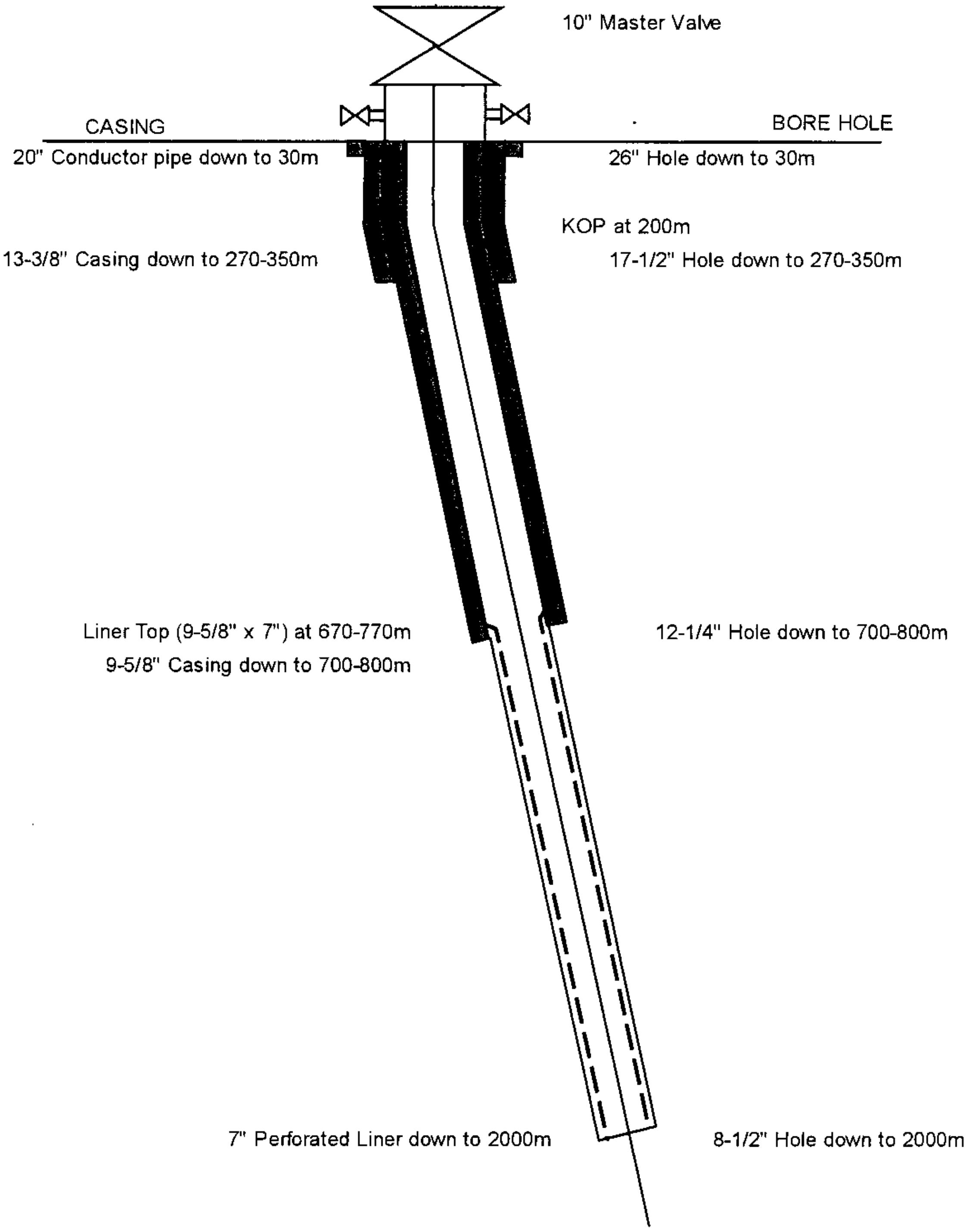


Fig. VI-5 Typical Exploratory Production Well (Well No. 1) Casing Program

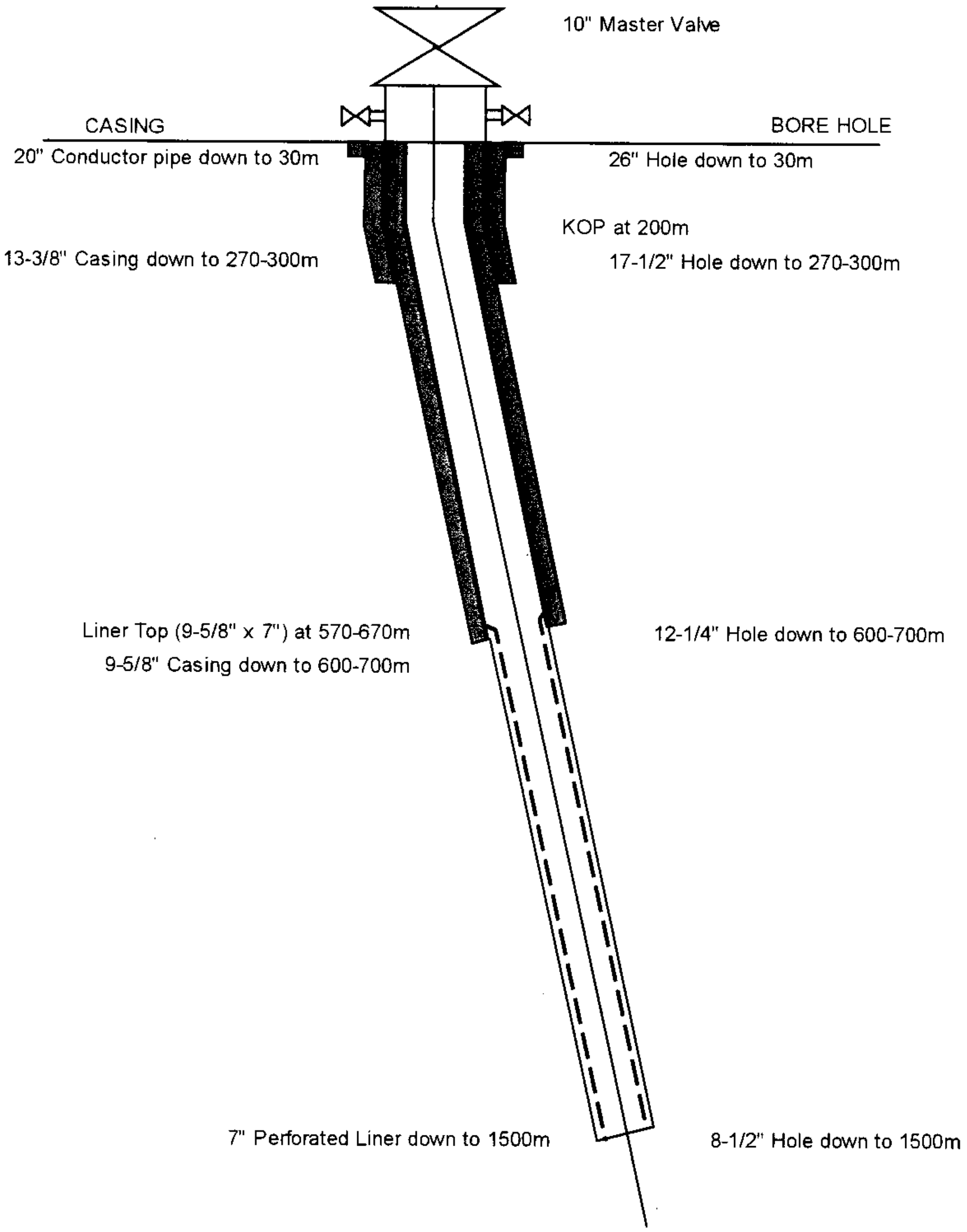


Fig. VI-6 Typical Exploratory Reinjection Well (Well No. 2) Casing Program

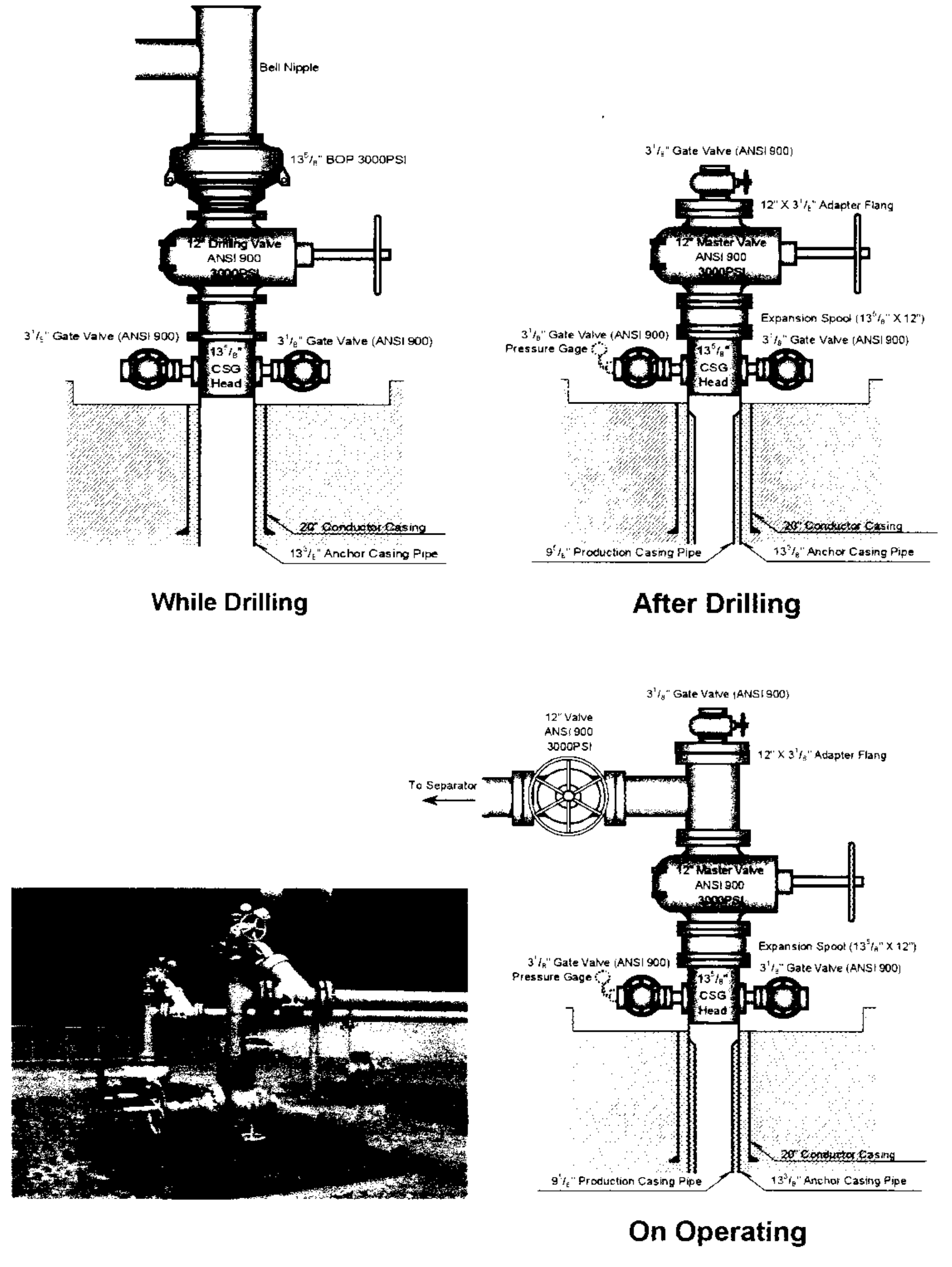


Fig. VI-7 Typical Well-head Equipment

(3) Geological logging (cuttings analysis)

The purpose of this study is to obtain subsurface geological information using the following techniques:

- Observation of cuttings and preparation of the geologic column
- Microscopic observation
- X-Ray diffraction analysis
- Fluid inclusion analysis (optional)

The geological information obtained will be utilized to understand the drilling conditions and revise the drilling program. The information will be analyzed and interpreted for the elaboration of a conceptual model of the geothermal system. Cuttings analysis will generate the following outputs:

- A geologic column of the well
- Results of Microscopic observation
- Results of X-Ray diffraction analysis
- Results of fluid inclusion analysis (optional)

Observation of cuttings

Cuttings taken during well drilling will be studied. The following items will be observed and described at intervals of 5 -10 m in depth.

- Rock type
- Color
- Hardness
- Rock faces
- Degree of hydrothermal alteration
- Characteristics of hydrothermal alteration
- Size of cuttings

The geologic column will be prepared through the integration of these observed items. Through comprehensive interpretation, the stratigraphy around the well will be determined.

Microscopic observation

Representative rock samples illustrating the lithology and hydrothermal alteration will be selected from the cuttings of the well. Thin sections of the selected rock samples will be prepared and observed. A polarizing petrography microscope will be used to study the textural classification, crystal content, mineral paragenesis, degree of alteration, occurrence of secondary minerals, etc.

X-Ray diffraction analysis

The aim of X-Ray diffraction analysis is to identify alteration minerals. Due to the interaction of rocks and geothermal fluid (hot water, steam and gas), chemical reactions take place between the rock-forming minerals and the geothermal fluid. The resulting rock-forming minerals are alteration minerals (secondary minerals). The changes observed in these alteration minerals depend upon the temperature, pressure and chemical composition of the geothermal fluid. With a knowledge of these dependencies, the temperature and pH of the geothermal fluid that caused the alteration can be estimated, based on the presence of alteration minerals detected by X-Ray diffraction analysis. In principle, rock samples should be obtained and analyzed for every 100 m of increasing depth (depending on the geological condition of the well).

Fluid inclusion analysis (optional)

