THE REPUBLIC OF INDONESIA
PT. PLN (PERSERO)

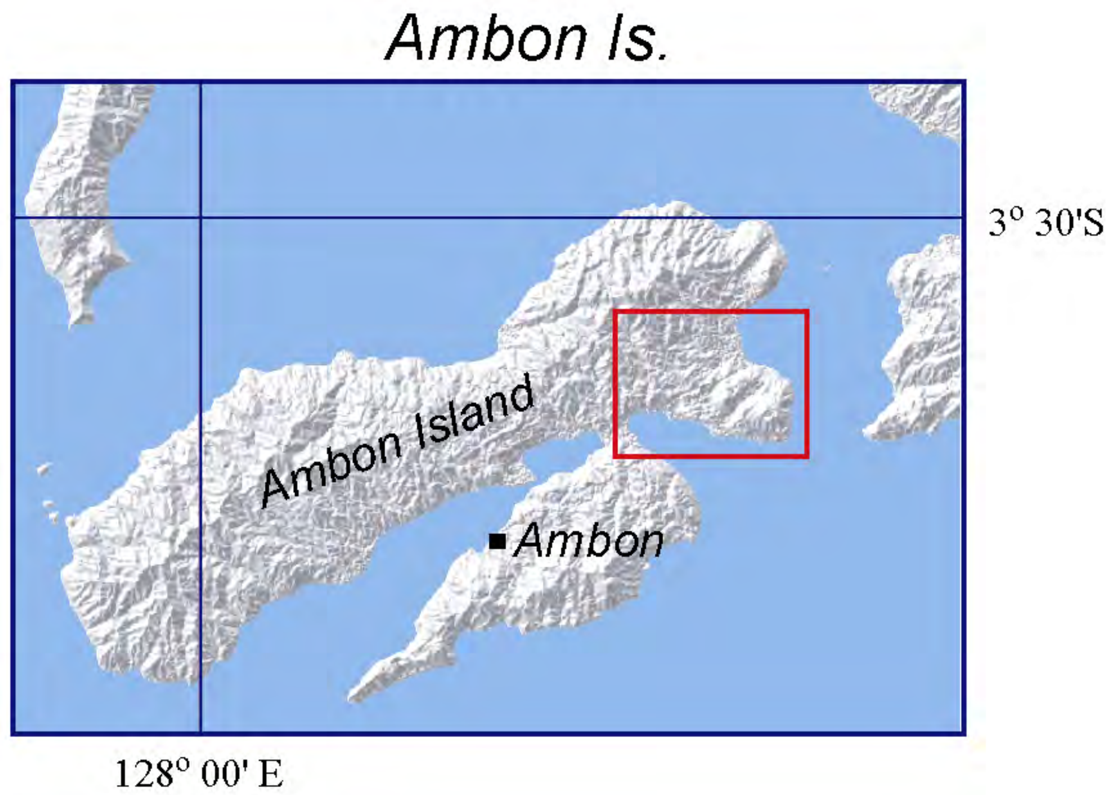
JICA PREPARATORY SURVEY
FOR
TULEHU GEOTHERMAL POWER PLANT

FINAL REPORT
(SUMMARY REPORT)

September 2011

JAPAN INTERNATIONAL COOPERATION AGENCY

WEST JAPAN ENGINEERING CONSULTANTS, INC.



Location of Tulehu Geothermal Field
(Ambon Island, Central Maluku Province)

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Abbreviations and Acronyms	Definitions
AMDAL	Environmental Impact Assessment (Analisis Mengenai Dampak Lingkungan)
BAPPENAS	National Development Planning Agency (Badan Perencanaan dan Pembangunan Nasional)
B/D	Bid Document
BPS	Statistical Bureau of Indonesia (Badan Pusat Statistik)
CB	Circuit Breaker
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CSAMT	Controlled-Source Audito-frequency Magneto-Telluric method
DCS	Distributed Control System
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
E/N	Exchange of Notes
EPC	Engineering, Procurement and Construction
ES	Engineering Service
FCRS	Fluid Collection and Reinjection System
FIRR	Financial Internal Rate of Return
F/S	Feasibility Study
GDP	Gross Domestic Product
GDRP	Gross Domestic Regional Product
GHG	Greenhouse Gas
GOI	Government of Indonesia
GPP	Geothermal Power Plant
ICB	International Competitive Bidding
IGRF	International Geomagnetic Reference Field
IPP	Independent Power Producer
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency
L/A	Loan Agreement
L/C	Letter of Credit

Abbreviations and Acronyms	Definitions
LCB	Local Competitive Bidding
L/Com	Letter of Commitment
LEC	Levelized Energy Cost
m asl	meters above sea level
MEMR	Ministry of Energy and Mineral Resources
MT	Magnetotelluric method
NCG	Non-condensable Gas
NEP	National Energy Policy
ODA	Official Development Assistance
O&M	Operation and Maintenance
PD	Presidential Decree
PDD	Project Design Document
PLN	Indonesian Government-owned Electricity Company (PT. Perusahaan Listrik Negara (Persero))
PLN Geothermal	PT. PLN Geothermal Subsidiary company of PT. PLN
PPA	Power Purchase Agreement
P/Q	Pre-Qualification
rpm	Revolutions Per Minute
RUKN	National Electricity Development Plan (Rencana Umum Ketenagalistrikan Nasional)
RUPTL	National Electricity Provision Plan (Rencana Usaha Penyediaan Tengah Listrik)
SLA	Subsidiary Loan Agreement
UKL	Environmental Management Effort (Upaya Pengelolaan Lingkungan)
UPL	Environmental Monitoring Effort (Upaya Pemantauan Lingkungan)
VAT	Value Added Tax
WACC	Weighted Average Cost of Capital

CHAPTER I

I INTRODUCTION

I.1 Study Area

The study area is Tulehu geothermal field in Maluku province, Ambon Island. (Fig. I-1)

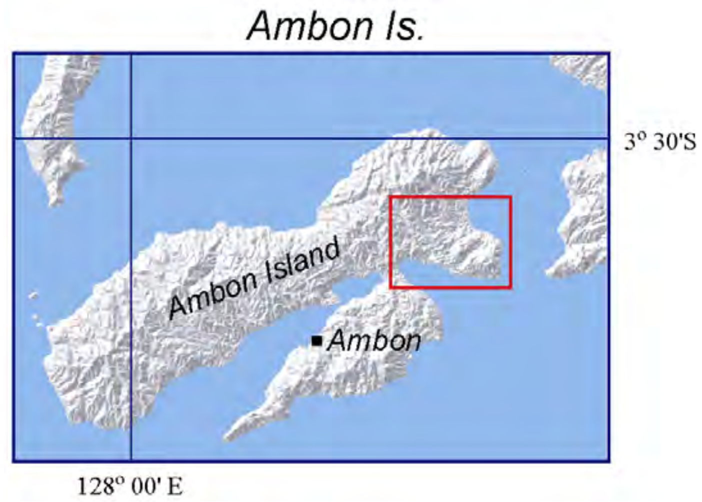


Fig. I-1 Study Area

I.2 Background

According to National Electricity General Plan 2008-2027 (RUKN2008-2027) of the Ministry of Energy and Mineral Resources (MEMR), the peak electricity demand in 2008 was 25,407 MW overall in Indonesia and future electricity demand is forecasted to increase at an average rate of 9.1% every year. In order to secure an increasing power supply, the Government of Indonesia (GOI) announced a development program, entitled "Crash Program". Following on the "Crash Program" in 2009, the GOI announced "Crash Program II" in January 2010, which includes 3,977 MW of Geothermal power among renewable energy power developments totaling 10,000 MW. It is well known that Indonesia has the world's largest reserve of geothermal power, equivalent to 27,000 MW. However, only about 1,300 MW of geothermal power have been developed in Indonesia as of today. To achieve the target of Crash Program II, the rapid development of geothermal power is required.

According to RUPTL 2010-2019 (Long Term Electricity Development Plan 2010-2019), the peak demand in the Maluku network (Ambon island), where the Tulehu geothermal field is located, was 36.6 MW in 2010 and it is forecasted to reach 81.1 MW in 2019 at an average annual rate of increase of 9.3%, owing to steady economic growth and an increase in the rate of rural electrification. The installed capacity of existing generating facilities in the network is 55 MW, consisting of diesel power plants with high generating costs and large greenhouse gas emissions. The dependable capacity in this network is only 30 MW out of 55 MW, i.e., the power supply is less than the demand on it. Thus, the development of Tulehu geothermal power plant is expected to resolve the capacity deficit and it to result in a reduction of fossil fuel consumption and greenhouse gas emissions.

The GOI and PT. PLN plan for most of the electrical power in areas in eastern Indonesia like Maluku on Ambon Island to be supplied from geothermal resources. The size of geothermal power plants in eastern Indonesia is less than 20 MW, due to the limited power demand, small size of the network, or scaling for the replacement of diesel power plants. In Ambon Island, the size of the plant is planned to be 20 MW (2 x 10 MW). The power generated by Tulehu geothermal power plant will be transmitted to the demand center of Ambon city.

I.3 Purpose of the Preparatory Survey

The purpose of the Preparatory Survey is to prepare feasibility study documents for the Tulehu geothermal power development project with conditions of the ODA Yen loan. The preparatory survey is to carry out the geothermal resource assessment, which will verify if the objective geothermal field could produce geothermal energy sufficient and suitable for the planned geothermal power development. As a result of the said assessment, the Survey Team is to formulate an implementation program for construction of the geothermal power station and associated transmission/distribution lines and substation. The precedent pre-feasibility study will be reviewed and updated.

I.4 Scope of the Geothermal Power Plant Development

The Tulehu Geothermal Power Plant Project consists of five (5) major components:

1) Construction of steam production facilities
2) Construction of a geothermal power plant
3) Construction of transmission and distribution lines
4) Construction of other appurtenant facilities for the geothermal power plant
5) Consulting services (preparation of bidding documents, assistance in bidding and contracting, construction supervision, environmental management, etc.)

I.5 Executing Agency

The executing agency of the Project is PT. PLN (including PT. PLN Geothermal).

I.6 TOR of the Preparatory Survey

Fig. I-2 depicts the flow of the preparatory study.

The preparatory survey covers the following issues.

1) Review and confirmation of necessity of the Project and electricity demand in Indonesia
   A. Review of the current status of the electricity sector in Maluku Province
   B. Review of development plan for new power plants and upgrading or removing existing power plants in and around Ambon Island
   C. Review of the overall scope of the Project in the context of electricity demand and supply, population and electrification in Ambon Island
2) Review of the details of the geothermal resource of the Project
   A. Review of the existing study results of surface surveys and exploratory well study such as geological study, geochemical study, geophysical survey and well log.
   B. Review of the geological structure of the geothermal reserve of the Project.
   C. Review of the geological and chemical status and conditions of underground steam and water
   D. Review of the estimated amount of geothermal energy including heat and water
3）Review of the detailed plans of the construction of the Project
   A. Review of the scope, cost and schedule of drilling for production and re-injection wells
   B. Review of the scope, cost and schedule of pipeline construction for steam production and water re-injection to the ground
   C. Review of the scope, cost and schedule of power plant construction, including the details of turbines and generators for the Project
   D. Review of the scope, cost and schedule of transmission and distribution lines
4) Calculation of the total project cost and O&M cost, and preparation of Implementation Program (IP)
   A. The Total project cost estimate (ODA loan and PT. PLN portions)
   B. Review of the methods of procurement and implementation of the Project
5) Examination and proposal of an effective scheme for project implementation and O&M
6) Examination of necessary procedures for socio-environmental clearance of the Project in GOI's context, and provision inputs on necessary/additional actions required for the Project based on the requirements under "JICA Guidelines for Confirmation of Environmental and Social Considerations (April 2010)
7) Calculation of Economic/Financial Internal Rate of Return (EIRR/FIRR): identification of Operation and Effect Indicators as per JICA requirements。
8) Holding a workshop during the study in which the Preparatory Survey team will present results of the survey on the items 1) to 7) above, and collection and reflection of comments from the GOI and PT. PLN to the Draft Final Report.

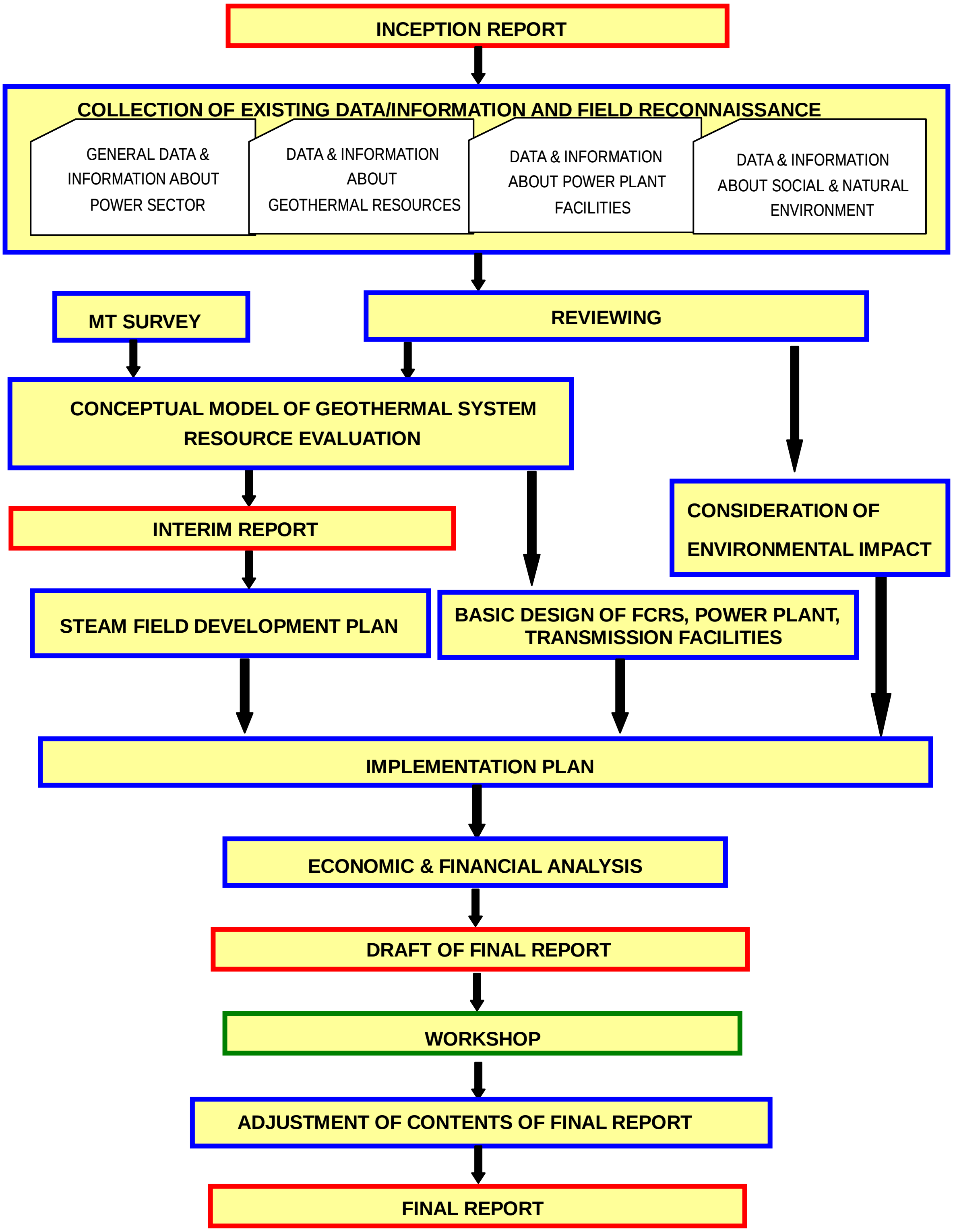


Fig. I-2 Flow of the Preparatory Survey

I.7 Survey Schedule

Table I-1 shows the overall survey schedule.

Table I-1 Schedule of JICA Preparation Survey for Tulehu Geothermal Power Plant

Month	FY2010									FY2011						
Work Item	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
1. Preparation Work in Japan																
(1) Collection of Available Data and Information																
(2) Study on Basic Policy, Contents and Methodology																
(3) Preparation of the 1st Work in Indonesia																
(4) Preparation of Inception Report																
2. The 1st Work Phase in Indonesia																
(1) The 1st Workshop																
(2) Discussion with PLN and Relevant Authorities																
(3) Site Survey (PP, T/L, Environment, Finance/Economy, Resources etc.)																
(4) Collection, Analysis and Study of Resource Related Data																
(5) Preparation and Discussion of Draft Interim Report																
3. The 1st Work Phase in Japan																
(1) Arrangement and Study of Collected Data																
(2) Reservoir Assessment and Confirmation of Study Items																
(3) Preparation of Interim Report																
4. The 2nd Work Phase in Indonesia																
(1) The 2nd Workshop																
(2) Confirmation of the Latest Power Demand Conditions																
(3) Confirmation of Project Implementation Organization w/ Relevant Agencies																
(4) Confirmation of Proposed Plant Site and FCRS Lines																
(5) Confirmation of Drilling Plan																
(7) Environmental Impact Assessment																
(8) MT Survey																
5. The 2nd Work Phase in Japan																
(1) Reservoir Assessment (Continued)																
(2) Formulation of Project Implementation Plan																
(3) Financial Evaluation of the Project																
6. The 3rd Work Phase in Indonesia																
(1) The 3rd Workshop																
7. The 3rd Work Phase in Japan																
(1) Environmental Impact Assessment																
(2) Reservoir Assessment (Continued)																
8. The 4th Work Phase in Japan																
(1) Analysis of Well Test Data, Evaluation of Well Characteristics																
(2)Reevaluation of Reservoir Assessment																
(3) Reevaluation of Project Implementation Plan																
(4) Study of Drilling Target, Drilling Program																
(5) Financial Evaluation of the Project																
10. The 4th Work Phase in Indonesia																
(1) The 4th Workshop (Discussion of Well Target and Drilling Program)																
11. The 5th Work Phase in Japan																
(1) Preparation of Draft Final Report																
12. The 5th Work Phase in Indonesia																
(1) The Final Workshop																
(2) Discussion of Draft Final Report																
13. The 6th Work Phase in Japan																
(1) Preparation of Final Report																
(2) Final Report Submission																

I.8 Members of the Study Team

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

Table I-2 Members of the Study Team

Name	Specialty	Assignment
SHIMADA, Kan'ichi	Survey Project Manager, Geochemist	Team Leader, Project Management, Technical Supervisor, Geothermal Resource Evaluation
SUEYOSHI, Yoshikazu	Drilling Engineer, Civil Engineer	Review of Drilling Plans, Estimation of Drilling Costs, Review of Procurement and Construction Methods
AKASAKO, Hideo	Geologist	Data Collection (Geology), Detailed Review of Geothermal Reservoir
UCHIYAMA, Noriaki	Geochemist	Data Collection (Geochemistry), Scaling Problem, Chemical Properties of Geothermal Fluid.
FUKUOKA, Koichiro	Well Test Engineer	Data Collection (Wells), Review of Logging Data, Resource Estimation
HONDA, Mitsuru	Geophysicist (A)	MT Survey including Data Analysis and Interpretation, Review of Geophysical Data Analysis / Interpretation. Data Analysis and Interpretation of MT data.
NAGANO, Hiroshi	Geophysicist (B)	Data Collection, Review of MT Analysis.
IRI, Shatei	Environmental Engineer	Social and Environmental Considerations
FUNAKOSHI, Yoshimi	Mechanical Engineer	Review of Power Plant Construction Plan, Confirmation of Organization of Project Execution and O&M, Review of Procurement and Construction, Planning on Project Execution, Review on Pipeline Construction Plan
SAKEMURA, Kenji	Electrical Engineer	Design of Electrical aspects and I&C of Power Plant and Transmission Line and Substation
FUJII, Kenji	Economist	Financial and Economic Evaluation

CHAPTER II

II POWER SUPPLY AND DEMAND IN THE STUDY AREA

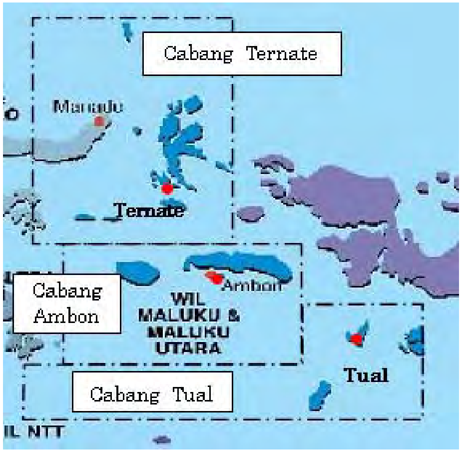
II.1 Power Supply and Demand in Maluku Province

Maluku Province is located in the eastern part of Indonesia and consists of 559 islands, such as the Maluku (Moluccas) Islands, Halmahera (Jailolo) Islands, Kai Islands, etc. with a large sea (Banda sea) to the south. The area of Maluku province as a whole is 581,376 km2, consisting of a vast sea area of 527,191 km^2 and a land area of 54,185 km^2. The capital city of the province is Ambon city on Ambon Island with 0.28 million of the 1.44 million population of the whole province (as of 2008). Table II-1 shows the Area and Population of the Province and Ambon city. (The data in brackets show the results of the 2010 Census)

Table II-1 Land Area and Population of Maluku Province and Ambon city (2008)

	Land Area (km^2)	Population	Population Growth (annual %)
Ambon City	377	281,293	3.95
Total Maluku	54,185	1,440,014 (1,531,402)	2.30
Total Indonesia	1,910,931	227,345,082 (237,556,363)	1.20

The electric power supply in Maluku province is provided by PLN Wilayah "Maluku dan Maluku Utara", which consists of three Cabangs (branches), namely Cabang Ambon, Ternate and Tual. See Fig. II-1. Each system (network) is isolated; that is to say that there is no interconnection between the systems. Cabang Ambon is the largest system among them. All generation units are Diesel generators according to PLN Wilayah Maluku dan Maluku Utara Statistik 2009. The dependable capacity of the generation units is 119.93 MW, which is only 59% of the total Wilayah installed capacity (203.26 MW). Tulehu geothermal power plant is to be located on Ambon Island, which is the territory of Cabang Ambon.



(Source; RUPTL 2010-2019)

Fig. II-1 Wilayah Maluku dan Maluku Utara

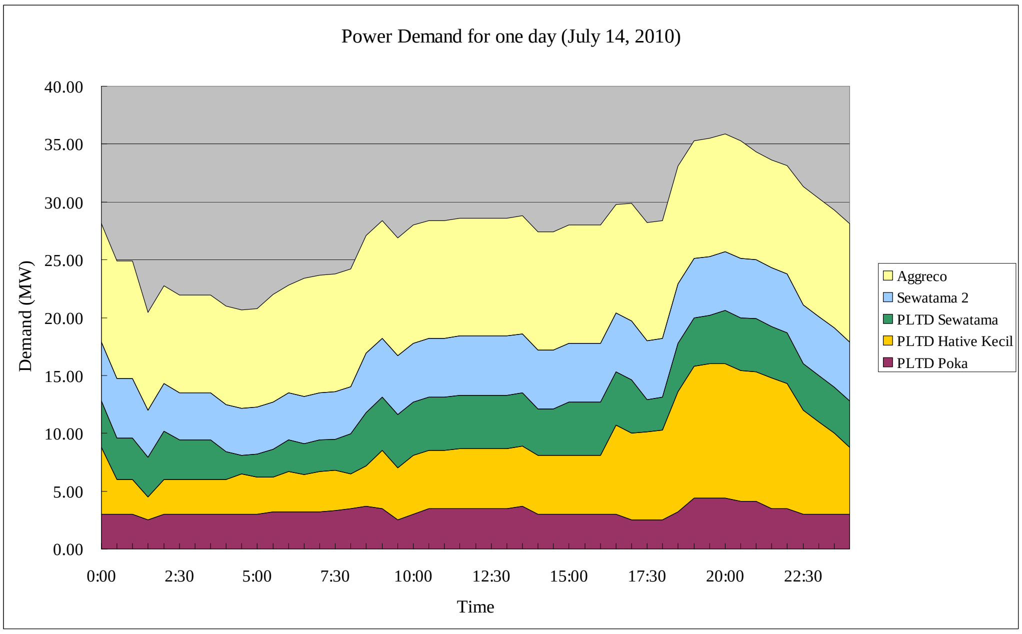
II.2 Power Supply and Demand in Ambon Island

The electrical system in Ambon Island (hereinafter called the Ambon system) is the largest system in Cabang Ambon and the system that Tulehu geothermal power plant will be connected to. The system consists of 20 kV distribution lines only, although there are plans to construct 70 kV Transmission lines in conjunction with the Waai coal-fired power plant (2 x 15 MW) which began in September, 2010. The first transmission line will be constructed from the Waai power plant to the center of Ambon city (Sirimau area).

The Ambon system has accounts for approximately 60% of the power demand in the Cabang Ambon area. Table II-2 indicates the minimum and maximum demand on July 14, 2010 with generating units, and Fig. II-2 shows the Power demand curve for the day. The peak demand of the day was recorded at 8 pm and it was 35.9 MW. 55% of the power generation was delivered by Rental units, as shown in Table II-4-2.

Table II-2 Minimum and Maximum Demand on July 14, 2010

Property	Power Plant	**Minimum**	**Maximum**		
		01:30	**20:00**		
		MW	MW	Total MW	%
PLN	PLTD Poka	2.5	4.4	16.0	45%
	PLTD Hative Kecil	2.0	11.6		
Rental	PLTD Sewatama	3.4	4.6	19.9	55%
	Aggreco	8.5	10.2		
	Sewatama 2	4.1	5.1		
Total		20.5	**35.9**	**35.9**	100%



(Source; PLN Wilayah Maluku dan Maluku Utara)

Fig. II-2 Power Demand for one day (July 14, 2010)

According to PLN Wilayah Maluku dan Maluku Utara Statistik 2009, there are 770 customers awaiting services amounting to 7,606 kVA. Furthermore, hotels, restaurants and other shops in Ambon city have their own generators in order to supply power during the frequent shutdowns of the System. These facts indicates that there is a large hidden potential demand in the system.

Table II-3 shows a list of the generating units in the Ambon system. In the Ambon system, there are two power plants, i.e., Poka and Hative Kecil power plants. While the total installed capacity of two plants is 55,072 kW, their dependable capacity is only 24,800 kW, as shown in Table II-3. For Poka power plant, the dependable capacity in 2008 was 19,100 kW against a 33,600 kW installed capacity. It decreased in 2009 to only 9,500 kW of the same installed capacity. Thus, the shortfall of supply has been made up with rental generators.

Table II-3 Generating Units in the Ambon System (as of August 10, 2009)

Power Plant	No.	Manufact-urer	Model	Year	Capacity (kW)		Remarks
					Rating	Depend-able	
Poka	1	GMT	A420-14	1988	6,400	4,500	
	2	GMT		1988	6,400	-	Damaged Crank shaft
	3	GMT		1988	6,400	4,000	
	4	Caterpillar	3616	2003	4,700	-	Damaged Crank shaft
	5	Caterpillar		2003	4,700	-	
	6	ABC	12V DZC-100-166A	2005	2,500	1,000	De-rating
	7	ABC		2005	2,500	-	
				Poka Total	33,600	**9,500**	
Hative Kecil	1	SWD	6TM 410RR	1978	2,296	1,800	De-rating
	2	SWD		1978	2,296	1,800	Ditto
	3	SWD		1983	3,280	2,200	Ditto
	4	SWD	12TM 410RR	1986	6,560	5,000	Ditto
	5	SWD		1991	7,040	4,500	Ditto
				Hative Kecil Total	21,472	15,300	
				PLN Ambon Total	**55,072**	**24,800**	
Rental Genset		CAT				5,750	5 units
		Cummins				10,200	12 units
		CAT				5,750	5 uints
				Rental Genset Total		21,700	
					Ambon System Total	**46,500**	

(Source; PLN Wilayah Maluku dan Maluku Utara)

II.3 Demand Projection

Based on information supplied by PLN Wilayah Maluku dan Maluku Utara, the latest demand projection from 2011 to 2020 in the Ambon system is shown in Table II-4-4. As shown in Table II-4-4, the peak demand in 2011 is 43.3 MW in the Ambon system and it is expected that the peak demand of the system will be 72.9 MW by 2016, given an average growth rate of 11%

per year driven by steady economic growth in the area and improvements in rural electrification. In 2017, the Ambon system will be interconnected with the Seram system. The interconnection will result in further demand in the whole system.

Table II-4 Demand and Supply Projection in the Ambon System (2011 - 2020)

Neraca Daya Sistem Ambon

Received on Aug. 23 '11

ELECTRICITY FOR A BETTER LIFE

Uraian	Size	Unit	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Kebutuhan												
Produksi Energi		GWh	224,0	241,5	266,0	292,1	320,0	350,6	383,9	420,1	459,4	501,9
Load Factor		%	59,1	58,3	57,4	56,6	55,7	54,9	54,1	53,3	52,5	51,7
Beban Puncak		MW	43,3	47,3	52,9	59,0	65,6	72,9	81,1	90,0	100,0	110,9
Pasokan												
Kapasitas Terpasang		MW	55,1	55,1	55,1	55,1	55,1	55,1	***=> Interkoneksi Pulau***			
Derating Capacity		MW	20,1	20,1	20,1	20,1	20,1	20,1	***Ambon - Seram***			
Pembangkit PLN									***(Transmisi 70 kV)***			
Manufacture	Size											
PLTD Hative Kecil	**21,5**	MW	**15,2**	**15,2**	**15,2**	**15,2**	**15,2**	**15,2**				
PLTD Poka	**33,6**	MW	**20,8**	**20,8**	**20,8**	**20,8**	**20,8**	**20,8**				
Pembangkit Sewa												
Sewa HSD		MW	20,2	-	-	-	-	-				
Sewa MFO		MW		25,0	25,0	25,0						
Project PLN												
Waai #1,2 (FTP 1)		PLTU		15,0	15,0							
Waai #3 (Ekspansi)		PLTU					15,0					
Tulehu (FTP 2)		PLTP					10,0	10,0				
Wai Tala		PLTA						15,0	45,0			
Project IPP / Swasta												
Jumlah Efektif		***MW***	***56,2***	***76,0***	***91,0***	***91,0***	***91,0***	***116,0***				
Cadangan		***MW***	***8,3***	***19,5***	***19,5***	***19,5***	***25,0***	***25,0***				
Pemeliharaan		MW	4,5	15,0	15,0	15,0	15,0	15,0				
Operasi		MW	3,8	4,5	4,5	4,5	10,0	10,0				
Surplus/Defisit (N-2)		***MW***	***4,6***	***9,2***	***18,6***	***12,5***	***0,4***	***18,1***				

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(Source; Data presented at Work shop on Draft Final Report in August 2011 by Wilayah Maluku dan Maluku Utara)

The electrical power in the system is supplied solely by diesel engine generators, which have higher generation costs and emit a lot of greenhouse gases. Furthermore, they are seriously derated, i.e., the dependable capacity in Ambon system is only 25 MW as of August 2010 (see Table II-3), while the installed capacity is 55 MW. Thus, rental diesel generators are used to mitigate power shortages. In addition to the power shortage, the necessity of reducing fossil fuel consumption and limiting greenhouse gas emissions makes imperative the immediate development of renewable sources of energy.

According to Table II-4, rental MFO generators will be retired in 2014, and after that, power will be supplied by the Waai coal-fired power plant (2 x 15 MW), Tulehu geothermal power plant (20 MW) and other plants. Tulehu geothermal power plant, however, cannot enter commercial operationuntil 2016 at the earliest, given the standard process for contract bidding, a standard construction period etc. Accordingly, the table requires revision before it can be used as a standard schedule. Table II-5 and Fig. II-3 show the demand projection, taking into consideration the commencement of operation of Tulehu geothermal power plant in 2016. As shown in the table and figure, additional power will be necessary due to power shortages in

2015.

Since the Ambon system is expected to increase at an average, steady growth rate of 11% per year (72.9 MW in 2016, 110.9 MW in 2019 plus Seram demand), a unit size from 10 MW to 20 MW is probably most suitable for the System.