Fluid inclusion thermometry is an effective methodology for estimating underground temperature around a well and for obtaining geochemical information concerning the geothermal fluid. The fluid inclusion homogenization temperature (Th) is measured, and the temperature at which the minerals were formed is determined by analyzing the hydrothermal minerals obtained from cuttings. In addition, in order to obtain information on the salinity of the inclusions, their ice melting point (IMP) is measured. The chemical condition of the trapped hot water is estimated from this information.

Fluid inclusions are micron-sized cavities filled with fluid that is trapped during mineral precipitation or during subsequent fracturing. Information on the trapping temperature and on the composition of the inclusion fluids is derived from phase changes occurring in the inclusions during heating and freezing. At room temperature, fluid inclusions from geothermal systems typically consist of both a liquid phase and a vapor phase. But where the inclusion has trapped a single phase, either liquid or vapor (steam), then the trapping temperature can be determined from the temperature at which the liquid and vapor phases homogenize under heating (homogenization temperature, Th). The salinity of fluid inclusions is calculated based on the temperature of liquid phase freezing (Ice Melting Point, IMP). Although fluid inclusion analysis is not common in geothermal resource exploration in India, considering the effectiveness of the method, it is recommendable to introduce this analytic technique into India.

(4) Production testing

a. Objective

The objective of production testing is to grasp the physical and chemical characteristics of the production fluid.

b. Production test equipment

Physical characteristics

The type and size of equipment needed for a production testing depends on the type of well and reservoir being tested and on the expected maximum flow rate and discharge enthalpy. In general, one of two test methods will be selected for a production test, the separator method or the lip pressure method. Figures VI-8 and VI-9 show the basic equipment setup for these two types of production test. If possible, it is recommended that the separator method be adopted because it's is more accurate than the lip pressure method.

The main equipment required is as follows.

1) Atmospheric separator
2) Orifice plates
3) Weir box
4) Pressure gauges, manometers and a barometer

Chemical characteristics

It must be noted that the chemical composition of fluid (hot water and gas including steam) discharged from a well is critical data for the design of a power plant and FCRS (fluid collection and reinjection system). For example, a high concentration of non-condensable gas (NCG) will require a gas-ejection system for the power plant, and when the fluid chemistry indicates that a serious erosion-corrosion problem and/or scaling problem will arise, economical countermeasures must be considered.

Two-phase fluids are introduced into the sampling separator from the sampling nozzle, and separated steam and gas are cooled by a sampling cooler to separate the condensate and gas (see Fig. VI-10). It is desirable to carry out sampling immediately after a physical well characteristics test. In addition to atmospheric temperature and pressure, separator pressure, and the temperature of the hot water are recorded during sampling. The components of sampled fluid that are analyzed are the following:

Hot water: pH, conductivity, Na, K, Li, NH_4, Ca, Mg, T-Fe, Al, Cl, SO_4, HCO_3, T-CO_2, F, Br, I, As, B, T-SiO_2, H_2S, T-Hg, $\delta D(H_2O)$, $\delta^{18}O(H_2O)$, $\delta^{18}O(SO_4)$, $\delta^{34}S(SO_4)$, and Tritium

Condensate: pH, conductivity, NH_4, Cl, T-CO_2, As, B, T-SiO_2, T-Hg, $\delta D(H_2O)$, and $\delta^{18}O(H_2O)$

Gas: volumetric ratio of total gas to total gas + steam, CO_2, H_2S, R-gas, $\delta D(H_2)$, $\delta^{13}C(CO_2)$, $\delta^{13}C(CH_4)$, $\delta^{34}S(H_2S)$; and the following components in R-gas: CH_4, H_2, N_2, O_2, Ar, and He

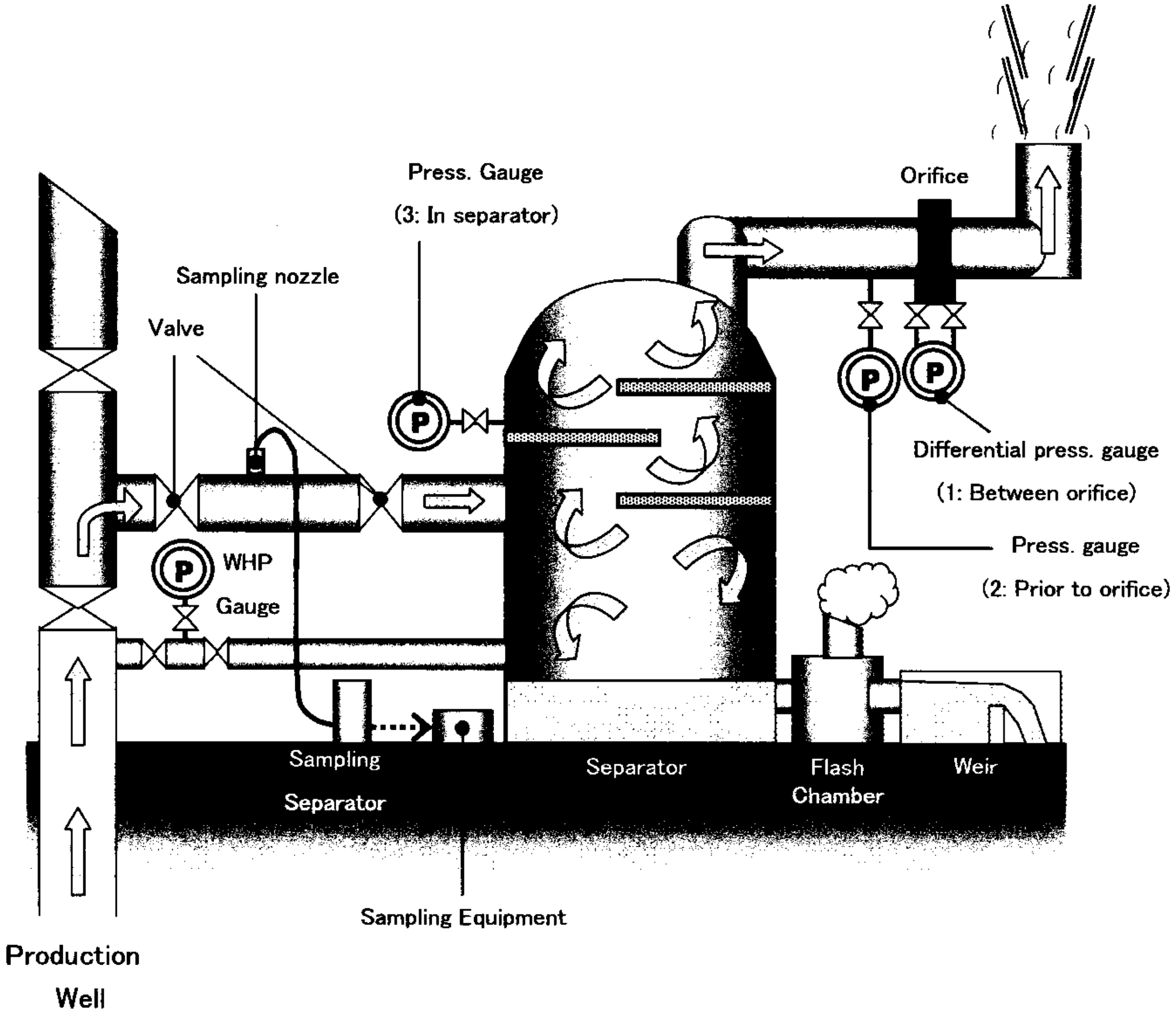


Fig. VI-8 Schematic Equipment Setup for the Separator Method

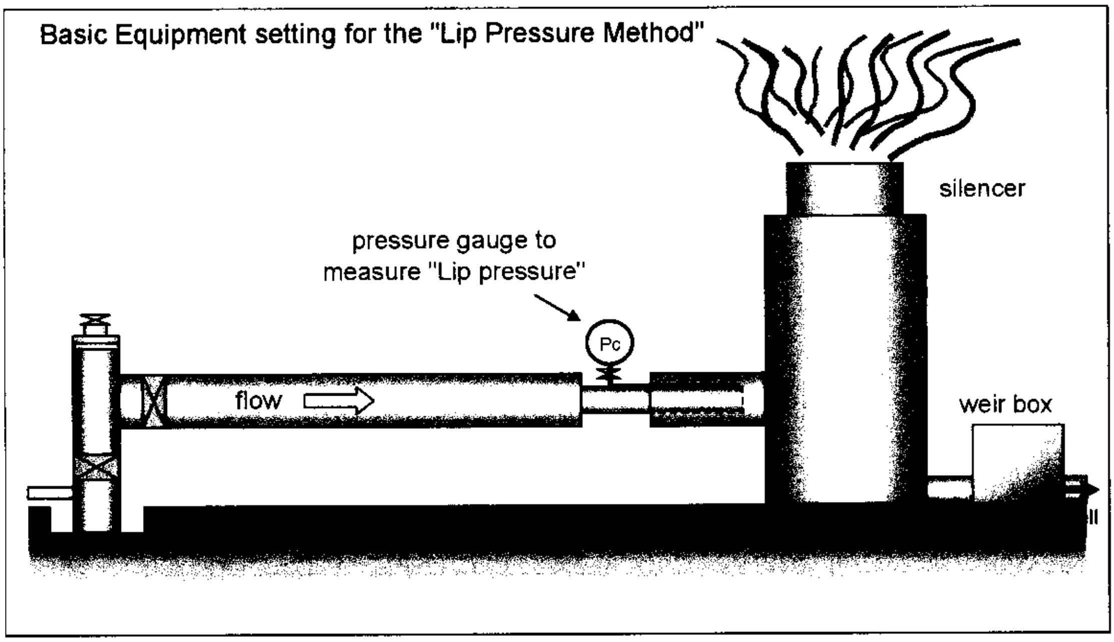


Fig. VI-9 Schematic Equipment Setup for the Lip Pressure Method

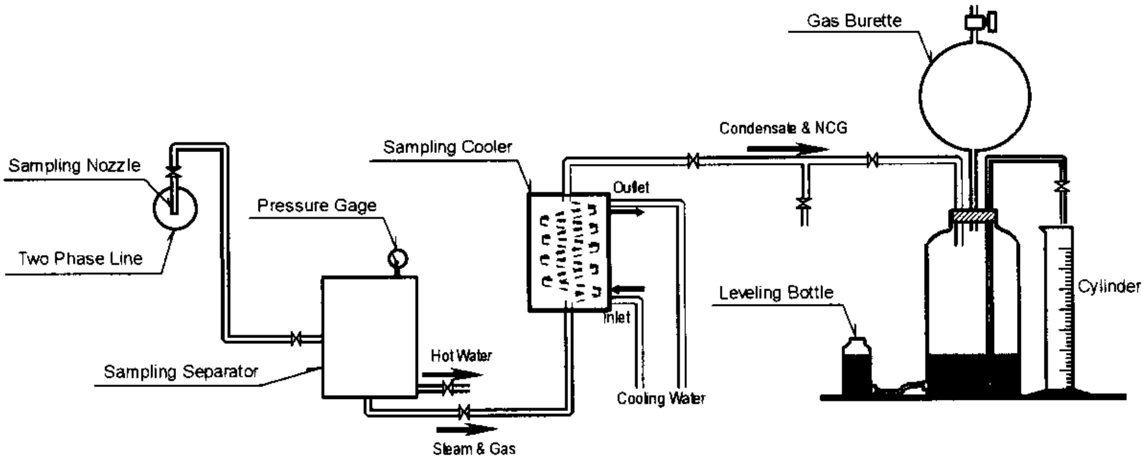


Fig. VI-10 Example of a Sampling System

(5) Production characteristics curve

In the separator method, the flow rate of separated steam can be measured by using an orifice plate and sampling the differential pressure between the front and back of the plate. The separated water can be flashed to atmospheric pressure, and the water flow rate measured using a weir.