Table II-5 Revised Demand and Supply Projection for Ambon System (2011- 2020)

(Standard Schedule version)

System		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Demand											
Production	GWh	224.0	241.5	266.0	292.1	320.0	350.6	383.9	420.1	459.4	501.9
Load Factor	%	59.1	58.3	57.4	56.6	55.7	54.9	54.1	53.3	52.5	51.7
Peak Load	**MW**	**43.3**	**47.3**	**52.9**	**59.0**	**65.6**	**72.9**	**81.1**	**90.0**	**100.0**	**110.9**
Supply								Interconnection between Ambon system and Seram system.			
Installed Capacity	MW	55.1	55.1	55.1	55.1	55.1	55.1				
Derating Capacity	MW	-20.1	-20.1	-20.1	-20.1	-20.1	-20.1				
PLN Generation											
Hative Kecil 21.5 MW	PLTD	15.2	15.2	15.2	15.2	15.2	15.2				
Poka 33.6 MW	PLTD	20.8	20.8	20.8	20.8	20.8	20.8				
Rental Facility											
Rental HSD	MW	20.2	0	0	0	0	0				
Rental MFO	MW	**25.0*	25.0	25.0	25.0	0	0	* Rental MFO will be in operation one (1) year ahead of their original schedule.			
PLN Projects											
Waai #1,2 (**FTP1)	PLTU		15.0	15.0				** FTP; Fast Track Program			
Waai #3 (Expansion)	PLTU					15.0					
Tulehu (FTP2)**	**PLTP**						**20.0**				
Wai Tala	PLTA						15.0	45.0			
IPP Project											
Total Supply	**MW**	**81.2**	**76.0**	**91.0**	**91.0**	**81.0**	**116.0**				
Existing Maintenance	MW	-8.3	-19.5	-19.5	-19.5	-25.0	-25.0				
Reserve	**MW**	**29.6**	**9.2**	**18.6**	**12.5**	**-9.6**	**18.1**				

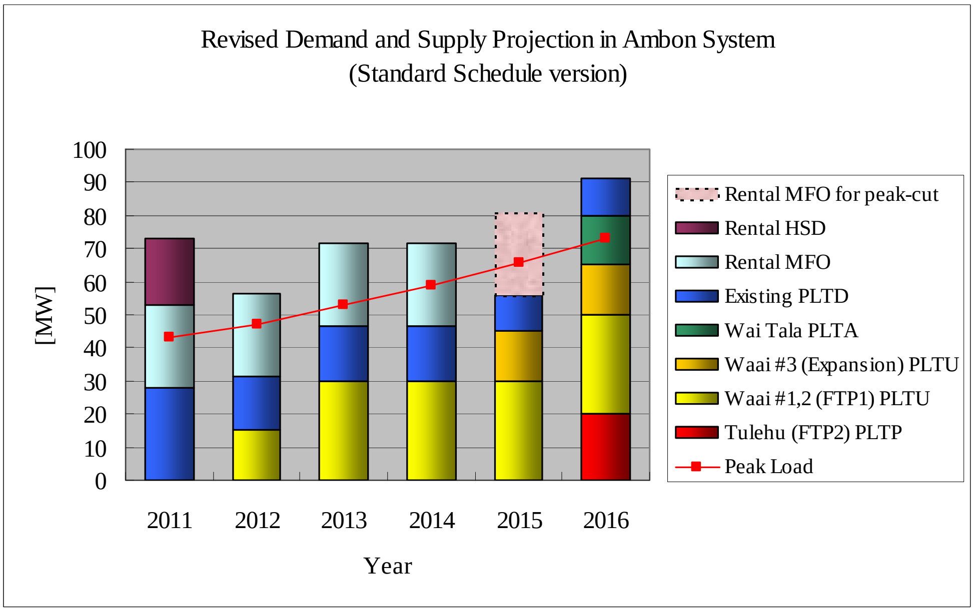


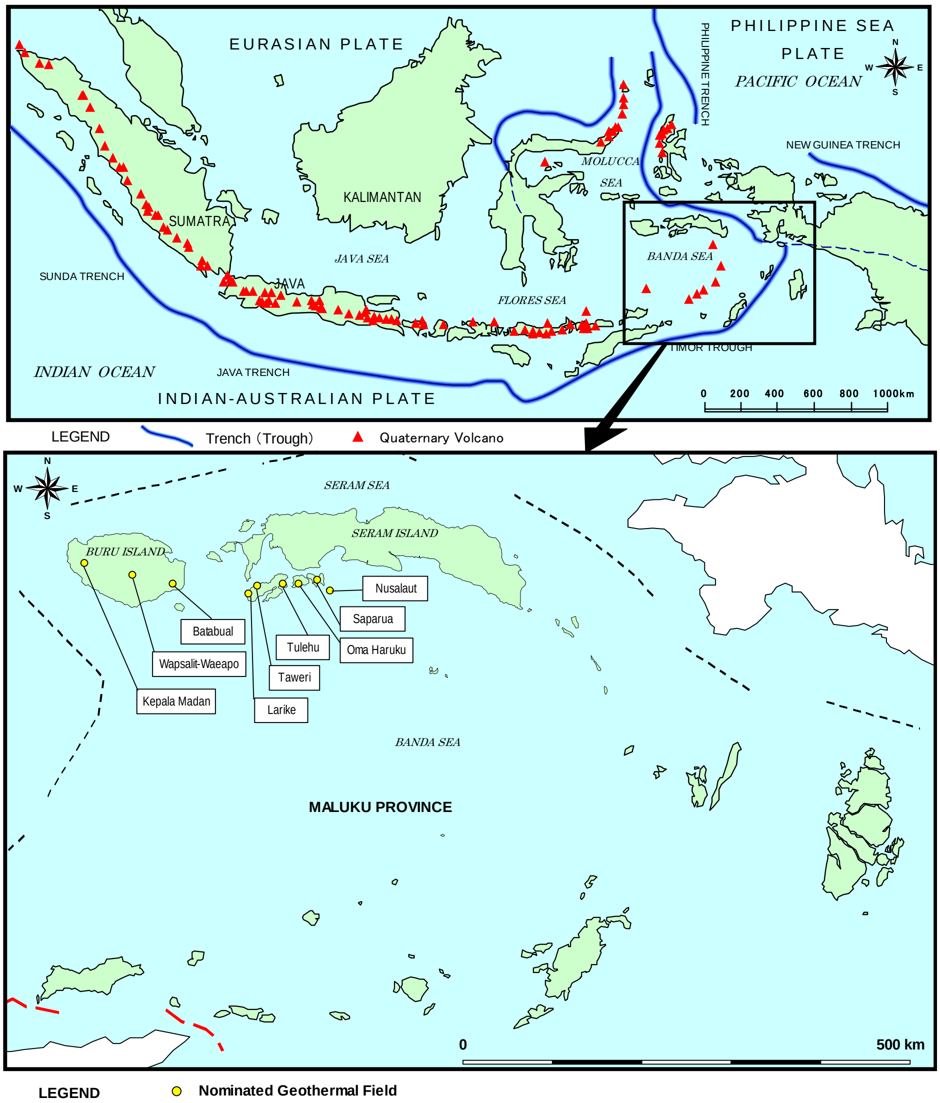
Fig. II-3 Revised Demand and Supply Projection for Ambon System (Standard Schedule Version)

CHAPTER III

III GEOTHERMAL RESOURCES IN TULEHU FIELD

Indonesia is situated on plate boundaries, between the Indian-Australian Plate and the Eurasian Plate and between the Eurasian Plate and the Philippine Sea Plate (see Fig. III-1). A typical island-arc system, characterized by a trench (or trough) and a Quaternary volcanic belt, is identified in Indonesia. There are many geothermal fields with considerable potential in and around the volcanic belts. In Maluku Province, the following nine (9) geothermal fields in five (5) islands are nominated by MEMR (2007).

> Kepala Madan (Buru Island), Wapsalit-Waeapo (Buru Island), Batabual (Buru Island), Larike (Ambon Island), Taweri (Ambon Island), Tulehu (Ambon Island), Oma Haruku (Haruku Island), Saparua (Saparua Island), and Nusalaut (Nusalaut Island).



Source: T. Simkin and L. Siebert (1994)、MEMR (2007)

Fig. III-1 Quaternary Volcanoes in Indonesia and Nominated Geothermal Fields in Maluku Province

III.1 Review of Existing Data and Information about Geothermal Resources

III.1.1 Current Status of Drilling Operations in Tulehu

In the Tulehu geothermal field, six (6) thermal gradient holes (40 m deep to 150 m depp) had been drilled (see Fig. III-2), three (3) thermal holes (40 m deep to 120 m deep) in 2008 and three (3) thermal holes (150 m deep) in 2009. The highest borehole bottom temperature (122.6°C) was recorded in the well W2.1. The first exploratory well TLU-01 was drilled from December 2010 to July 2011 (drilled depth = 932.65 m). Its drilling site is located near by the well W2.1.

Fig. III-2 Location of Existing Wells and Drilling Site for Exploratory Well

III.1.2 Exploration Data and Information

1. Existing Geological Data

In the Tulehu geothermal field, surface geology consists of the following thirteen (13) units; Sandstone unit, Tanjung basalt lava unit, Salahutu-1 dacitic lava unit, Salahutu-2 dacitic lava, Bukitbakar andesite lava unit, Bukitbakar pyroclastic unit, Huwe pyroclastic unit, Mt. Simalopu pyroclastic unit, Mt. Salahutu pyroclastic unit, Mt. Kadera pyroclastic unit, Mt. Eriwakang pyroclastic unit, Limestone unit and Alluvium deposits, in order from old age to young (see Fig. III-3).

The following eight (8) faults are estimated in the Tulehu field. The Wairutung fault, trending in northeast to southwest, is a normal fault dipping southeast. The Huwe fault, trending in northeast to southwest, is a normal fault dipping northwest. There is a depression zone between these two faults. In this depression zone, there are two faults trending in northeast to southwest, the Banda-Hatuasa fault and the Banda fault. These two faults are also normal faults dipping northwest. The Waiyari fault, trending in northwest to southeast, is a right-lateral fault. The Salahutu fault, trending in northwest to southeast, is also a right-lateral fault. The Tulehu fault, trending in northwest to southeast, is a normal fault dipping northeast. The Kadera fault trends in west to east, though its eastern part trends in northeast to southwest. The Kadera fault is a normal fault dipping south.

Geothermal manifestations in the Tulehu field can be classified into two groups by their locations; hot springs around Mt. Terang Alam and hot springs around Mt. Eriwakang. There are hot springs along the coast on the northern foot of Mt. Terang Alam, namely Batu Lompa hot springs and Batu Luda hot spring. These hot springs occur around intersecting point of the Huwe fault with the southeastern extent of the Tulehu fault. Their discharging temperatures are about 40°C to 70°C. Around Mt. Eriwakang, hot springs align along the Banda fault and the Banda-Hatuasan fault (see Fig. III-3). Around intersecting point of the Banda fault with the Tulehu fault, in Mamokeng, some hot springs are identified on the beach and in the sea. Their discharging temperatures are about 40°C. There are Telaga Biru hot springs and Sila hot springs on the northern foot of Mt. Eriwakang, along the Banda fault. Discharging temperatures of hot springs in Telaga Biru are 35°C to 48°C. Discharging temperatures of hot springs in Sila are 38°C to 80°C. Around the riverside of the Yari River, there is Hatuing hot spring along the Banda fault. Discharging temperature of this hot spring is 49°C. Along the Banda-Hatuasa fault, there is Hatuasa hot spa and discharging temperature is 56°C to 60°C. Banda alteration zone occurs along the Banda-Hatuasa fault. Identified secondary minerals are quartz, montmorillonite, kaolinite, illite, alunite, gypsum and so on.

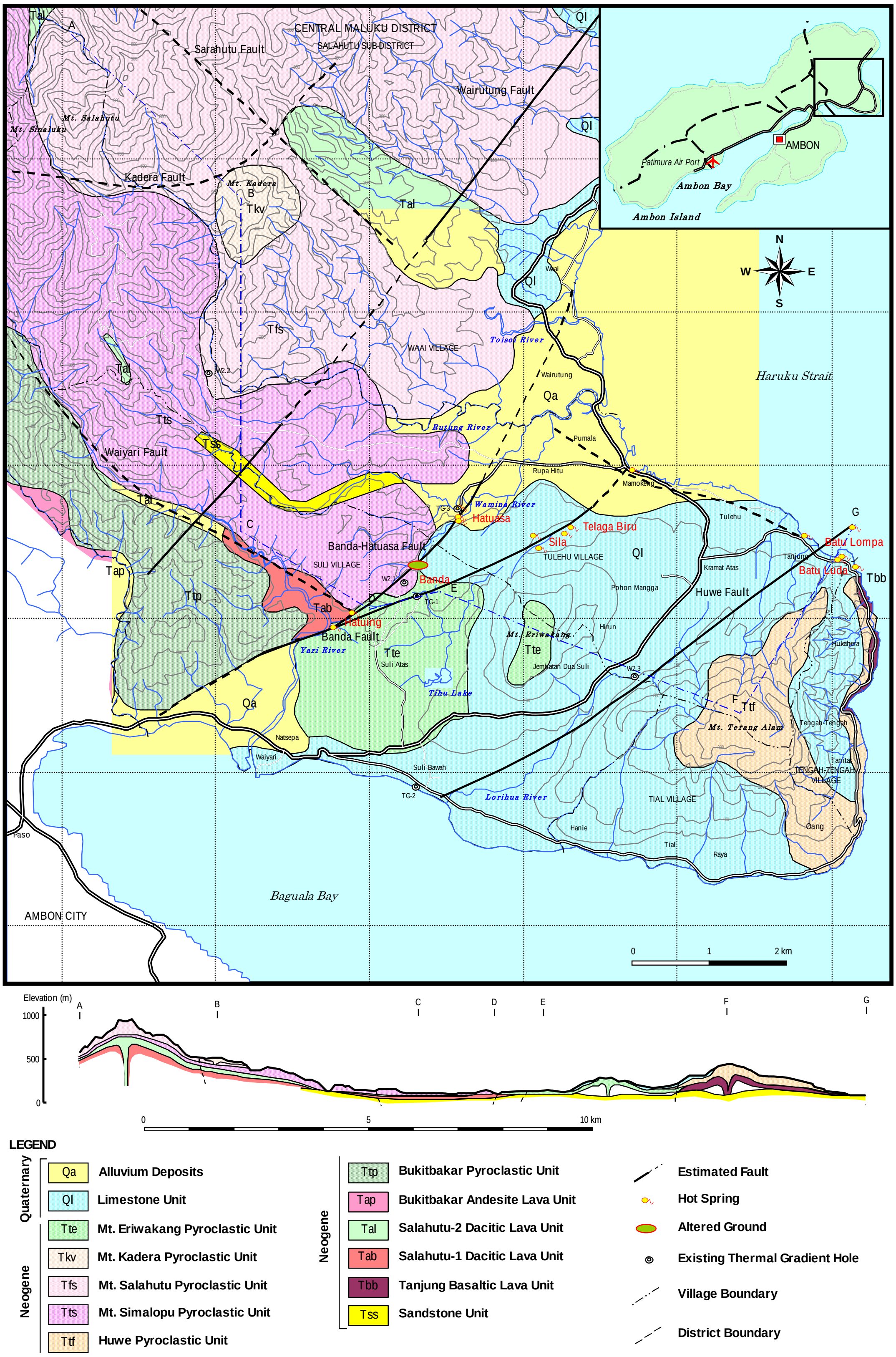


Fig. III-3 Geological Map in Tulehu

2. Existing Geophysical Exploration Data

a. Gravity Survey

In the Tulehu field, a gravity survey was carried out in the area of 25km^2 (PLN, 2008). The number of gravity station is 247 and spacing among the stations ranges from 300 m to 600 m. The Bouger anomaly map is shown in Fig. III-4. Five gravity lineaments, GL1 to GL5, are estimated. There are a low-gravity anomaly zone in the northeastern part of the survey area and a high-gravity anomaly zone in the southwestern part of the survey area. The estimated gravity lineament GL1 is situated on a boundary between the gravity anomaly zones. Between gravity lineaments GL3 and GL4, a local high-gravity anomaly zone extends northeast and a low- gravity anomaly zone extends on the northwestern side of the gravity lineament GL3.

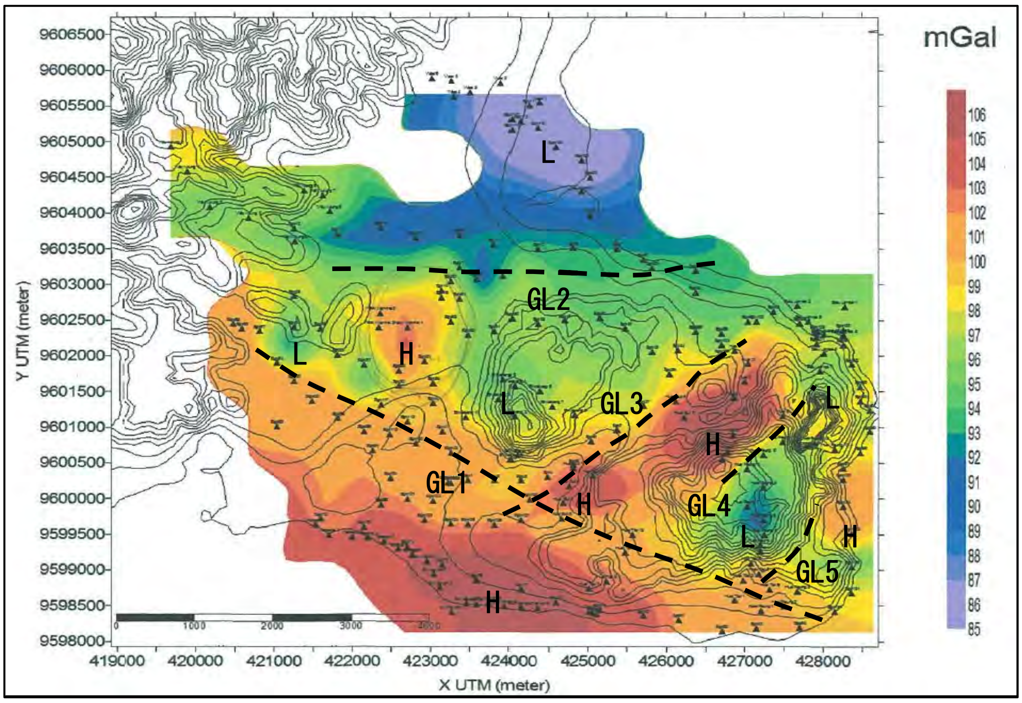


Fig. III-4 Bouger Anomaly Map in Tuhelu

b. Magnetic Survey

The magnetic survey was also carried out in the area of 25 km^2 (PLN, 2008). The number of magnetic station is 247 that are the same locations of the gravity stations. IGRF (International Geomagnetic Reference Field) residual map is shown in Fig. III-5. There are positive anomaly in the north part of the survey area and negative anomaly in the south part of the survey area. Areas showing rapid change of IGRF residual values in the map are possible to indicate discontinuity of distribution of magnetic materials but these have no relevance to faults and formation boundary in the survey area. Geothermal manifestations in this field occur in the positive anomaly area. Generally, a poor magnetic anomaly is observed at the altered ground in and around the geothermal manifestations. A magnetic anomaly is not detected above magnetic materials in the survey area, because Tulehu geothermal prospect is located in the lower latitudes.