In the lip pressure method, the steam-water mixture is discharged through an appropriate sized pipe into a silencer to separate the steam and water phases at atmospheric pressure. The lip pressure is measured at the end of the discharge pipe. The flow rate of the steam-water mixture can be calculated based on the empirical formula developed by James.

If a longer-term production test can be done, the continuous measurement of the flow rate at three different pressures is desirable to generate the kind of production characteristics curve (the deliverability curve) shown in Fig. VI-11. In this test, the valve is throttled or opened to adjust planning wellhead pressures.

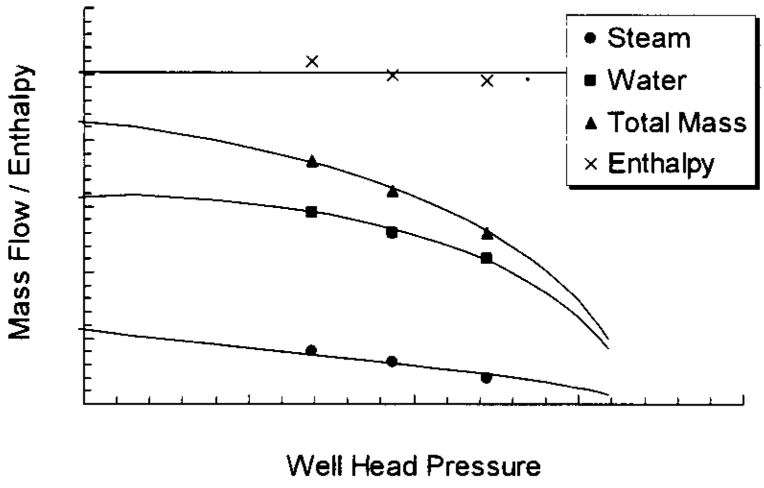


Fig. VI-11 Example of a Production Characteristics Curve

(6) PTS logging

a. Objective

The "feed point" is the depth at which geothermal fluid flows into the wellbore from the surrounding formation. To distinguish the feed points, P (pressure) T (temperature) S (spinner) logging is conducted for the well during production.

b. Equipment

There are two types of PTS equipment. One is the onboard memory type, which stores the PTS data in its internal memory. The other is the real-time type, which sends the PTS data to the surface data recorder through an electric cable. A wire line winch unit is used for the logging operation. A raiser pipe (lubricator unit) should be set on the wellhead valve to maintain a closed condition and avoid leakage of produced fluids to the atmosphere during the logging.

c. Example

An example of PTS logging results is shown in Fig. VI-12. The PTS data is very useful for understanding conditions in the flowing well, such as the entering mass flow and enthalpy at each feed point. The data is also utilized in drawing up future drilling plans.

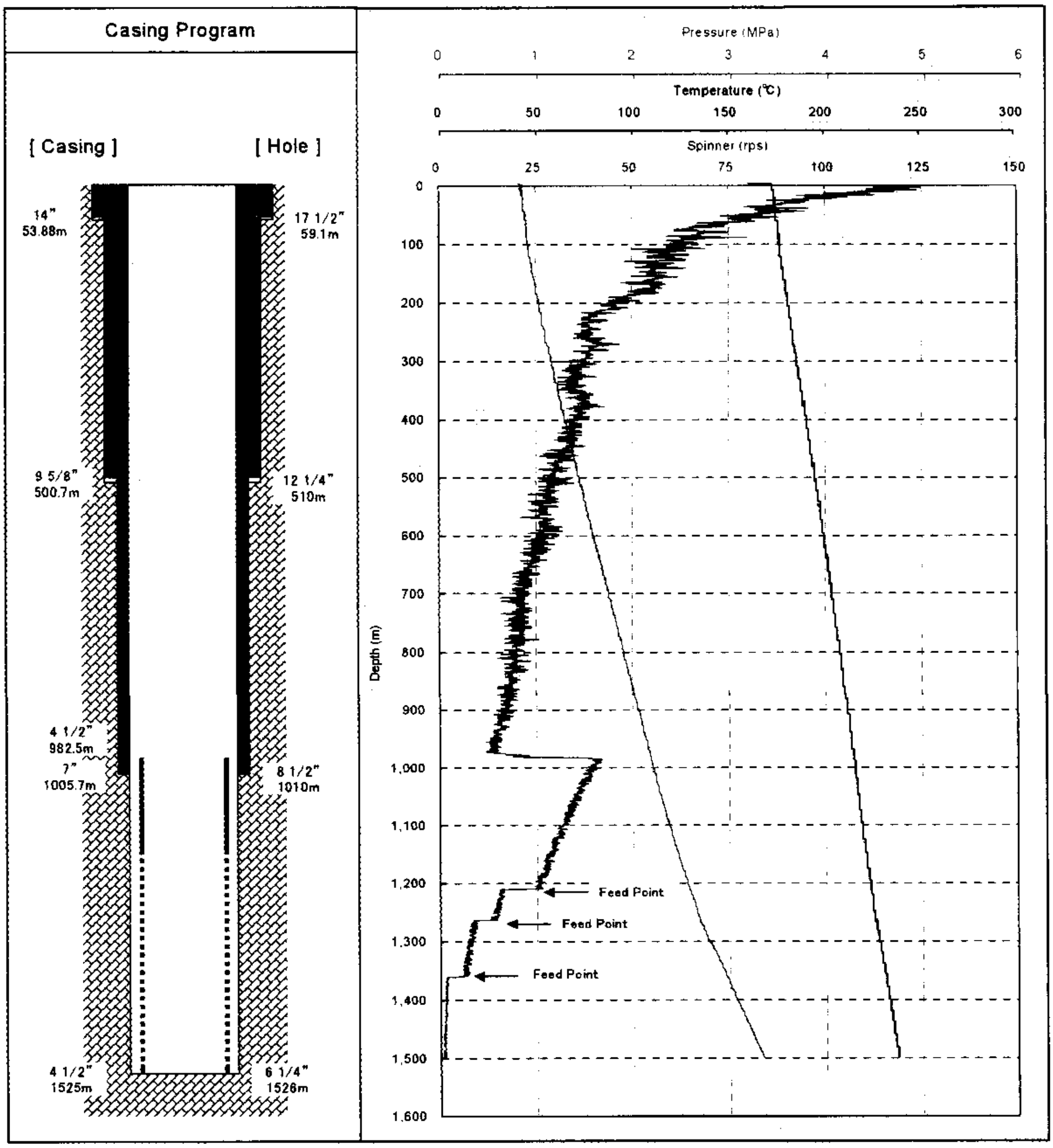


Fig. VI-12 Example of PTS Logging Data

(7) Estimation of geothermal conceptual model

The previous geothermal conceptual model is refined on the basis of the drilling results and testing results. Key parameters such as the distribution of cap rock (an impermeable layer), highly permeable zones, high temperature zones, fluid paths, heat sources, up-flow zones and fluid flow direction should be represented in the reservoir conceptual model, which will include the following:

- Distribution of strata
- Distribution of underground temperature and pressure
- Extent of the geothermal reservoir
- Extent of argillized impermeable layers

- Chemistry of reservoir fluid
- Fluid flow pattern

(8) Resource evaluation

During resource evaluation, a three-dimensional (3D) numerical simulation will be carried out to assess the geothermal resource capacity by forecasting the future behavior of the geothermal reservoir and productivity of the well under the assumed development scenario. Through this process, the optimum development scenario can be decided. The numerical model can also be used and updated for the purpose of reservoir management over the longer term of power plant operation.