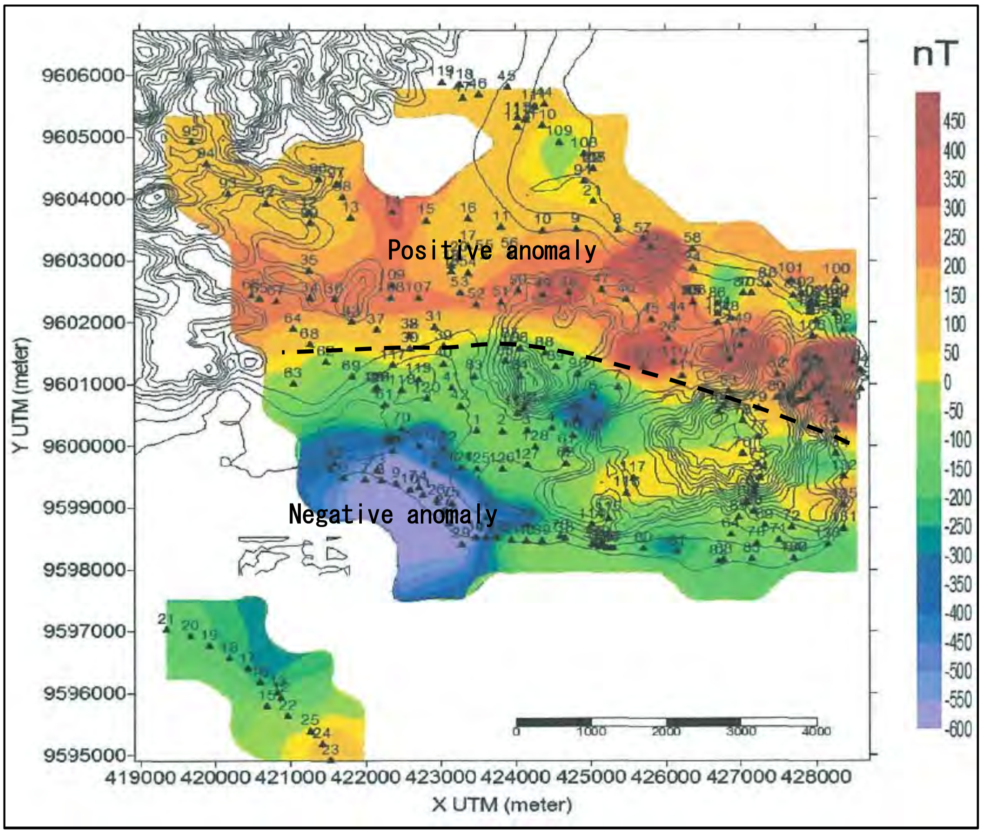
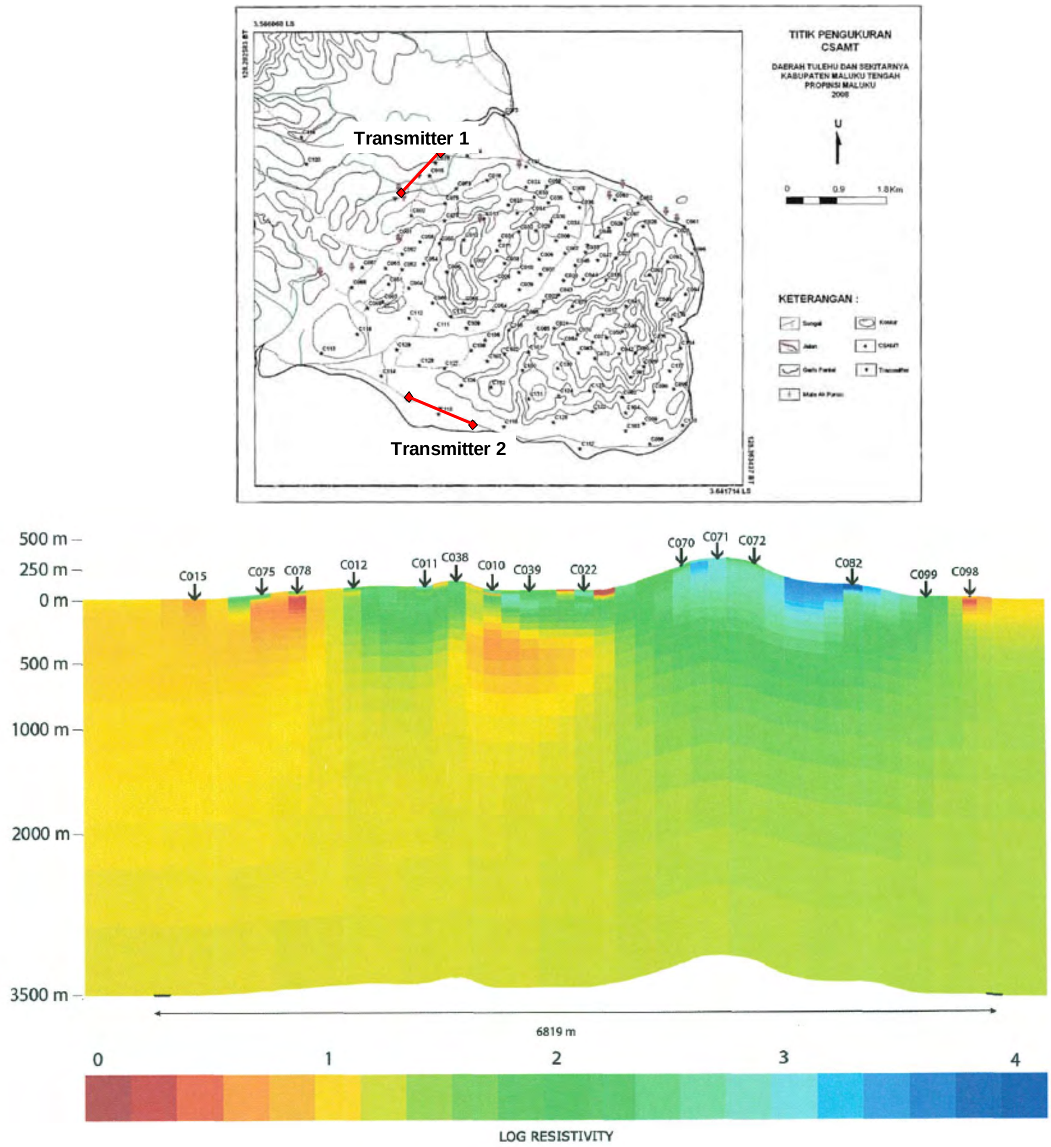


Fig. III-5 IGRF Residual Anomaly Map in Tulehu

c. CSAMT Survey

A Controlled Source Audio-frequency Magneto-Telluric (CSAMT) exploration with approximately 130 sites was conducted in the Tulehu field (PLN, 2008). Many inverted sections that exceeded more than 30 slices are shown in the report. An example of such inverted resistivity section is shown in Fig. III-6. In CSAMT survey, the distance between observation sites and transmitters should be sufficiently far so that the distances exceed 3 times the maximum depth of investigation, in order to avoid so-called Near Field Effect. The site layout in Fig. III-6 shows that the distances are too close. Thus, it was doubtful that if acquired CSAMT data were sufficient to conduct inversion analysis. For the mesh settings of the inverted resistivity sections, all the inverted section shows that the thickness of the inversion meshes were about 4km. In general, the depth of investigation of CSAMT survey is inevitably limited to less than 1km due to the near field effect. Thus it was concluded that the CSAMT resistivity sections were excluded from the integrated interpretation of the geothermal structure of the Tulehu field.



(Source; PLN Geothermal)

Fig. III-6 Site Layout and an Example of Inverted Section

3. Geochemical Data

Table III-1 shows the chemical data on geothermal gases from the hot springs in and around the field. There is no information about content of hydrogen sulfide gas. However, it seems to be low in this field, because there was no smell of hydrogen sulfide gas at hot springs in this field during the field survey and temperatures of the gases were reported to be relatively low. Since the gas compositions in this table were considered to be influenced by mixing with air, it seemed to be difficult to clarify the characteristics and the degree of promise of the geothermal resources by these data.

Table III-1 Chemical Composition of Gases from Hot Springs and Fumaroles in and around Tulehu Geothermal Field

Sample No.	CO_2	O_2	N_2	Ar	CH_4	Location	
TLH-3	1.83	32.62	66.48	0.00	0.07	Close to Tulehu Beach	Tulehu
BTL-1	27.71	30.73	38.61	0.00	2.95	Batu Lompa Beach	
HTS-3	47.38	10.55	41.68	0.00	0.39	Hatuasa	
BTL-3	8.85	3.95	6.35	0.00	0.00	Batu Lompa Beach 2	
HRK-1	95.57	2.33	1.72	0.38	0.00	Haruku	Haruku
OMA	16.07	29.08	54.66	0.00	0.18	Oma	
OMA-2	96.01	0.80	2.71	0.00	0.48	Oma	

(Pre-FS report by PLN Geothermal, February 2010)

Chemical data (molar fraction) of the geothermal gases of TLH-3 was used on the presumption that the gases of TLH-3 were derived from the geothermal reservoir, as TLH-3 gas shows the chemical characteristics that are normally associated with geothermal fields. Moreover, chemistry of hot spring water from TLH-3 indicates that this water is formed by water-rock interaction. The following content and composition of non-condensable gases (NCG) in the geothermal steam were calculated.

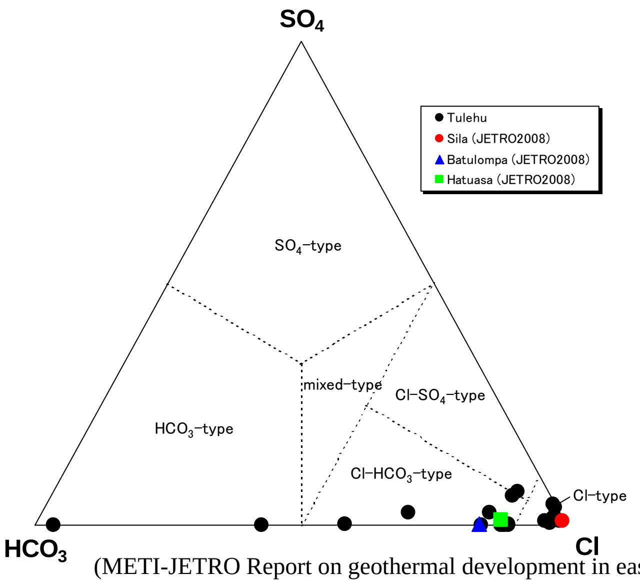
It must be noted that this calculation is based on uncertain assumption to be examined. Moreover, location of TLH-3 is rather far from the targeting area for the project and sampling condition is also uncertain. Therefore, it is difficult to deduce that chemical data calculated from the TLH-3 data is appropriate as the chemical characteristics of the steam from the wells in the Tulehu field. Even if the conceptual design of the geothermal plant is conducted by using these data, it is necessary to review the design based on the measured chemical characteristics of well discharge after future well discharge test.

Chemical composition of the hot spring waters in and around this field are shown in Table III-2. As shown in Fig. III-7, the hot spring waters in this field were classified into Cl type or Cl-HCO_3 type. The highest concentration of Cl ion in hot spring water was reported to be 5,730 mg/L. It is thought that these high contents of Cl ion in the waters are caused by mixture of seawater and meteoric water (see Fig. III-8). However, there are hot spring waters of relatively large oxygen-18 shift that shows interaction of hot water with reservoir rocks under high temperature condition, such as the hot spring water at Sila, as shown in Fig. III-9. Its Cl/B molar ratio is about 130, though Cl/B molar ratio of seawater shows about 1200. Although exact estimation of the reservoir temperature by geochemical thermometers is difficult, Na-K-Ca temperature at Sila indicates 200^oC (see Table III-3). From these, the altered hot-spring water is derived from the geothermal reservoir of higher than 200^oC and it is considered that geothermal water originated from mixture of seawater and meteoric groundwater.

As hot waters from hot springs in the north of Mt. Eriwakang have similar Cl/B molar ratio (about 130), there is possibly that these hot spring waters are derived from a common geothermal reservoir. These hot springs seems to distribute along geological structure such as faults.

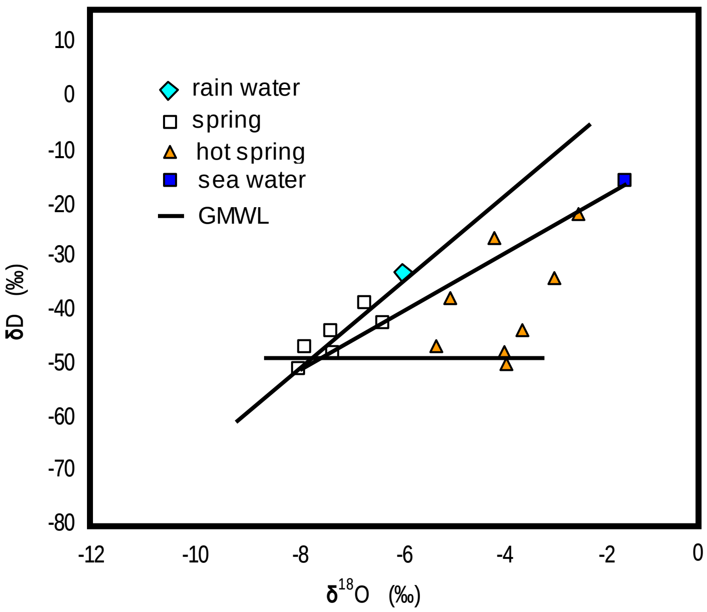
High content of carbonate ion in the hot spring waters show a possibility that sedimentary rocks or limestone influence hot spring waters. In case of reservoir in sedimentary rocks or limestone, there is a possibility that serious problems such as carbonate scaling in production well and pipeline and high content of NCG occur in this field. Therefore, it will be desired to examine existence of these rocks by well drilling.

According to chemical characteristics of geothermal reservoir fluid assumed from those of hot spring waters, there is no possibility that corrosion troubles occurs in this field. However, silica scale from the geothermal water in this field seems to deposit easily due to relatively high content of salts dissolved in the water. Mineral acid injection into the reinjection line is considered to be effective to prevent silica scale deposition, because silica content in the water separated from geothermal fluid of about 200^oC must not be so high. Adequate countermeasures against such scale troubles should be considered based on chemical characteristics of well discharge after the completion of well discharge testing.



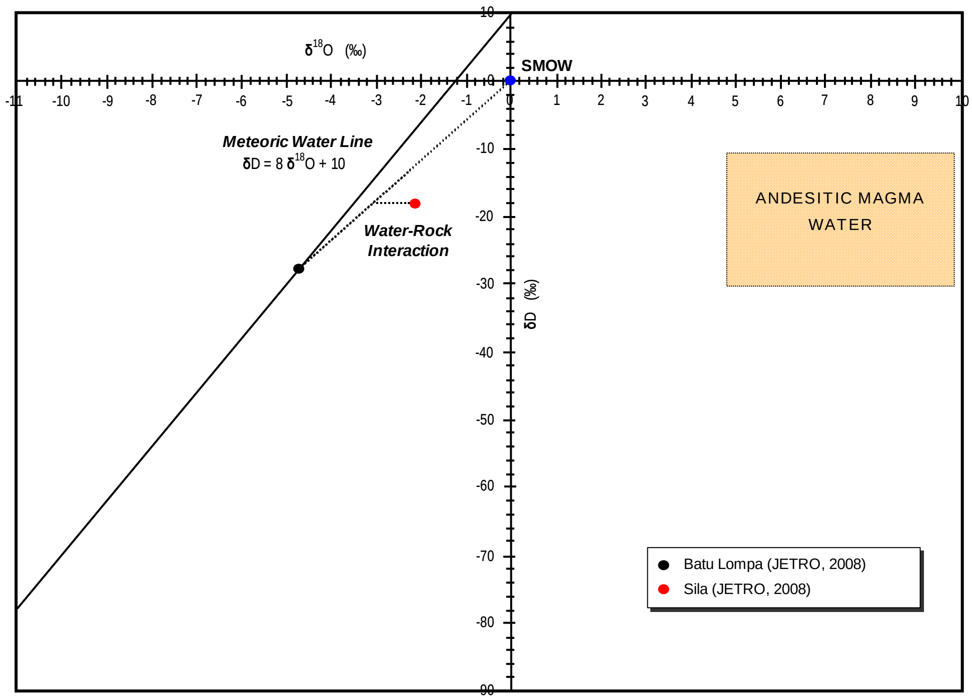
(METI-JETRO Report on geothermal development in east Indonesia, March 2009)

Fig. III-7 Tri-linear Diagram of Major Anions in and around Tulehu Field



(Pre-FS report by PLN Geothermal, February 2010)

Fig. III-8 Hydrogen and Oxygen-18 Diagram of Hot Spring Waters in and around Tulehu Field



(METI-JETRO Report on geothermal development in east Indonesia, March 2009)

Fig. III-9 Hydrogen and Oxygen-18 Diagram of Hot Spring Waters at Sila

Table III-2 Chemical Composition of Hot Spring Waters in and around Tulehu Geothermal Field