The numerical model has to be constructed based on the conceptual model of the geothermal reservoir. A discrete model (also known as a numerical model) is constructed alongside the conceptual model. The numerical model is a set of interconnected elements, each of which represents given portions of the actual underground. The thermal and hydraulic properties (porosity, density, permeability, heat conductivity and heat capacity) of the rock materials are represented, as well as the thermodynamic properties of the water that the represented media contain.

To ensure that the constructed numerical model truly represents the reservoir, it is subjected to two steps of calibration. The first step is a natural state calibration, which consists in the progressive modification of the thermal and hydraulic properties of the assumed media until the numerical model can reproduce the pressures and temperatures encountered prior to the exploitation of the reservoir. The second step is a history-matching calibration, which is carried out similarly, but with the goal of having the model reproduce the response of the reservoir under production as well as the production characteristics of wells. Both calibrations are sequentially repeated as many times as is necessary for the model to match both the natural state and the production/reinjection conditions. Once the numerical model is finally calibrated, the model is subjected to exploitation conditions to forecast reservoir response and generation capacity.

VI-2 Plant Feasibility Study

On the basis of the optimum resource development plan determined from the results of resource studies, a basic design of the power plant can be drafted. In general, on the basis of the results of economic and financial analysis at this stage, the economic and financial viability of the project will be judged. After fundamental decisions on the geothermal power development project are taken, the following stages of work, such as the detailed design of the power plant, additional well drilling, and construction work for the fluid collection and reinjection system, will be undertaken.

VI-3 Construction Stage

The details of the Tapovan geothermal power plant project will be formulated in a plant feasibility study, which will be carried out on the basis of the geothermal resource study (Phase 3). A tentative project plan assumed in this study is shown as a reference.

For a 10 MWe geothermal power plant in Tapovan field, the development work items listed below will need to be completed by the commencement of power plant operation.

<Geothermal resource development>

- Site preparation for production well pad, reinjection well pad and power plant site
- Construction of access road

- Drilling of production wells and reinjection wells

<Piping to transport produced hot water (fluid collection and reinjection system)>

<Construction of a 10 MW binary geothermal power plant>

VI-3-1 Geothermal Resource Development

(1) Earthwork for power plant and drilling pad

The Tapovan geothermal field is characterized by a steep topography, and there are few sites suitable for a power plant and well drilling pads. The candidate sites for the power plant and drilling pads are shown in Fig. V-12.

One (1) production well pad and one (1) reinjection well pad will be necessary for a 10 MW geothermal power plant in Tapovan field. Five (5) production wells and five (5) reinjection wells will be required at each pad. Flat areas suitable for a power plant site are very limited in this field, and the limited flat area available is close to a school. The reinjection well pad will be located next to the production well pad. The candidate site for the reinjection well pad is to the southwest of the power plant site (Fig. V-12). It must be located at a lower level than the power plant site in order to enable gravity transport of reinjection water from production wells to reinjection wells. Table VI-1 shows the land area for the power plant and well drilling pads.

Table VI-1 Land Area for Power Plant and Well Drilling Pad

Item	Size (Flat area)	Land acquisition area	Remarks
Production well pad	100m x 70m	10,000 m^2 (100 x 70 x 1.5)	Modified by actual rig size
Reinjection well pad	100m x 70m	10,000 m^2 (100 x 70 x 1.5)	Modified by actual rig size
Plant site	150m x 80m	13,000 m^2 (150 x 80 – 100 x 35) x 1.5	Plant site will consist of a part of the production well pad and others
Reinjection pipe line	5m x 200m	2,000 m^2 (5 x 200 x 2.0)	Including patrol road

(2) Access road

For geothermal field development in the Tapovan field, it is possible to hire civil contractors and to purchase materials for civil work in Deheradun city, which is capital city of Uttarakhand state.

The road between Dehradun and Joshimath on national highway 58 is mostly paved with asphalt and runs via Devapurayag, Rudraprayag and Chamoli. From Joshimath to Tapovan, a less substantial road runs through the steep topography of the river valley.

Although there is some landside damage on the way to the site, repair work has been carried out, so large-sized trucks are able to pass through the damaged locations. The total distance from Dehradun to the proposed site in Tapovan is estimated at around 300 km.

With respect to access to the proposed power plant and drilling site from the existing public road, as mentioned earlier, there is no access road allowing large vehicles to access the drilling site. The existing pavement from Tapovan village to the site will require extensive upgrading. To permit the future transportation of large items of drilling equipment and power generation equipment, the road should be about 6 m wide, and is expected to be approximately 2 km long (Fig. VI-12).

(3) Production and reinjection well drilling

It is recommended that a drilling rig should have an output of around 800-1,000 HP to drill wells to an average depth of 1,500 to 2,000 m. Directional drilling will be used for both production and reinjection drilling in order to drill multiple targets from a single well pad. The detailed drilling depths and well profiles (casing program) should be determined in the light of the geothermal conceptual model that is elaborated on the basis of exploratory well testing and surface study integrating geology, geochemistry and geophysics.

VI-3-2 Piping to Transport Produced Hot Water (Fluid Collection and Reinjection System)

Figure V-12 shows the layout of the site in Tapovan field. A production pipeline will be constructed from the production wells to the binary power plant, and a reinjection pipeline will be constructed from the power plant to the reinjection well pad.

VI-3-3 Construction of a 10 MW Binary Geothermal Power Plant

As reported in SNC and JETRO (2010), the geoscience characterizes the geothermal resource in this field as water-dominated and of medium temperature. A binary cycle plant is able to exploit the energy in geothermal water of this temperature, and so a binary power plant is recommendable for power generation for this project. Plans for the geothermal power plant will be re-examined after detailed geothermal resource study including exploratory well drilling.

VI-4 Tentative Schedule for Tapovan Geothermal Power Plant Project

The schedule for Tapovan Geothermal Power Plant Project is tentatively reviewed in the light of SNC and JETRO (2010) and the basic schedule for geothermal power plant projects (Fig. VI-13). It should be noted that this schedule is a tentative schedule, which will be re-examined and updated after the geothermal resource study including exploratory well drilling (Phase 3).

After completion of this data collection study, the consultant for the "Phase 3 (Resource Evaluation)" study will first be selected. Prior to exploratory well drilling, approval and the necessary permissions required for well drilling will be obtained. A work period of twenty-eight (28) months is assumed for Phase 3 (Resource Evaluation). A final resource feasibility report will be submitted for Tapovan Geothermal PP Project, following which a Feasibility study will be carried out on the basis of the resource feasibility report.

After the submission of feasibility study report, approval and permissions required for power plant construction will be obtained. The consultant will first be selected, and then procurement of a well drilling/testing contractor will proceed in parallel. Commencement of commercial operation will follow immediately on the completion of the project.

Phase 3 (Resource Evaluation)

Twenty-eight (28) months is assumed for Exploratory Well Drilling and Testing, and Resource Evaluation.

Feasibility Study

Three (3) months is assumed for Basic Design of Power Plant & Feasibility Study.

Engineering Services

For faster implementation of the project, the consultant should be selected as early as possible. Four (4) months for selection of the consultant and a service period of 60 months are assumed in the Construction Stage and Warranty Period.

Well Drilling/Testing

For faster implementation of the project, the contractor should be selected as early as possible. Four (4) months for selection of the contractor.

3 months for site preparation and rig mobilization.

27 months for production/reinjection well drilling, well production tests.