No.	Code	SiO_2 (ppm)	Al (ppm)	Fe (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Li (ppm)	NH_3 (ppm)	Cl (ppm)	SO_4 (ppm)	HCO_3 (ppm)	H_2S (ppm)	B (ppm)	pH lab.	flow rate (l/min.)	water temp. (°C)	Location	
1	TLH-1	149.9	0	1.06	145.3	16.55	373.8	39.73	0.18	2	473.86	0	655.44	1.33	1.64	6.2	6	57	Beach behind Tuluhu Hospital	Tulehu
2	TLH-3	178.9	0	0.77	262.03	18.6	1062.1	152.8	0.79	3	1826.44	1.2	474.76	1	4.8	6.4	1.3	78	Batu Lompa Cape	
3	TLH-4	82.98	0	0.09	265.78	119.36	1961.19	148.6	0.13	0.75	3128.92	258.93	520.9	2	1.26	6.9	2.8	40	Mamokeng Beach	
4	SL-1	183.4	0	0.2	702.5	9.5	2824.64	302.6	1.2	1.36	5282.24	64.47	120.65	1.99	12.05	6.6	0.3	90	Sila	
5	SL-2	86.75	0	0	288.38	5.24	1115.52	103.7	0.52	1.41	2055.75	15.48	151.35	1.99	4.78	7.6	-	38	Sila	
6	HTS-1	163.4	0	0.05	312.6	9.39	1040.64	96.28	0.54	4.69	1811.54	25	423.78	13.39	3.46	6.4	7.5	60	River of Hatuasa	
7	HTS-2	155.5	0	0.08	299.2	8.85	997.92	91	0.51	5.63	1741.85	23.03	395.11	13.39	4.26	6.5	23.8	60	Hatuasa Hot Spring Pool	
8	HTS-3	172.8	0	0.14	288.2	9.22	966	92.06	0.53	4.69	1741.85	21.05	441.86	12.68	7.49	7.3	15	60	Hatuasa	
9	BTL	179.4	0	1.64	969	418.5	8788	715	3.47	7.81	14989.6	833.33	188.4	10.63	24.55	6.6	0.5	49	Batu Lompa Island	
10	Suli Beach	92.19	0	0	52.3	4.26	173.6	9.39	0.05	1.88	226.99	10.12	198.36	1.66	0.46	8.3	23.5	35	Suli Beach	
11	SLM-1	181.3	0	0.1	213.2	22.7	1107	89.3	0.54	1.5	1811.85	3.87	442.55	1.99	6.14	6.4	1.5	61	Hatuing	
12	SLM-2	124.5	0	1.65	492	9.15	2096	203.6	1.04	4.69	3818.82	72.62	153.94	5.32	6.9	5.9	7	70	Hatuing	
1	OMA-1	208.3	0	2.97	289	308	3436	217.4	0.3	1.56	5400.7	815.79	575.19	4.65	2.09	6.7	1.5	65	Oma	Haruku
2	OMA-2	239.4	0	0.57	64.02	4.63	768	70.24	0.48	3.5	1067.94	85.71	396.75	1.33	2.85	6.8	15	72	Oma	
3	HRK-1	100.1	0	0.2	63.08	10.2	862	72.66	0.48	5	1118.92	95.39	532.52	2.66	2.09	7.8	3	85	Haruku	

(Pre-FS report by PLN Geothermal, February 2010)

Table III-3 Geochemical Temperatures in and around Tulehu Geothermal Field

No.	Code	Temperature (°C)			Location	
		Na-K (Fournier)	Na-K (Giggenbach)	Na-K-Ca		
1	TLH-1	222.42	237.37	119.00	Beach behind Tuluhu Hospital	Tulehu
2	TLH-3	250.43	263.26	179.96	Batu Lompa Cape	
3	TLH-4	194.45	211.24	189.19	Mamokeng Beach	
4	SL-1	223.11*	238.01	199.84	Sila	
5	SL-2	210.95	226.69	157.58	Sila	
6	HTS-1	210.56	226.32	150.32	River of Hatuasa	
7	HTS-2	209.35	225.20	148.38	Hatuasa Hot Spring Pool	
8	HTS-3	213.04	228.64	149.59	Hatuasa	
9	BTL	200.07	216.51	269.02	Batu Lompa Island	
10	Suli Beach	169.56	187.74	81.72	Suli Beach	
11	SLM-1	199.38	215.87	160.01	Hatuing	
12	SLM-2	214.66	230.15	185.09	Hatuing	
1	OMA-1	180.80	198.38	219.92	Oma	Haruku
2	OMA-2	209.60	225.43	182.92	Oma	
3	HRK-1	202.91	219.17	187.47	Haruku	

(Pre-FS report by PLN Geothermal, February 2010)

4. Well Testing Data

a. Thermal Gradient Hole

Well TG-1 is drilled to 40 m deep. Measured temperature at the bottom is 41^{o}C. The following formations (see Fig. III-10) are identified; tuffaceous clay (surface to 17 m deep) corresponding to the Eriwakang pyroclastic unit and silicified dacite (17 m to the bottom) corresponding to the Salahutu-2 dacitic lava unit.

Well TG-2 is drilled to 120 m deep. Measured temperature at the bottom is 36^{o}C. The following formations (see Fig. III-10) are identified; sandy clay and sand (surface to 33 m deep) being surface soil, coral limestone (33 m to 51 m deep) corresponding to the Limestone unit, clay (51 m to 110 m deep) corresponding to the Eriwakang pyroclastic unit, and dacite (110 m to the bottom) corresponding to the Salahutu-2 dacitic lava unit.

Well TG-3 is drilled to 40 m deep. Measured temperature at the bottom is 31^{o}C. The following formations (see Fig. III-10) are identified; clay and sandy clay (surface to 25 m deep) being Alluvium deposits and dacite (25 m to the bottom) corresponding to the Salahutu-2 dacitic lava unit.

Well W2.1 is drilled to 150 m deep. Measured temperature at the bottom is 122.6^{o}C. Underground temperature increases as increasing depth. The following formations (see Fig. III-11) are identified; pyroclastic (surface to 69 m deep) corresponding to the Simalopu pyroclastic unit, claystone and dacite (69 m to 84 m deep) corresponding to thr Salahutu-2 dacitic lava unit, and claystone and dacite (84 m to the bottom) corresponding to the Salahutu-1 dacitic lava unit.

Well W2.2 is drilled to 150 m deep (see Fig. III-11). Measured temperature at the bottom is 32.4^{o}C. Underground temperature increases as increasing depth, though it is not so remarkable. The following formations (see Fig. III-11) are identified; pyroclastic (surface to 7 m deep) corresponding to the Simalopu pyroclastic unit, dacite (7 m to 69.6 m deep) corresponding to the Salahutu-2 dacitic lava unit, claystone and Dacite (69.6 m to 132.5 m deep) corresponding to the Salahutu-2 dacitic lava unit or the Salahutu-1 dacitic lava unit, and sandstone and dacite (132.5 m to the bottom) corresponding to the Salahutu-1 dacitic lava unit.

Well W2.3 is drilled to 150 m deep. Underground temperature is rather constant, near the surface to the bottom. Measured temperature at the bottom is 27.5^{o}C. The following formations (see Fig. III-11) are identified; coral limestone and pyroclastic (surface to 55 m deep) corresponding to the Limestone unit, pyroclastic (55 m to 111.4 m deep) corresponding to the Huwe pyroclastic unit, and dacite and pyroclastic (111.4 m to the bottom) corresponding to the Salahutu-2 dacitic lava unit.

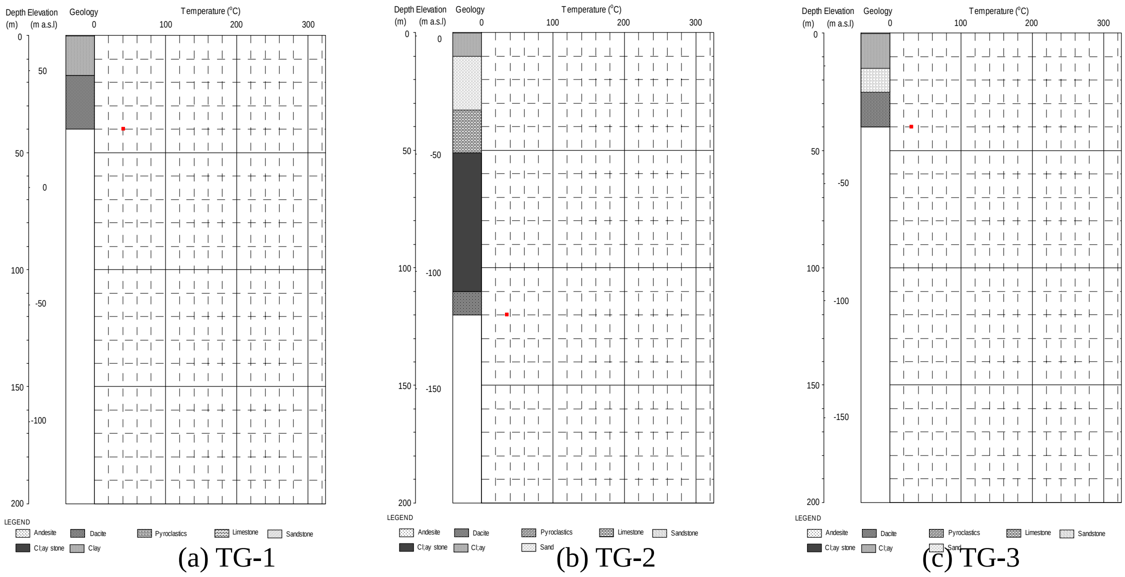
b. Exploratory Well

The first exploratory well TLU-01 in this field is located between the wells TG-1 and W2.1. This well was drilled to 911 m (original hole and vertical well) but side tracked from a depth of 521.09 m to a depth of 932.67 m (vertical depth is 930.75 m). The following formations (see Fig. III-12) are identified; pyroclastic (surface to 64 m deep) corresponding to the Simalopu pyroclastic unit, altered andesite (64 m to 85 m deep) corresponding to the Salahutu-2 dacitic lava unit, and pyroclastic and andesite (85 m to the bottom) corresponding to the Salahutu-1 dacitic lava unit (temporally correlated in this paper).

Partial lost circulation occurred at a depth of 330 m and total lost circulation happened for a time (from 332 m to 350 m). From a depth of 350 m, partial lost circulation continued until a depth of 618 m. In the original hole, partial lost circulation occurred at a depth of 725 m and continues to the bottom (911 m). Drilling breaks are detected from 735 m to 737 m and from 740 m to 750 m, they can be correlated with lost circulation zones. In the side tracked hole, partial lost circulation started around a depth of 644 m and total lost circulation happened around a depth of 703 m. Partial lost circulation and total lost circulation alternately occurred until a depth of 932.67 m (bottom of the hole). From injection test data, there are major lost circulation zones at depths of 703 m and of around 900 m. From fall off test data after the injection test, permeability-thickness (kh) was estimated to be 5.3 to 9.6 darcy-m. These values indicate that the well TLU-01 has good permeability.

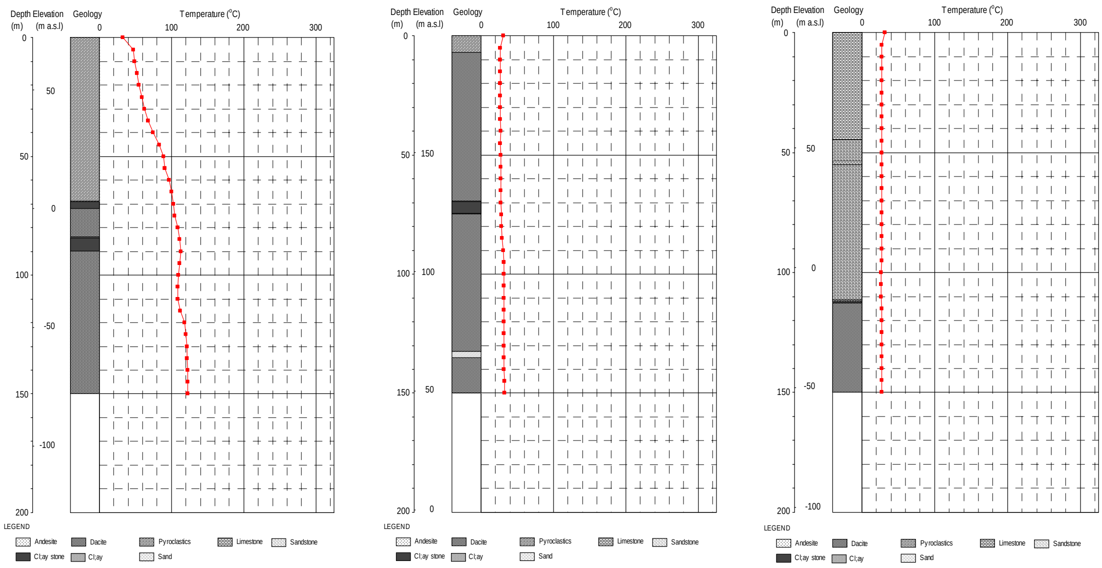
A heating up test was conducted after the injection test. In this test, pressure and temperature loggings were carried out, at passed times of 14 hours, 28 hours, 40 hours, 52 hours, 63 hours, 87 hours, and 111 hours after water injection stop (see Fig. III-12 and Table III-4). The highest temperature of 115.42^{o}C was recorded at a depth of 500 m (water level = 550 m) at a passed time of 63 hours after water injection stop. As considerable amount of drilling fluid was injected in this well to keep suitable borehole condition, remained cooling effect by this injection must bring about very slow temperature recovery.

Calculated equilibrium temperatures based on measured data are given in Table III-4. Equilibrium temperature (original subsurface temperature before drilling) is usually estimated using relationship between measured temperatures and standing times after the last water injection. As a water level of TLU-01 was changed about 550 m by repetition of confining compressed air and releasing confined air during a heating up test, passed time after water injection stop cannot be regarded to be a “standing time”. Therefore, there is a possibility that the estimated equilibrium temperatures are different from original subsurface temperatures before drilling. However, it is considered that effect by changing water level is rather little around the bottom of the well. Moreover, sufficient coincidence is recognized between measured temperatures and calculated temperature at a depth of 900 m. This may suggest that calculated temperature (about 230°C) at a depth of 900 m closes to the original subsurface temperature before drilling. Judging from occurrences of secondary minerals (especially chlorite and epidote), temperature of exceeding 200°C will be expected under a depth of about 360 m. Although it must be examined, these data suggest that temperatures at a depth of 360 m (about –287 m above sea level) and at a depth of 900 m (about –825 m above sea level) reach around 200°C and around 230°C, respectively (see Fig. III-13).



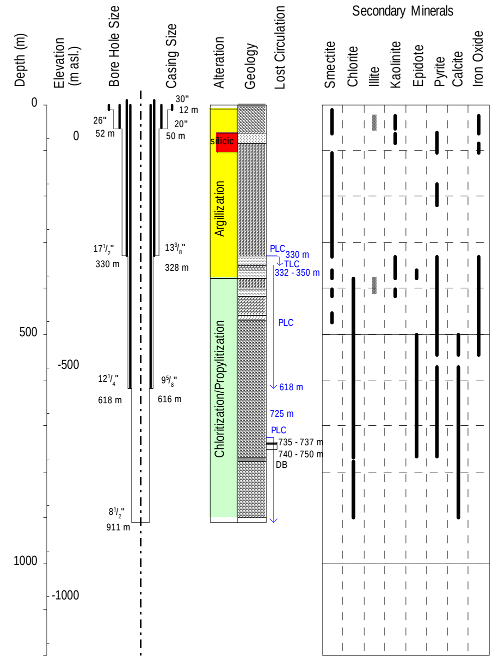
(a) TG-1 (b) TG-2 (c) TG-3

Fig. III-10 Columnar Section of TG-1, TG-2 and TG-3

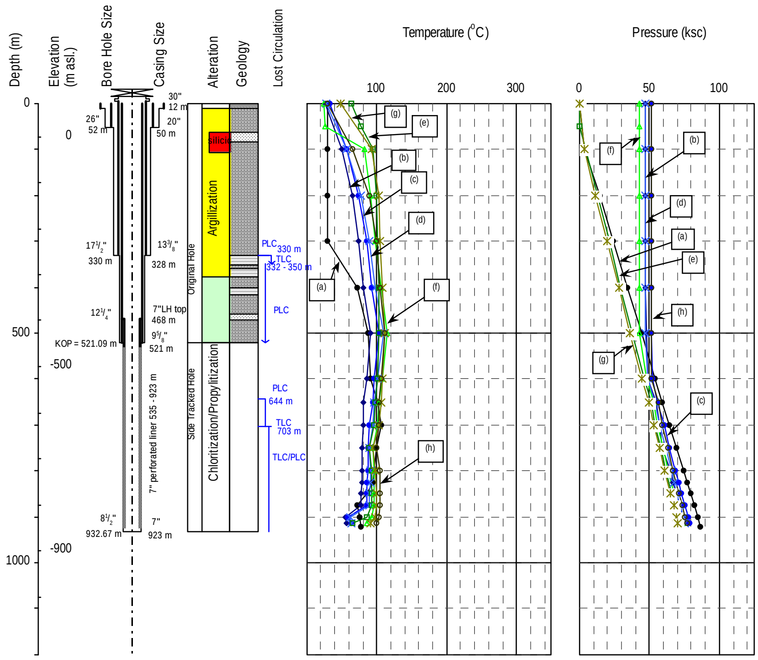


(a) W2.1 (b) W2.2 (c) W2.3

Fig. III-11 Columnar Sections of W2.1, W2.2, W2.3



(a) Original Hole



(a) 2011/7/2-3, 44 hrs. after injection stop, after 7" liner set, WL = 60 m

(b) 2011/7/3-4, 14 hrs. after injection stop, confining air at WHP = 47.5 kscg, WL = 600 m

(c) 2011/7/4, 28 hrs. after injection stop, confining air at WHP = 51 kscg, WL = 600 m

(d) 2011/7/5, 40 hrs. after injection stop, confining air at WHP = 46.99 kscg, WL = 600 m

(e) 2011/7/5, ST.52 hrs. after injection stop, after releasing confined air, WHP = 0 kscg, WL = 60 m

(f) 2011/7/6, 63 hrs. after injection stop, after compressing to confine air, WHP = 43.01 kscg, WL = 550 m

(g) 2011/7/7, 87 hrs. after injection stop, after releasing confined air, WHP = 0 kscg, WL = 60 m

(h) 2011/7/8, 111 hrs. after injection stop, after compressing to confine air, WHP = 51 kscg, WL = 600 m

(b) Side Tracked Hole

Legend

Dacite **Andesite** **Andesitic breccia** **Tuff breccia** **Tuff** **No cuttings**

TLC **Total Lost Circulation** PLC **Partial Lost Circulation** DB **Drilling Break**

Fig. III-12 Columnar Section of TLU-01

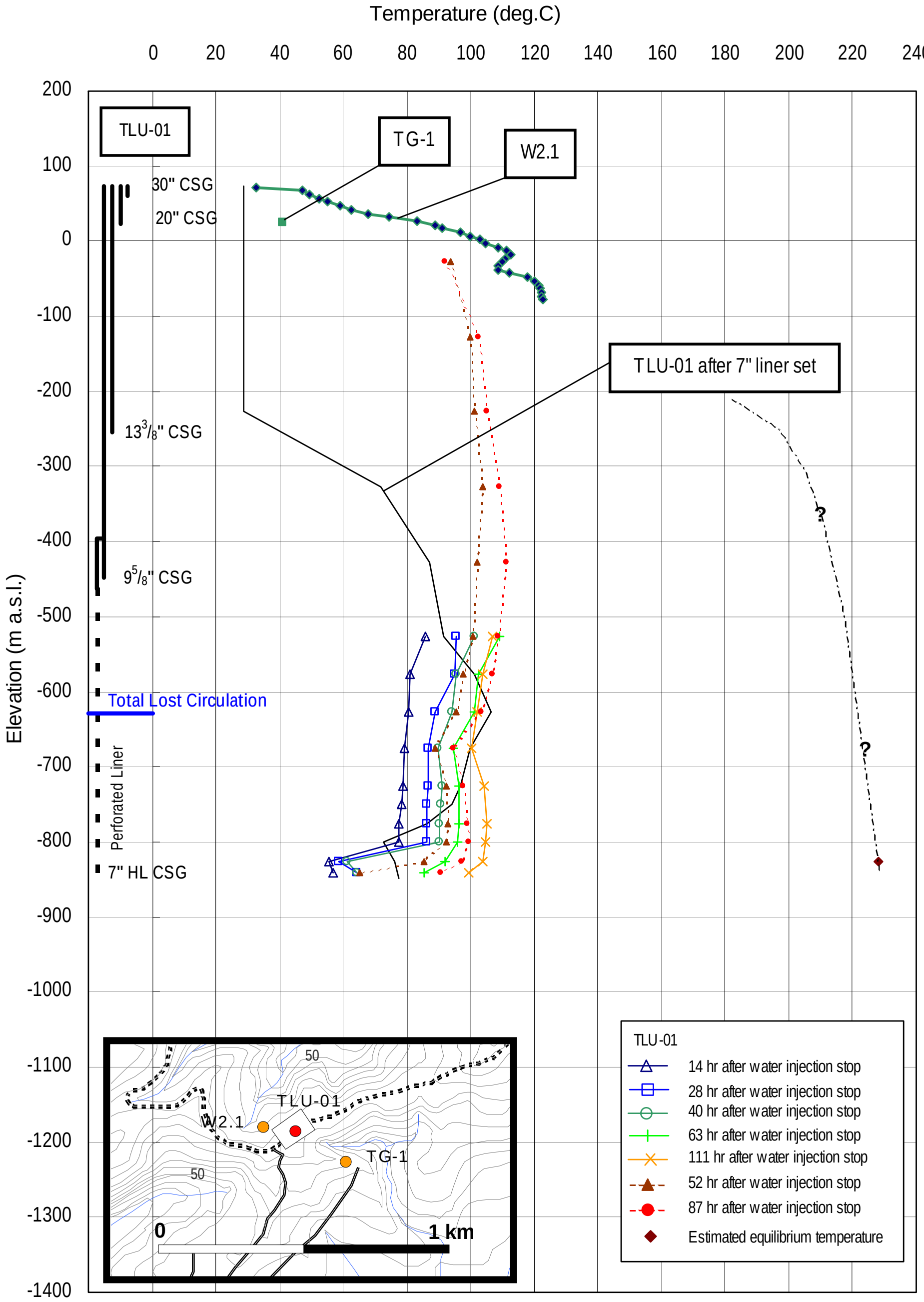


Fig. III-13 Temperature Profiles of TLU-01 and Its Neighboring Wells

Table III-4 Pressure and Temperature Logging Data of TLU-01

				Heating Up Test														Estimated Equilibrium Temperature
Date		2011/7/2-3		2011/7/3-4		2011/7/4		2011/7/5		2011/7/5		2011/7/6		2011/7/7		2011/7/8		
Depth	Elevation	Temp.	Pressure	Temp.	Pressure	Temp.	Pressure	Temp.	Pressure	Temp.	Pressure	Temp.	Pressure	Temp.	Pressure	Temp.	Pressure	
(m)	(m)	(°C)	(kscg)	(°C)	(kscg)	(°C)	(kscg)	(°C)	(kscg)	(°C)	(kscg)	(°C)	(kscg)	(°C)	(kscg)	(°C)	(kscg)	(°C)
0	73	28.76	0.00	25.56	47.50	33.77	51.00	28.16	46.99	63.83	0.00	23.55	43.01	47.80	0.00	28.76	51.00	
50	23									77.65	0.00	26.36	43.01					
100	-27	28.76	3.94	49.80	47.50	56.81	51.00	56.91	46.99	93.88	3.94	83.26	43.01	92.08	3.24	64.83	51.00	
200	-127	28.76	14.21	64.93	47.50	74.05	51.00	76.95	46.99	99.79	12.81	91.68	43.01	102.70	11.54	88.87	51.00	
300	-227	28.76	23.99	73.65	47.50	85.07	51.00	89.07	46.99	101.20	21.18	98.69	43.01	105.20	20.12	99.69	51.00	
400	-327	72.04	34.26	80.76	47.50	92.48	51.00	97.79	46.99	103.70	29.47	106.51	43.01	108.91	28.07	105.10	51.00	
500	-427	87.17	44.32	91.78	47.78	102.70	51.21	109.41	46.99	102.30	37.56	115.42	43.01	111.32	36.02	110.92	51.00	
600	-527	91.68	54.30	85.67	48.91	95.69	52.40	101.10	48.89	100.70	45.93	108.91	47.65	108.61	44.32	106.91	51.00	
650	-577	101.30	59.37	81.06	54.67	94.89	55.78	95.69	54.23	97.89	51.14	102.70	52.99	106.91	49.80	103.70	56.20	135
700	-626	106.31	64.43	80.66	57.14	88.87	60.35	94.08	57.05	95.39	53.95	101.00	55.67	103.20	52.69	102.30	58.81	122
750	-676	99.90	69.71	79.16	59.32	86.87	64.57	89.58	61.20	89.07	58.38	94.69	60.03	94.48	57.26	100.30	62.96	120
800	-726	96.69	74.56	78.76	65.15	86.87	68.65	90.98	65.56	92.38	61.90	96.19	63.76	97.69	60.98	104.30	66.90	131
825	-751	94.28	76.95	78.25	67.05	86.17	70.62	90.48	67.38									
850	-776	86.17	79.34	77.65	69.23	86.07	72.80	90.18	69.49	92.98	66.05	96.49	67.76	99.19	65.42	105.10	70.83	137
875	-800	72.84	81.87	77.65	71.48	86.07	75.12	90.18	71.96	92.38	68.51	96.09	70.09	99.29	67.53	104.70	73.37	136
900	-825	76.15	84.41	55.41	73.66	58.42	77.58	61.22	74.14	85.57	70.20	92.08	71.98	97.09	69.21	103.70	75.19	228
915	-840			56.71	75.21	64.43	78.78	64.23	75.61	65.03	71.82	85.27	73.39	90.48	70.41	99.59	76.60	
923	-848	77.25	86.80															
Elapsed Time after Water Injection Stop		44 hours		14 hours		28 hours		40 hours		52 hours		63 hours		87 hours		111 hours		
Water Level		60 m		600 m		600 m		600 m		60 m		550 m		60 m		600 m		
Well Head Pressure		0 kscg		48 kscg		52.47 kscg		48 - 46 kscg		0 kscg		44 kscg		0 kscg		51 kscg		
Maximum Temperature		106.3°C @700 m		91.8°C @500 m		102.7°C @500 m		109.4°C @500 m		103.7°C @400 m		115.4°C @500 m		111.3°C @500 m		110.9°C @500 m		

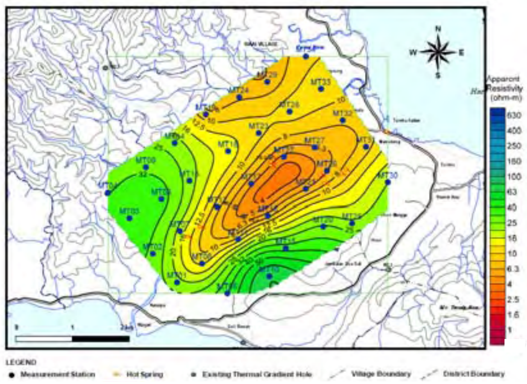
III.1.3 MT Survey

Remote-reference Magnetotelluric (MT) survey was carried out in area of about 13 km^2. A site roughly 10 km north of the Tulehu survey area was selected as a remote reference site. Measuring stations were placed in a grid configuration of station-separations from approximately 700 m to 800 m. The total number of stations in each survey was 34. More than 50 frequencies in the range from 320 Hz to 0.001 Hz were utilized for the MT data acquisition. Apparent resistivity values and impedance phase were calculated and checked for every stations, during the field work. In addition, three-dimensional resistivity inversion with smoothness constraint was conducted to estimate the detailed subsurface resistivity structure in the Tulehu geothermal field.

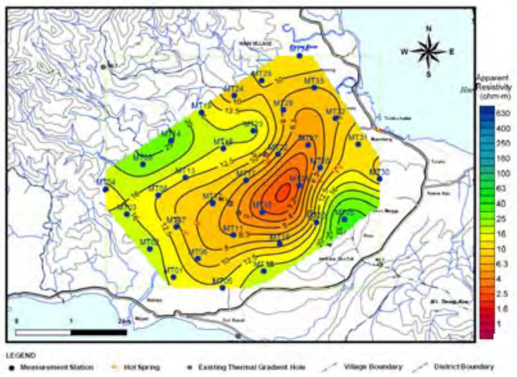
Apparent resistivity maps are shown in Fig. III-14. The resistivity information at 100 Hz can be regarded to be averaged resistivity in a depth range from the surface to the penetration depth, which is roughly in the range of 80 m to 290 m. On the apparent resistivity map at frequency of 100 Hz, a low apparent resistivity zone, less than 8 ohm-m, extends from northeast to southwest in the center portion of the survey area. Since some geothermal manifestations are located inside of this low apparent resistivity zone, this low anomaly indicates hydrothermal alteration zone. The resistivity information at 1 Hz can be regarded to be averaged resistivity in a depth range from the surface to the penetration depth, which is roughly in the range of 600 m to 2,000 m. The apparent resistivity map at 1 Hz gives similar pattern to that at 100 Hz, while a low apparent resistivity zone of less than 8 ohm-m is more widely distributed in the northern and western portions of the survey area. The resistivity information at 0.1 Hz can be regarded to be averaged resistivity in a depth range from the surface to the penetration depth, which is greater than 5,000 m. No low resistivity zone of less than 10 ohm-m can be detected, though a relatively low apparent resistivity zone of less than 25 ohm-m is recognized around the stations MT16, MT20 and MT21.

On the basis of the results obtained from the 3-D resistivity inversion, a resistivity model derived from the three-dimensional resistivity inversion reveals three layers: a very shallow high resistivity layer of about 5 to 50 ohm-m, an intermediate low resistivity layer of less than 5 ohm-m underlying the upper high resistivity layer, and a deep high resistivity layer with values roughly greater than 20 ohm-m underlying the low resistivity layer. Three resistivity discontinuities (R1, R2 and R3) are estimated in this field, based on the 3-D resistivity inversion results (see Fig. III-15 and Fig. III-16). R1 runs in the central portion of the survey area, east-northeast to west-southwest, and is clearly defined on the resistivity maps at depths of 100 m and 150 m. R2 runs in the southeastern portion, northeast to southwest, and is defined on the resistivity maps at depths of 100 m, 150 m, 700 m and 1,000 m. On the rersistivity maps at depths of 100 m and of 150 m, a low resistivity zone of less than 5 ohm-m extends between R1 and R2. This low resistivity zone must correspond with argillized zone characterized by occurrence of smectite and/or interstratified clay minerals. As geothermal manifestations and altered ground are situated around R1 and R2, R1 and R2 must correspond with major fractured zone controlling the geothermal activity. R3 runs in the western portion of the survey area, north-northwest to south-southeast. R3 can be defined on the resistivity maps at depths of 150 m and 250 m. Although the feature of R3 is relatively weak compared to those of R1 and R2, R3 possibly indicates a fault or a fracture zone.

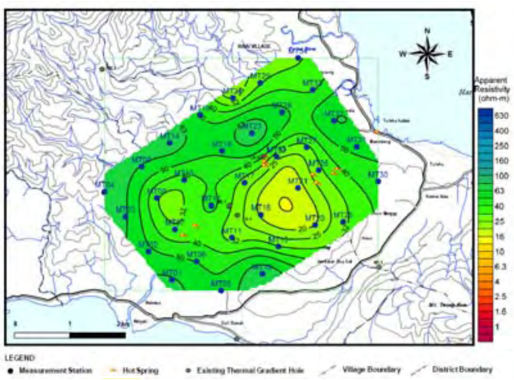
On the resistivity maps at depths of 750 m and 1,000 m, a high resistivity zone is identified around R1 and between R1 and R2. A low resistivity zone extends upon this high resistivity zone. As mentioned previously, a high temperature zone can be expected in a high resistivity zone with overlying low resistivity zone. Therefore, this uplifted relatively high resistivity zone, detected at depths of 750 m and 1,000 m, is indicative of a geothermal reservoir with a higher temperature.