Power Plant Construction (EPC)

After selection of the consultant, nine (9) months for selection of the EPC contractor (for the FCRS and power plant)

FCRS Construction

20 months for design, civil work, manufacturing, transportation, construction, and commissioning

Geothermal Power Plant Construction

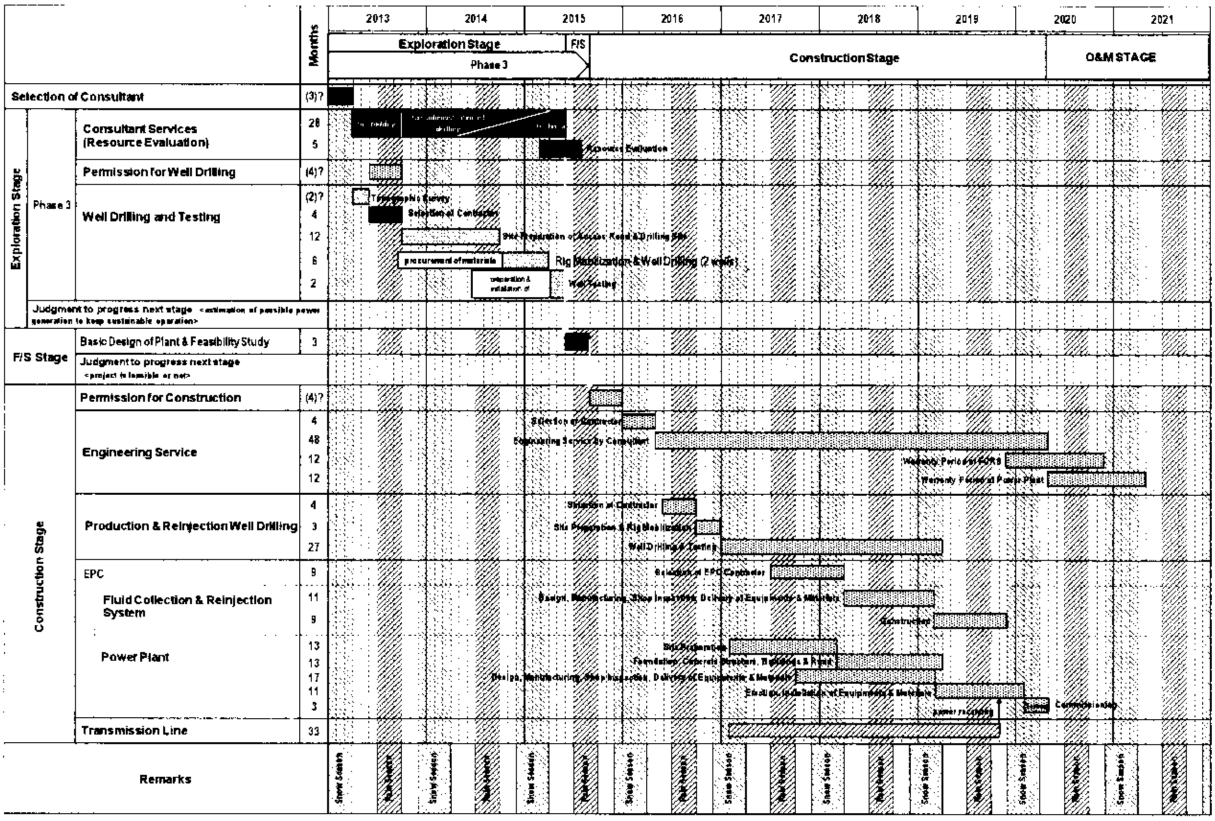
39 months for site preparation, design, manufacture, transportation, construction, and commissioning

Transmission Line Construction

33 months for site preparation, design, manufacture, transportation, construction, and commissioning

Completion of Project and Commencement of Commercial Operation

Ninety-three (88) months from the selection of the consultant for "Phase 3 (Resource Evaluation)" to commencement of commercial operation of Tapovan Power Plant (Fig. VI-13).



**Non-working periods due to the snow season and rainy season are not considered in the Construction Stage.

Fig. VI-13 Tentative Project Implementation Schedule

VI-5 Project Cost Estimation

VI-5-1 Cost Components

The project cost is estimated for the following components;

- Exploratory Drilling Stage

(Access road, Drilling pad, Drilling)

- Plant Construction Stage

The project cost components are shown in Table VI-2.

Table VI-2 Cost Components

I. Exploratory Drilling Stage	
	Access (including water supply) Drilling pad construction Exploratory drilling and testing Production well : 2,000 m x 1 well Reinjection well : 1,500 m x 1 well Resource Evaluation F/S

II. Plant Construction Stage	
1. Steam Field Development	Well drilling and testing Production wells : 2,000 m x 4 wells Reinjection wells : 1,500 m x 4 wells
2. Power Plant	Binary Cycle Generation System Construction of Power Plant Fluid Collection and Reinjection System Construction of Fluid Collection and Reinjection System Silencer etc. Civil work Power plant site, etc.
3. Transmission Line	Geothermal PS Switch yard Step-up Transformer (11/66 kV, 11MVA) 66 kV Transmission Line (10 km) Joshimath S/S 66 kV, 2 Bays
4. Consultant Fee	10% of 1, 2, and 3
5. Contingency	5% of 1, 2, 3 and 4
6. Administration Costs	5% of 1, 2, and 3

VI-5-2 Project Cost Estimation

Project costs are divided into the two (2) stages of exploration well drilling and power plant construction, and their breakdown is shown in Table VI-3. In addition, the drilling cost estimates are shown in Table VI-4.

Table VI-3 Project Costs

	Work Item	Cost Estimate (US$)
Exploratory Well Drilling Stage	New access construction (2km)	800,000
	Water supply (including high pressure pump)	200,000
	Well pad construction (2 pads)	1,000,000
	Rig Mobilization/De-mobilization	2,000,000
	Exploratory production well drilling and testing (1 well)	4,310,000
	Exploratory reinjection well drilling (1 well)	3,410,000
	Consultant fee related to the drilling	500,000
	Resource Evaluation F/S	500,000
	Total	12,720,000
Construction Stage	Steam Field Development	
	a. Rig Mobilization/De-mobilization	2,000,000
	b. Production well drilling and testing (4 wells)	17,240,000
	c. Reinjection well drilling (4 wells)	13,640,000
	Power Plant	20,510,000
	Transmission Line*	0
	Consultant Fee	5,339,000
	Physical Contingency	2,936,000
	Administration Cost	2,670,000
	Total	64,335,000
Grand Total		77,055,000

*Note;

1. Assuming that UPCL (Uttarakhand Power Corporation Ltd.) / PTCUL (Power Transmission Corporation of Uttarakhand Ltd.) undertakes to transmit the power generated through its grid based on the "Policy for Harnessing Renewable Energy Sources in Uttarakhand with Private Sector/Community Participation", the cost of the transmission line can be excluded.
2. The drilling cost estimates are based on the current market price in India and/or Southeast Asian countries such as Indonesia, Philippines.

Table VI-4 Drilling Cost Estimates

Unit: US$

Item	Production well Ave. Depth: 2,000m	Reinjection well Ave. Depth: 1,500m
1. Rig Hire		
a. Drilling cost		
*Rig Operation ($25,000/day)	1,500,000	1,250,000
*Air drilling package	N/A	N/A
b. Rig Move (On location)	150,000	150,000
Sub-total	1,650,000	1,400,000
2. Drilling Services		
a. Directional drilling service	360,000	300,000
b. Cementing services	360,000	300,000
c. Mud Log	60,000	50,000
d. Mud Engineering	50,000	40,000
e. Top drive	N/A	N/A
f. H2S Monitoring	N/A	N/A
g. Well logging	90,000	60,000
Sub-total	920,000	750,000
5. Drilling materials		
a. Bit and others	160,000	120,000
b. Casing and accessories	700,000	500,000
c. Wellhead and valves	100,000	100,000
d. Mud materials	60,000	40,000
e. Cement and additives	120,000	100,000
f. Fuel and Oil supply	300,000	250,000
g. Drilling consumables-Foreign	-	-
h. Drilling consumables-Local	-	-
Sub-total	1,440,000	1,110,000
6. Drilling support		
a. Transport (in site)	20,000	20,000
b. Water supply (Operation)	40,000	30,000
c. Others (Catering, etc.)	60,000	50,000
Sub-total	120,000	100,000
7. Well Testing	180,000	50,000
Grand Total for Drilling	**US$4,310,000/well**	**US$3,410,000/well**

VI-6 Tasks Remaining for the Implementation of the Tapovan Geothermal Power Plant Project

Tasks remaining for the implementation of the Tapovan Geothermal Power Plant Project are summarized as follows.

(1) Phase 3: Geothermal Potential Evaluation

Access and drilling pad construction stage

- Possible environmental impacts on the elementary school and the residences near the drilling pad should be carefully evaluated, and any environmental impacts on them should be mitigated.
- Before civil work, it is necessary to carry out a topographic survey to ensure that there is enough flat area for a drilling pad and a geothermal power plant, and detailed designs for such facilities must be elaborated.
- Detailed investigation of the suitability of the existing road around the site for heavy equipment transportation and necessary upgrading must be carried out.

  A transportation route survey should be carried out by a drilling contractor before rig mobilization.
- Limitations on field work during the rainy season and the snow season

  Careful consideration is required of possible impacts of inclement weather on the work schedule and safety measures.

Drilling stage

- Detailed investigation of the potential drilling contract bidders will be required.