(a) 100 Hz

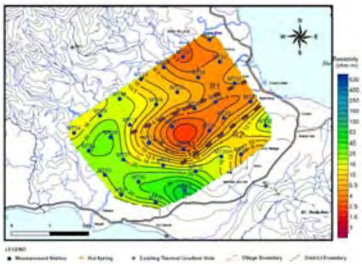


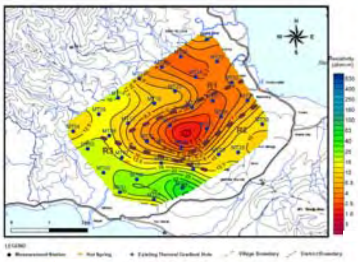
(b) 1 Hz

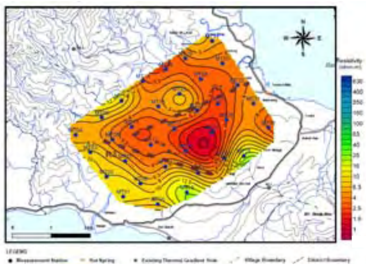


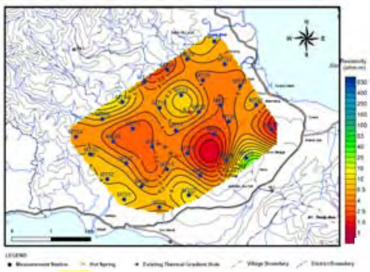
(c) 0.1 Hz

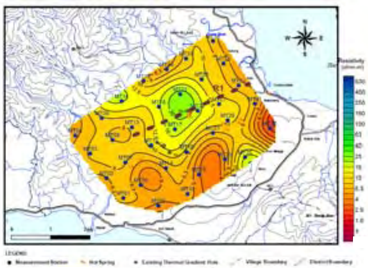
Fig. III-14 Apparent Resistivity Map

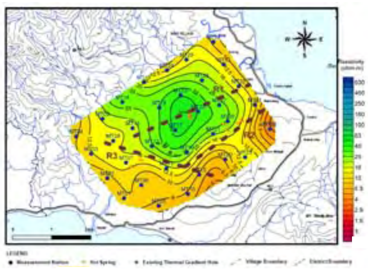

(a) at 100 m deep

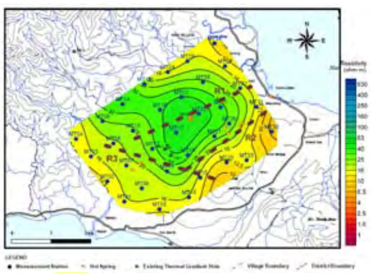

(b) at 150 m deep

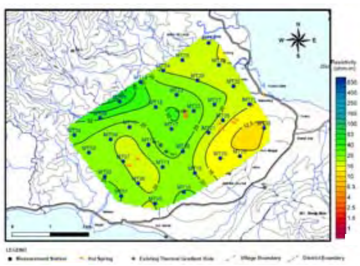

(c) at 250 m deep

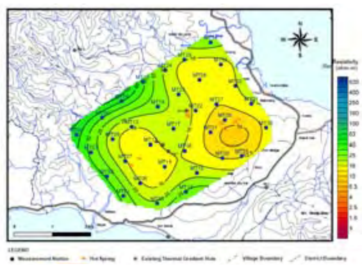

(d) at 350 m deep


(e) at 500 m deep


(f) at 750 m deep


(g) at 1,000 m deep


(h) at 1,500 m deep


(i) at 2,000 m deep

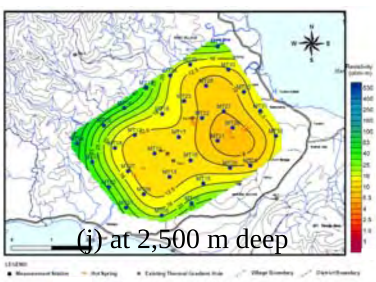

(j) at 2,500 m deep

Fig. III-15 Resistivity Map

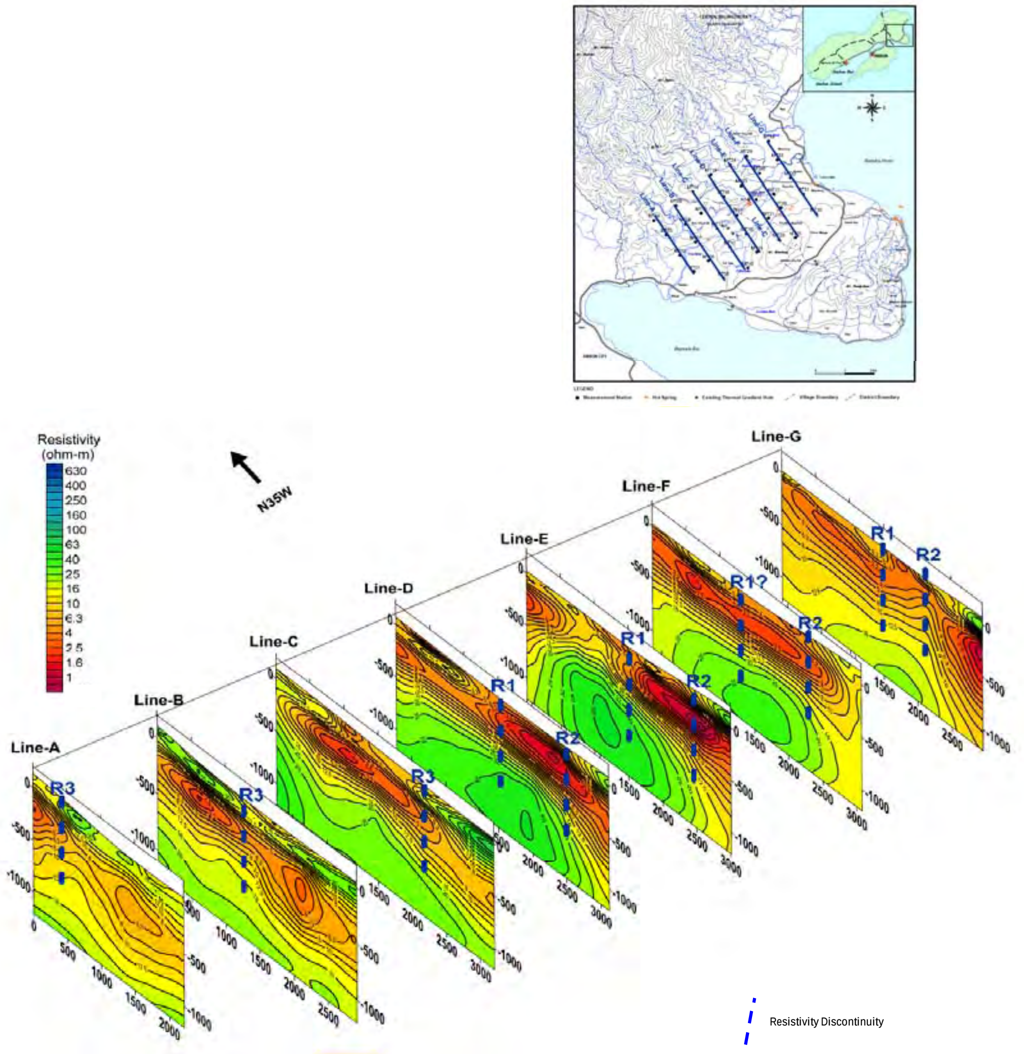


Fig. III-16 Resistivity Sections

III.2 Conceptual Model of Geothermal Resources

III.2.1 Prospective Area

A low resistivity zone is usually detected above a geothermal reservoir and relatively high resistivity zone extends under the low resistivity zone in a prospective geothermal field. And the low resistivity zone corresponds with an impermeable zone (cap rock). Moreover, temperature at the bottom of the low resistivity zone is about 200°C. From these, a low resistivity zone with considerable extent at a shallow depth, together with underlying high resistivity zone, will characterize a prospective area for geothermal development.

In the Tulehu field, a remarkable low resistivity zone of less than 10 ohm-m is detected at a shallow depth and a high resistivity zone extends under the low resistivity zone on the northwestern side of Mt. Eriwakang. The most active geothermal manifestations and altered ground are situated in this low resistivity zone, the Sila hot springs, the Telaga Biru hot springs, the Hatuasa hot spa and the Banda alteration zone. The most prospective geothermal resource will extend under this low resistivity zone. As minimum extent of a prospective area, an area of about 7 km^2 will be proposed; this area approximately corresponds with low resistivity zone of less than 6.5 ohm-m at a depth of 150 m (see Fig. III-17). As maximum extent of a prospective area, an area of about 10 km2 will be proposed; this area approximately corresponds with low resistivity zone, of which resistivity is lower than 10 ohm-m at a depth of 150 m.

Judging from the resistivity map at a depth of 1,000 m (see Fig. III-15), relatively high resistivity (higher than 40 ohm-m) zone, under the low resistivity zone, extends along the Wamina river. The Hatuasa hot spa and the Banda alteration zone are situated in this high resistivity zone. It is considered that one of geothermal activity center in the Tulehu field is in this high resistivity zone. Considering chemistry of hot spring water, it must be noted that hot waters from the Sila hot springs are derived from a geothermal reservoir with the highest temperature in this field. Therefore, there is possibility that there is another geothermal activity center around the Sila hot springs.

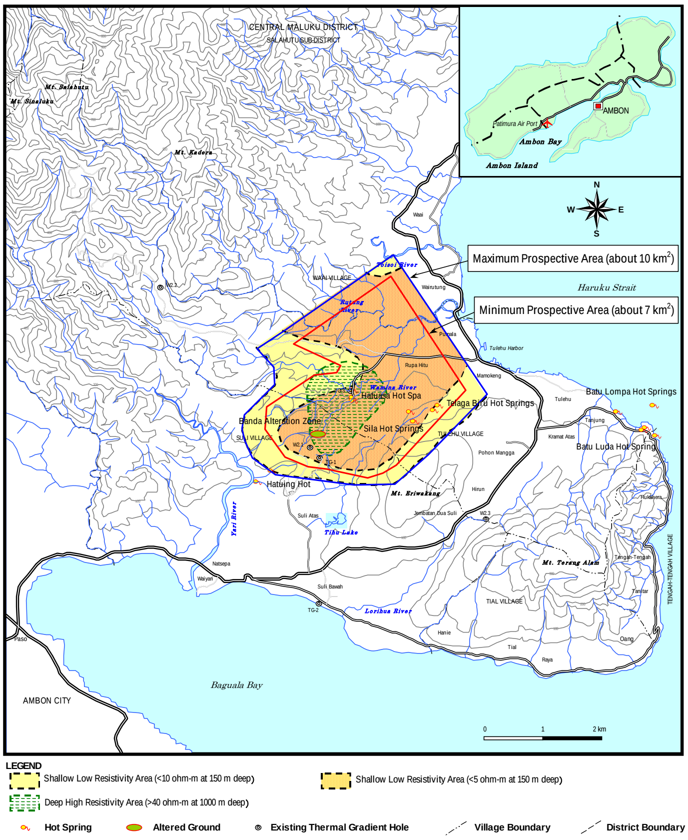


Fig. III-17 Proposed Prospective Area

III.2.2 Permeable and Impermeable Structures Controlling Geothermal Activity

In the Tulehu field, faults or fault-like structures were estimated from some geothermal explorations (see Fig. III-18). In and around the proposed prospective area, five faults were estimated from geological data, Waiyari fault, Banda Hatuasa fault, Banda fault, Tulehu fault and Huwe fault. From resistivity data, three faults were estimated, R1, R2 and R3. From gravity data, three faults were estimated, GL1, GL2 and GL3.

The Waiyari fault trends in northwest to southeast. The fault-like structure GL1 is situated just on the southeastern extension of the Waiyari fault. Moreover, the fault-like structure R3 was detected near by these structures by MT survey. It can be regarded that they are the same structure. The Waiyari fault was regarded to be a right-lateral-slip fault. However, a high Bouger anomaly area extends on the southwestern side of the fault-like structure GL1 and a depression zone extends on the northeastern side. Judging from this, the Waiyari fault may be a right-normal-slip fault dipping northeast. The Banda Hatuasa fault, trending in northeast to southwest, is a normal fault dipping northwest. The fault-like structure R1 detected by MT survey near by this fault can be regarded to correspond with the Banda Hatuasa fault.

The Banda fault, trending in northeast to southwest, is a normal fault dipping northwest. Near by this fault, the fault-like structure R2 was detected by MT survey. Considering location of MT stations, northern half of R2 can be regarded to coincide with the Banda fault. However, its southern half is located on the southeastern side of the fault. Considering dipping direction of the Banda fault, the southern half of R2 will be regarded to be different structure (will be referred as the R2 fault) from the Banda fault, branching off from the Banda fault.

The Tulehu fault, trending in northwest to southeast, is a normal fault dipping northeast. Around this fault, no fault-like structure is estimated from geophysical explorations. This must be resulted from the fact that location of this fault is outside or marginal part of the exploration areas. The Huwe fault trends in northeast to southwest. This fault is a normal fault dipping northwest. There is a depression zone on the northwestern side of this fault. Near by this fault, the fault-like structure GL3 is estimated from gravity data. This structure can be regarded to coincide with the Huwe fault.

From the above consideration, six permeable structures area are estimated in and around the prospective (see Fig. III-19).

Waiyari fault: strike-dip = S61.7^{o}E85^{o}NE, Hatuing hot springs around a point of intersection with the Banda Hatuasa fault.

Banda Hatuasa fault: strike-dip = N46.4^{o}E80^{o}NW, Hatuasa hot spa and Banda alteration zone along this fault.

Banda fault: strike-dip = N53^{o}E80^{o}NW in the northern pat, N69^{o}E80^{o}NW in the southern part, Sila hot springs, Telaga Biru hot springs and hot springs on Mamokeng beach along this fault.

R2 fault: strike-dip = N53^{o}E80^{o}NW, branched out from Banda fault around Sila hot springs.

Tulehu fault: strike-dip = S65^{o}E80^{o}NE, hot springs on Mamokeng beach, Batu Lompa hot springs and Batu Luda hot springs along this fault.

Huwe fault: strike-dip = N56°E80°NW, Batu Lompa hot springs around this fault.

A major impermeable structure in the Tulehu field must be an argillized layer corresponding with the low resistivity zone detected by MT survey. The bottom of the impermeable zone around the drilling site of TLU-01 is at an elevation of about 300 m under sea level (see Fig. III-20).