  In this study, only the names of the potential bidders for the drilling contract were listed. Before actual bid selection takes place, a detailed investigation of potential contractors, including such factors as drilling rig capacity, should be carried out.
- Transportation route survey

  At the time of bidding, it will be necessary for the contractor to investigate the public roads available for the transportation of drilling equipment from the rig base of the drilling contractor to the drilling site.
- Drilling water supply

  Further investigation is needed of water intake points, pumping methods, piping routes etc.
- The hardness of the rocks

  There is a need to investigate the local geological conditions in detail, including such factors as the hardness of the rock and its potential effects on the rate of penetration during drilling.
- Artesian water

  Because the presence of artesian groundwater is anticipated in this area, it is necessary to consider measures in advance to be taken in case such formations are encountered during drilling.
- Local constraints on the work during periods of heavy rain and snow

Local weather conditions will impose restrictions on the timing of the implementation of field operations during the season of heavy rain from July to September and during the snow season from December to March. It will sometimes be difficult to carry out continuous drilling operations. Debris flow and landslides during the rainy season are frequent, and access from local towns (such as Joshimath) to the site is frequently interrupted, creating many limitations on work at the site. Therefore, it is necessary to consider the logistics carefully, and to consider, for example, setting up a base camp at the drilling site during the construction period.

(2) Social Environmental concerns arising from exploratory well drilling

- Noise pollution:

  An elementary school and residential area are located 250 m from the planned exploratory well drilling site. The A-weighted sound pressure level of well drilling ranges from 100 to 110 dB(A) in general and drilling operates for 24 hours a day. Thus, a negative impact is expected on the elementary school in the daytime and on residences at night. Sound insulation measures for the drilling equipment, and relocation of the elementary school are desirable.

- Water quality:

  The residents of Ringi village use drinking water from tributaries at higher elevations, whereas the water for exploratory well drilling is pumped up from the mainstream at lower elevations. Thus, no negative impact is expected on drinking water. But if the residents are anxious about this, the monitoring of drinking water quality is recommended.

- Air quality:

  The possibility of hydrogen sulfide exposure from exploratory wells is low, but monitoring during production testing is recommended.

- Social infrastructure:

  In order to create an access road from the main road to the exploratory well drilling site, it is planned to improve the community trail used by the residents of Ringi Village. After improvement, the amount of construction traffic on the road will increase. Therefore, securing an alternative community road might be necessary, should the local residents request one.

As described above, there are a number of tasks to clear for the geothermal power development. The main tasks are land condition and the impacts on the social environment. Possible areas for civil work (flat to moderate slopes) are quite limited around Ringi village. In addition, the western part of this area is already utilized as an army base, and the remaining part is also utilized as cultivated land or residential areas. Therefore, negotiations with the local people for land use will be required. Steam-field development risk also remains. Although drilling targets for exploratory wells were examined in this study, the problem is that it has not been possible to ascertain the distribution of faults underground with great precision. In addition, a 40° maximum drift angle for exploratory wells is planned in order to enable long-distance deviation that can penetrate some permeable structures. This is necessary due to topographic constraints on the construction of well pads. It will be necessary for the drilling contractor to carefully consider the geological conditions and drilling techniques to drill on the planned drift angle. Considering these land conditions (topographic condition, social environmental condition etc.), it is deduced that some tasks are still remained to clear for the geothermal development in this field.

CHAPTER VII

VII SUPPORT FOR GEOTHERMAL RESOURCE DEVELOPMENT SURVEYS IN OTHER FIELDS

Concerning support for geothermal resource development surveys in other fields, following studies and supports are assumed in Uttarakhand state and other states.

VII-1 Uttarakhand State

In Uttarakhand State, it is likely that it will possible to carry out surveys in other fields in the state with less difficulty than in other states, since this is a state where NTPC has already applied for and obtained permits to survey Tapovan field.

In Uttarakhand State, there are other fields in addition to Tapovan where hot springs discharging. Among these is Beda, where a temperature of about 200°C has been calculated for the hot waters, making this field a promising prospect. In addition, considering the Na-K-Ca temperatures, it is possible that hot waters with a temperature greater than 100°C are present in Yamnotri, Gangnani, Khirao, Gari, Juma, Balati, Dar and Kalapani. However, it is anticipated that these fields will be similar to the Tapovan field in their geological conditions, that it will be difficult to clarify the subsurface geological structure with any precision, and that it will sometimes be impossible to proceed to drilling target selection. In consideration of these constraints, it is judged that geothermal resource exploration in Uttarakhand state should have a lower priority than exploration in Chhattisgarh state, which will be discussed next.

Considering present status of the progress of geothermal resource study in Uttarakhand state, following studies are required.

Survey Items	Contents
Existing data collection/Data review	- Data collection/Data review - Preliminary evaluation of fields - Selection of fields for supplementary geological and geochemical surveys.

↓

Survey Items in Selected Fields		Contents
Phase 1 Geological and geochemical studies (2 - 3 fields)		- Geological field survey (geology, alteration zone, fault distribution, rock sampling etc.) - Hot water sampling etc. - Geological laboratory analysis (microscopic observation, X-ray diffraction analysis, rock dating) - Geochemical laboratory analysis (chemical composition, isotope) - Integration of survey results - Selection of field for geophysical survey
Phase 2	Geophysical survey (MT survey)	- Approximately 35 stations

	Collection of data and information related to well drilling	- Land use - Restriction of National park and forest - Access load - water use, water in-take point - Permissions of drilling works
	Resource Assessment/Planning (drilling targets, specification of drilled well)	- Integration of survey results - Construction of geothermal conceptual model - Evaluation of geothermal resource potential - Planning future resource development program

↓

Items	Contents
Exploratory well drillings	- Earthwork for drilling pad, construction of access road - Exploratory well drillings (3 wells)
Well logging and well test	- Well logging - Well injection test - Well interference test - Well discharge test
Construction of geothermal conceptual model, potential evaluation (reservoir simulation)	- Improve geothermal conceptual model - 3 D geothermal reservoir simulation
FS	- Steam field development planning - Basic design of power plant (engineering FS) - Financial and economic evaluation
Environmental Impact Assessment	Environmental Impact Assessment

VII-2 Other States

In some geothermal fields in India, geothermal exploration is relatively advanced, having reached the stage of Resource Evaluation (Phase 3) or the stage of Detailed Study (Phase 2) as described in Chapter IV. The following types of exploration are thought to be necessary in the future to move towards the construction of a geothermal power plant in these geothermal fields:

1. Review of existing surveys, together with selection of exploratory well-drilling targets and planning of drilling specifications.
2. Drilling of exploratory wells (3 wells are anticipated), together with production testing and evaluation of resource potential.
3. Feasibility study.

In addition, if the selection of exploratory drilling targets on the basis of existing survey results alone is judged to be too difficult, supplementary survey will be required. According to the overseas risk information provided by the Foreign Ministry of Japan, some geothermal fields in India falls into the category of destinations to which "the necessity of travel should be carefully considered", creating a restriction on the on-site survey activities of Japanese personnel. A support system and details of support for geothermal resource exploration which take these restrictions into account is expected to assume the following form.

(1) Implementation System

As a support system for the current survey stage, two systems can be hypothesized. In one of these alternatives, the actual survey is carried out by the Indian side, with technical advisory service being provided by JICA. In the other, the actual survey is carried out by the JICA side acting independently and subcontracting only the on-site work to local research organizations such as those of the Indian government. However, it is feared that, if the leading body carrying out the survey is unable to conduct on-site confirmation surveys, that will present an obstacle to discussions on the details of the project and the like and result in them being less adequate and complete than they must be. In consideration of this, it is thought that a support system structured around providing technical advisory service is the most realistic option (Fig. VII-1).

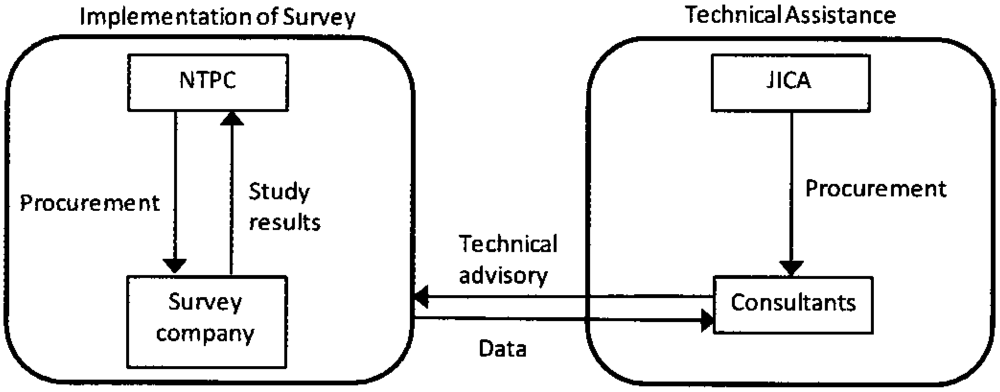


Fig. VII-1 Implementation System: Technical Advisory Service Being Provided by JICA

(2) Implementation Programs

Surface study

Survey Items	Contents
Existing data collection/Data review	- Data collection/Data review - Planning of supplementary survey, if necessary

Supplementary surface survey (if necessary)

Survey Items	Contents
Supplementary geological study	- Geological field survey (geology, alteration zone, fault distribution, rock sampling etc.) - Geological laboratory analysis (microscopic observation, X-ray diffraction analysis, rock dating)

Supplementary geochemical study	- Hot water sampling etc. - Geochemical laboratory analysis (chemical composition, isotope)
Additional Geophysical survey (MT survey)	- Re-analysis of existing geophysical survey data - Additional Geophysical survey (MT survey)
Collection of data and information related to well drilling	- Land use - Restriction of National park and forest - Access load - water use, water in-take point - Permissions of drilling works
Resource Assessment/Planning (drilling targets, specification of drilled well)	- Integration of survey results - Construction of geothermal conceptual model - Evaluation of geothermal resource potential - Planning future resource development program

Resource Evaluation (Well Drilling and Production Test)

Items	Contents
Exploratory well drillings	- Earthwork for drilling pad, construction of access road - Exploratory well drillings (3 wells)
Well logging and well test	- Well logging - Well injection test - Well interference test - Well discharge test
Construction of geothermal conceptual model, potential evaluation (reservoir simulation)	- Improve geothermal conceptual model - 3 D geothermal reservoir simulation
FS	- Steam field development planning - Basic design of power plant (engineering FS) - Financial and economic evaluation
Environmental Impact Assessment	Environmental Impact Assessment

Furthermore, it is thought that the implementation of a program of lectures and on-site inspections in Japan for NTPC technical personnel lacking geothermal development experience in order to encourage the acquisition of basic knowledge of the entire field of geothermal power generation development would be an effective way to promote geothermal power generation development in India. Such technical training in Japan would include the following topics:

- ✓ geothermal resource survey methods (lectures)
- ✓ geothermal reservoir evaluation (lectures)

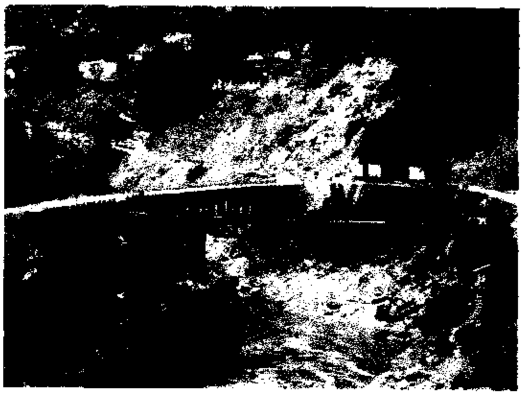
- ✓ geothermal generation system (lectures)
- ✓ geothermal power plant operation and maintenance (lectures)
- ✓ geothermal development economics (lectures)
- ✓ geothermal power plant study tours (visits)

ATTACHMENT

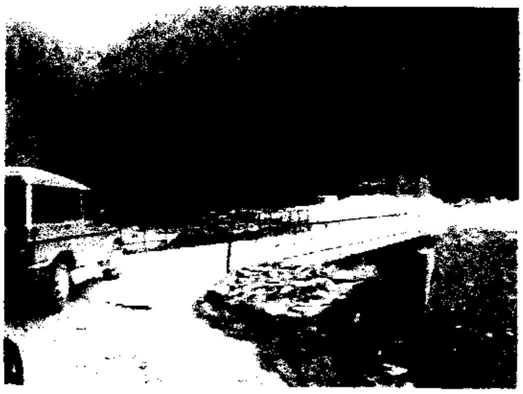
Attachment

Photographs of Tapovan Field

Road Conditions (NH 58): Rishikesh-Joshimath



Road Conditions: Joshimath-Tapovan



Present Condition of Tapovan Field

Well AGW-3

Well AGW-3

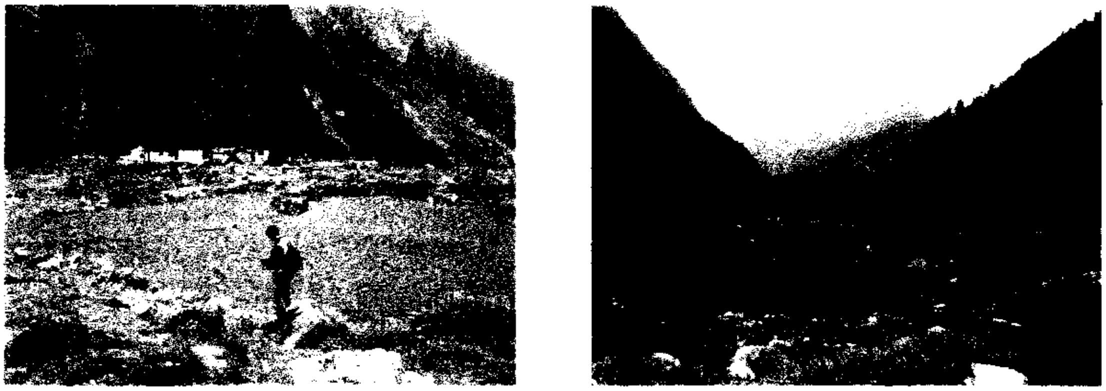
Overview of Tapovan

Interviewing Local People

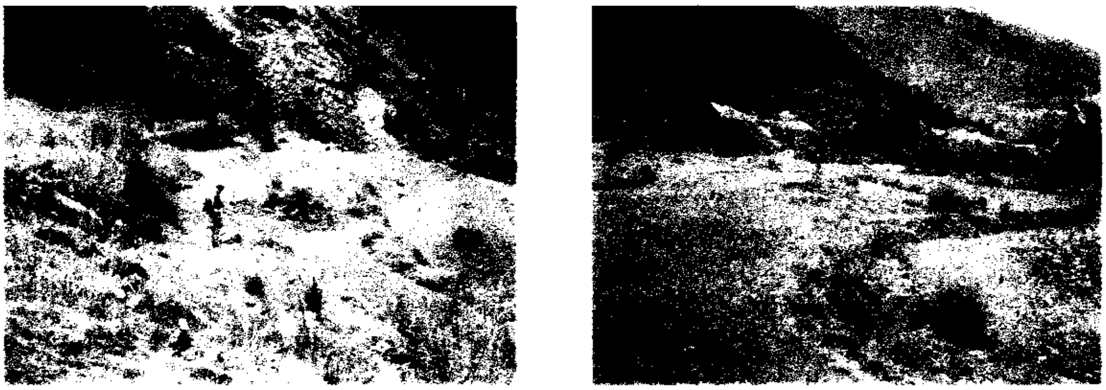
Ringi Village

Ringi Village

Water in Ringi Village

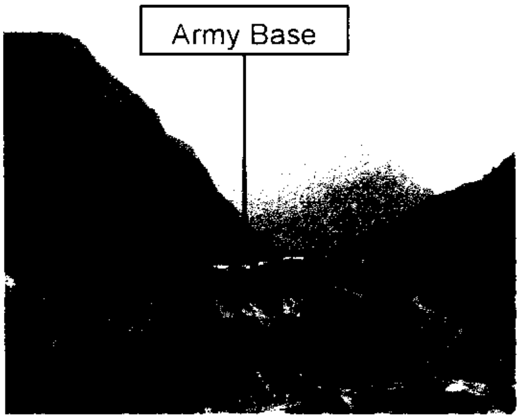


Candidate Site for Drilling Pads and Power Plant



Candidate Site for Drilling Pads and Power Plant

Access Road to Candidate Site for Drilling Pads and Power Plant



Access Road to Candidate Site for Drilling Pads and Power Plant and Army Base