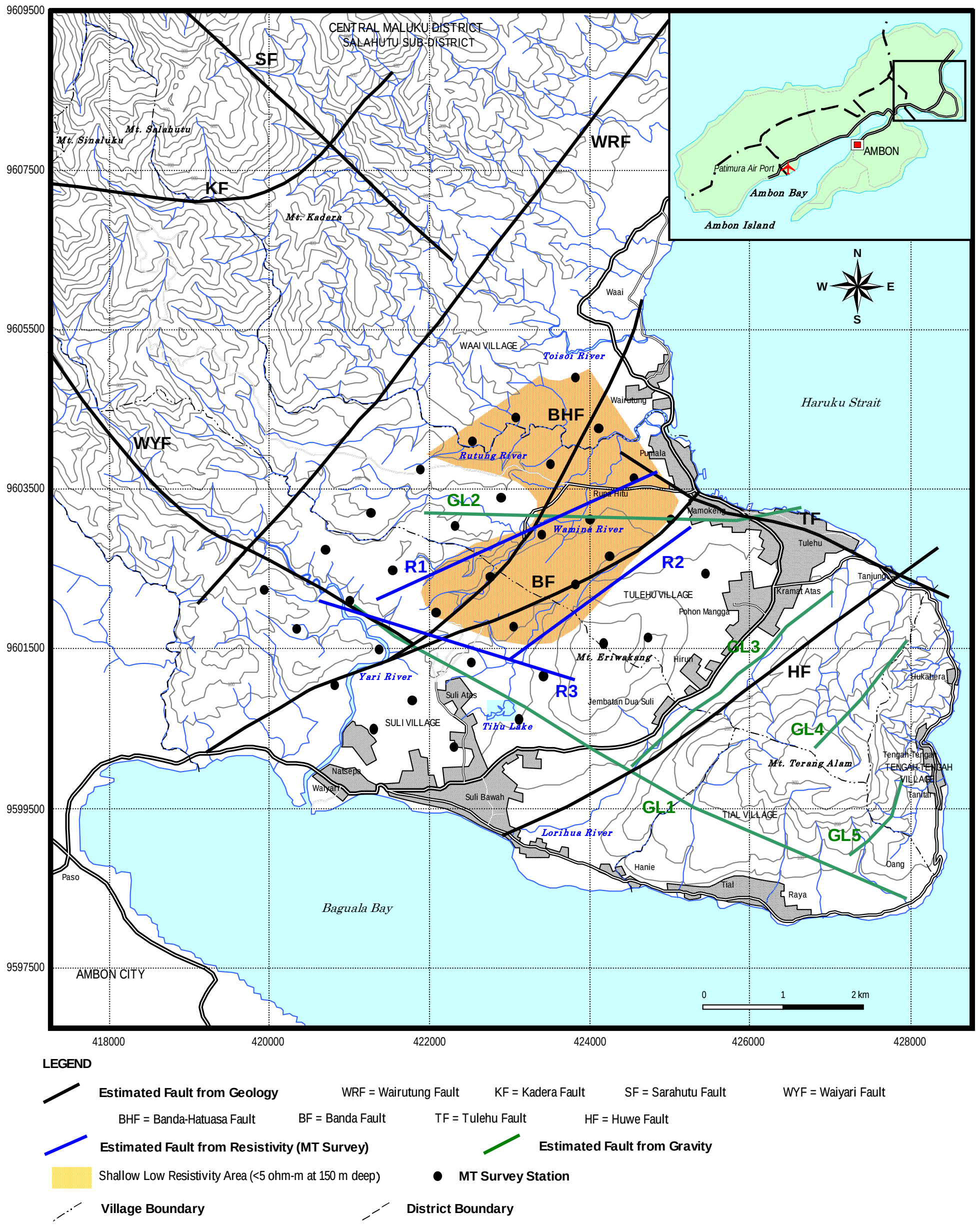


Fig. III-18 Faults Estimated from Geothermal Explorations

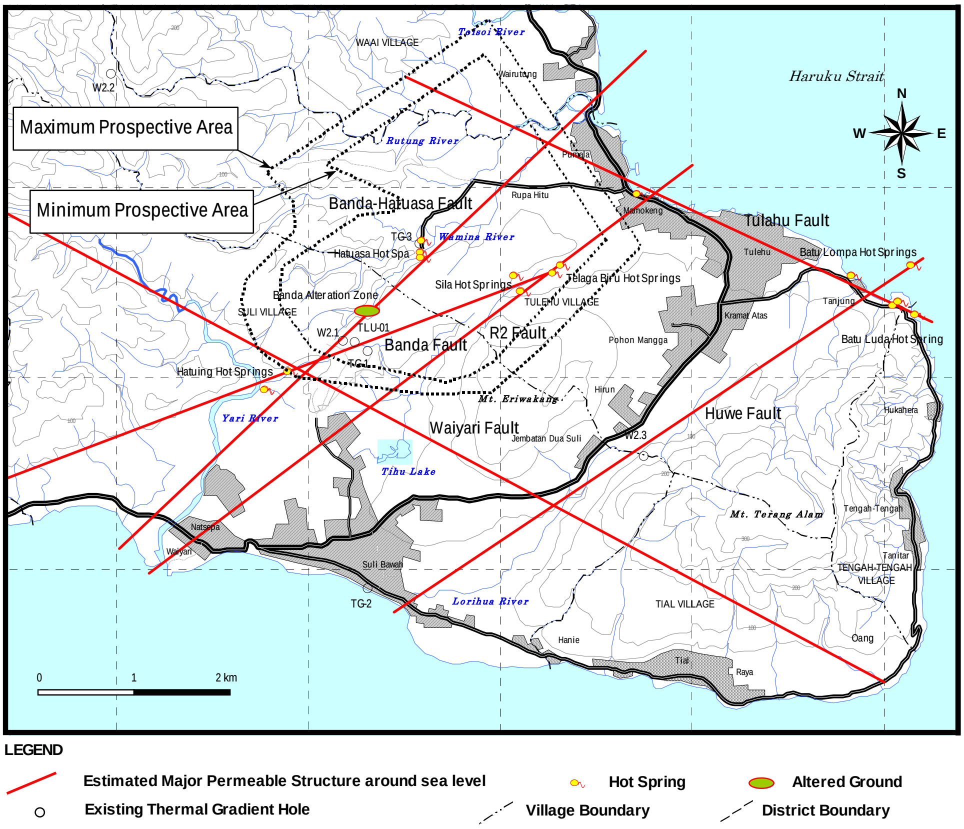


Fig. III-19 Estimated Major Permeable Structures

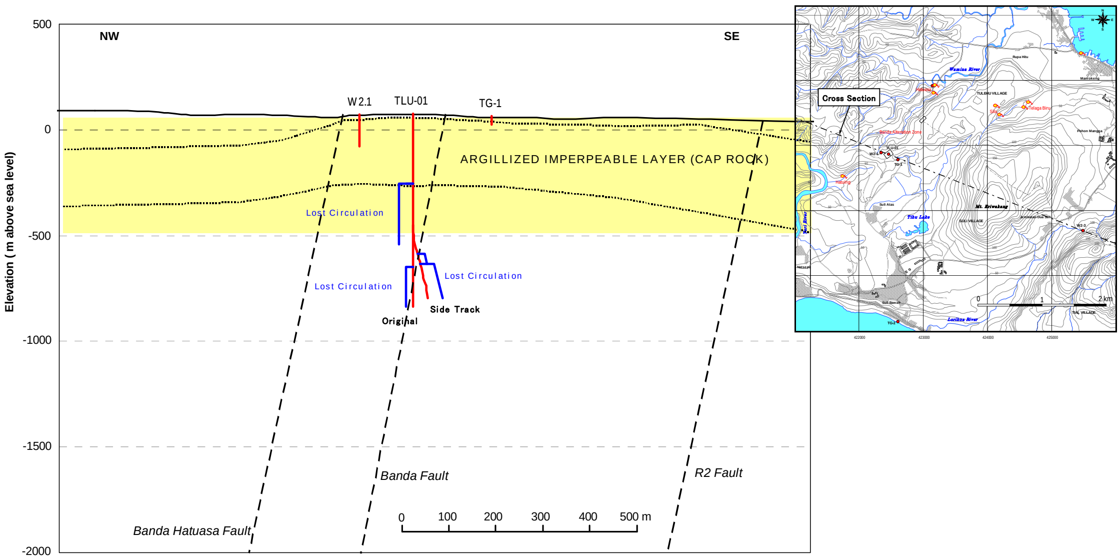


Fig. III-20 Extent of Estimated Impermeable Zone around TLU-01

III.2.3 Conceptual Model

A tentative model for geothermal system in the Tulehu geothermal field, based on obtained data, is represented in Fig. III-21. A prospective area for a geothermal development extends on the northwestern side of Mt. Eriwakang. It is considered that geothermal activity center exists along the Banda Hatuiasa fault between the Hatuasa hot spa and the Banda alteration zone. And it is expected that geothermal reservoir extends along the Banda Hatuasa fault from this center. Hot waters from the Hatuasa hot spa do not contain deep geothermal brine. This can be easily explained by existence of the impermeable zone; this impermeable zone prevents flowing-up of deep geothermal fluid. And temperature of 200^{o}C will be expected around the bottom of the detected low resistivity zone. Therefore, the Banda Hatuasa fault can be regarded as a main target for steam field development in this field. Judging from chemistry of hot spring waters, it can be deduced that hot waters from the Sila hot springs contain deep geothermal brine. The Sila hot springs occur around the branching point of the R2 fault from the Banda fault. Therefore, it will be expected that geothermal reservoir also extends along the Banda fault and the R2 fault.

From the above, the following conceptual model is proposed (see Fig. III-21). Geothermal fluid with sufficient temperature flows up between the Hatuasa hot spa and the Banda alteration zone, from a deeper part. This fluid spreads along permeable zones resulted from the Banda Hatuasa fault. Although location of its up-flow center is uncertain, geothermal reservoir also extends along the R2 fault and the Banda fault. Considering underground temperature measured from the wells W2.2 and W2.3 (temperature increasing as increasing depth is scarcely identified), there are recharge areas around Mt. Terang Alam and around Mt. Salahutu.

It must be noted that the following subjects are still remained to examine through a discharge test of the planned exploratory well. From geochemical study, high content of carbonate ion in the most of hot spring waters in this field show a possibility that hot spring waters were influenced by sedimentary rocks or limestone. However, such rocks are identified only near the ground surface in this field. Whether sedimentary rocks or limestone extends in deeper part or not should be examined by chemistry of discharged fluid from the exploratory well. In case of reservoir in sedimentary rocks or limestone, there is a possibility that serious problems such as carbonate scaling in production well and pipeline and high content of NCG occur in this field.

Regarding scale problem, carbonate scale will be formed when production wells tap sedimentary rock reservoir. Silica scale deposition depends on operation condition of production well. However, silica scale from the geothermal water in this field seems to deposit easily due to relatively high content of salts dissolved in the water. Mineral acid injection into the reinjection line is considered to be effective to prevent silica scale deposition, because silica content in the water separated from geothermal fluid of about 200^{o}C must not be so high. Adequate countermeasures against such scale troubles should be considered based on chemical characteristics of well discharge after completion of well discharge test.

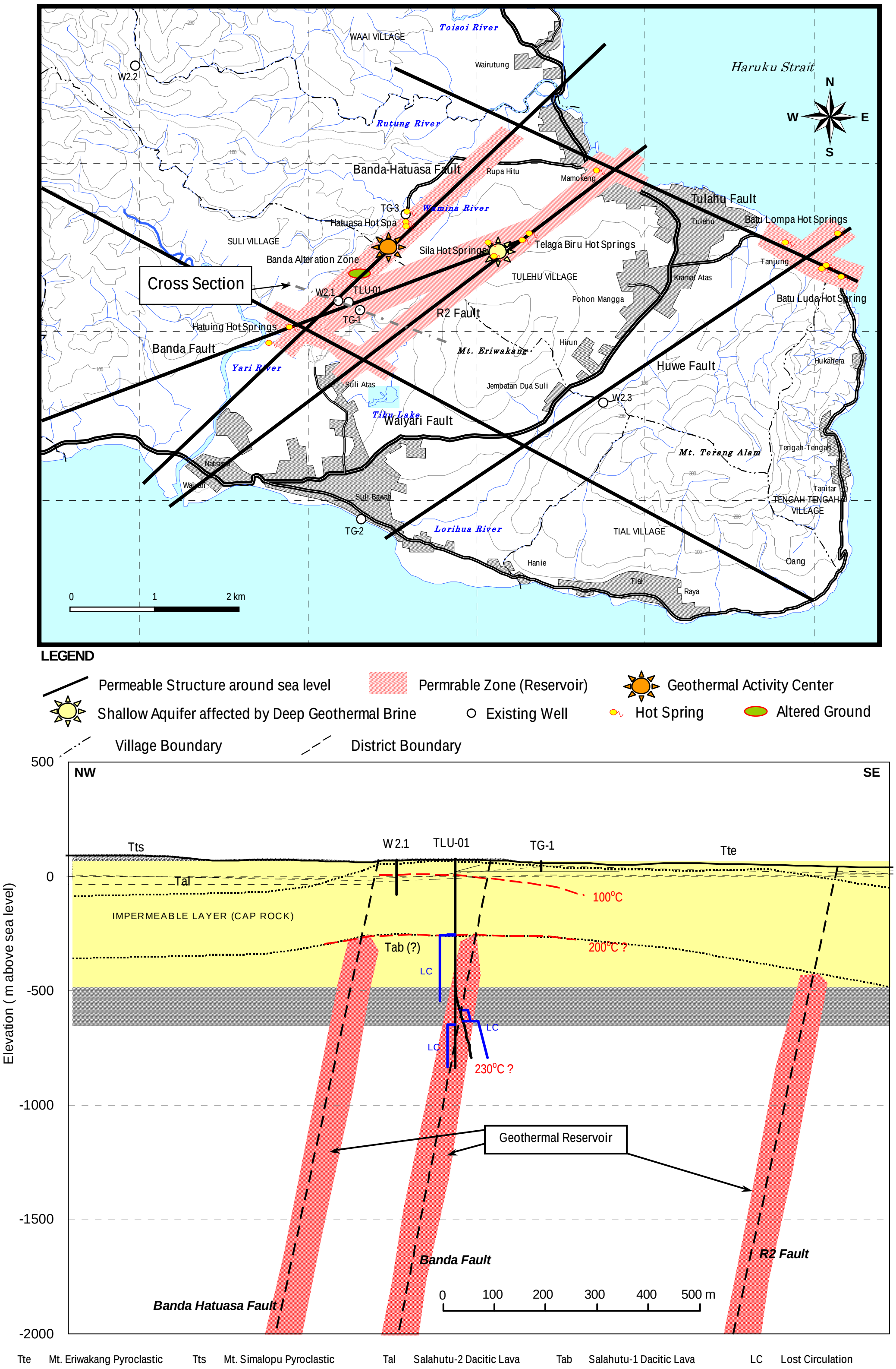


Fig. III-21 Conceptual Model for Geothermal System in Tulehu Field

III.3 Evaluation of Geothermal Resource Potential in Tulehu

For evaluation of geothermal resource potential in the Tulehu field, stored heat calculations applying a Monte Carlo Analysis were conducted. The stored heat method, a type of volumetric method, applies the following equations. In order to compensate for the uncertainty of each reservoir parameter mentioned above, a statistical analysis called Monte Carlo Analysis was combined with the stored heat method.

Stored Heat (S.H.) $=(T_r - T_a) \times \{(1-\phi) C_{pr} \rho_r + \phi C_{pw} \rho_w\} \times V$

Heat Recovery (H.R.) = S.H.× Recovery Factor

Power Output = (H.R. × C.E.) / (Lf × P.L.)

Tr :Reservoir Temperature（^oC）

Ta : Abandonment Temperature（^oC）

ϕ : Porosity（%）

ρ r : Rock Density（kg/m^3）

ρ w : Fluid Density（kg/m^3）

C_{pr} : Rock Specific Heat（kJ/kg・^oC）

C_{pw} : Fluid Specific Heat（kJ/kg・^oC）

V : Reservoir Volume（km^3）

C.E. : Conversion Efficiency（%）

Lf : Plant Life（year）

P.L. : Load Factor（%）

Table III-4 shows the variations in reservoir parameters for the stored heat calculations, which are applied for Monte Carlo Analysis. The minimum and maximum areal extensions of the reservoir were assumed as 7 km^2 and 10 km^2, respectively, based on the conceptual model. The thickness of the reservoirs was assumed to be thicker than 1 km and does not exceed 2.0 km, and the most likely to have a thickness of 1.5 km. Therefore, the reservoir has a volume that ranges from the minimum estimate of 7 km^3 to the maximum estimate of 20 km^3. The most likely average reservoir temperature was assumed to be 220^oC within the expected range from 200^oC to 240^oC. The average rock porosity was assumed to lie within the range from 5% to 10%. The recovery factor was assumed to vary within the range from 12.5% to 25%. The most likely average rock density was assumed to be 2500 kg/m^3 with the expected range from 2400 kg/m^3 to 2600 kg/m^3. The average rock specific heat was assumed to vary from 0.70 kJ/kg^oC to 1.0 kJ/kg^oC. For the heat-electricity conversion efficiency, its range was assumed to be from 12% to 14%. The other three parameters, abandonment temperature, plant life and capacity factor, are fixed as 180^oC, 30 years and 85 %, respectively.

Table III-4 Input Parameters for Monte Carlo Analysis

Parameter	min.	most likely	max.
Reservoir Area (km^2)	7.00	-	10.00
Reservoir Thickness (m)	1000	1500	2000
Rock Density (kg/m^3)	2400	2500	2600
Porosity (-)	0.05	-	0.10
Recovery factor (-)	0.125	-	0.250
Rock Specific Heat (kJ/kg^oC)	0.70	-	1.00
Reservoir Average Temperature (^oC)	200	220	240
Reservoir Average Pressure (MPa)	-	11.96	-
Heat-Electricity Conversion Efficiency (-)	0.12	-	0.14
Plant Life (year)	-	30	-
Load Factor (-)	0.80	0.85	0.90
Abandonment Temperature (^oC)	-	180	-

The results of Monte Carlo Analysis that was conducted by taking 100,000 samples are shown in Fig. III-22, which shows the frequency (possibility) distribution. The mode (the most frequently arisen class mark, or peak value) was 30 MW (its frequency was about 17.2%).
The residual frequency polygon, subtracting the cumulative frequency from the total frequency, is shown in Fig. III-23. When desired possibility is decided (for example, 80%), corresponding output (about 22 MW) will be found out on this diagram. This does not mean that output of about 22 MW can be expected on a likelihood level of 80 %, but represents that output exceeding 22 MW can be expected on a likelihood level of 80 %. Conversely, when desired output is decided (for example, 20 MW), corresponding likelihood (about 85 %) will be found out on this diagram. This means that output of exceeding 20 MW can be expected on a likelihood level of 85 %. The cumulative occurrences for various threshold values are summarized in Table III-4-2.
From these diagrams and table, it is deduced that the Tulehu field has potential of not lessexceeding than 20 MW on a possibility level of 85.2 % and that the most likely potential is 30 MW. Consequently, it was concluded that the reservoir must have enough capacity to sustain a 20 MW power development.

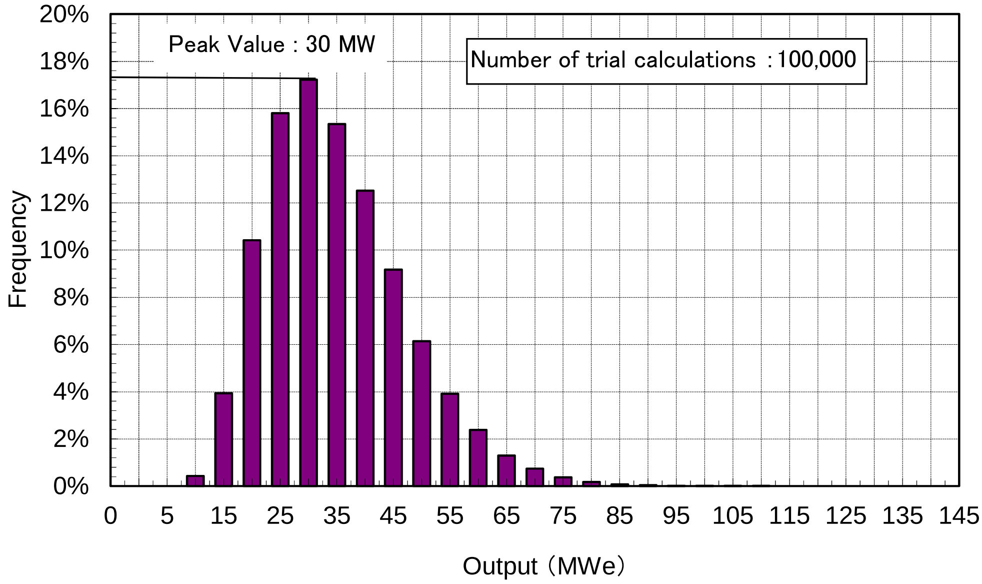
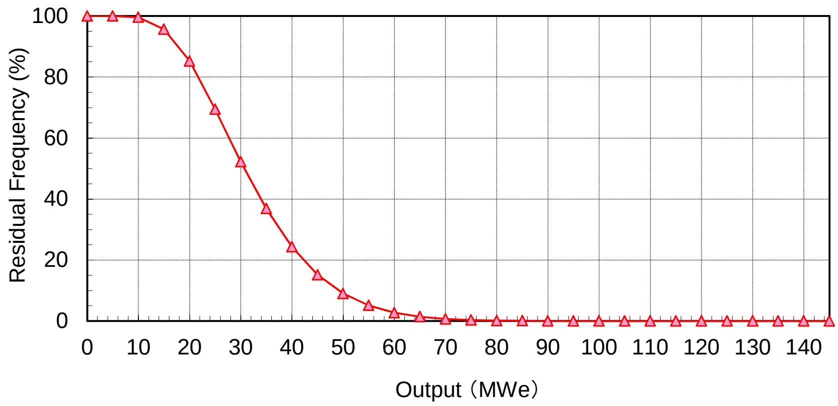


Fig. III-22 Frequency Distribution of Geothermal Power Potential in Tulehu



[Residual frequency] = [Total frequency] – [Cumulative frequency]

Fig. III-23 Residual Frequency Polygon of Geothermal Power Potential in Tulehu

Table III-5 Result of Monte Carlo Analysis of the Geothermal Resource Potential in Tulehu

Resource Potential	Likelihood
Larger than 10 MW	99.6 %
Larger than 20 MW	85.2 %
Larger than 30 MW	52.2 %
Larger than 40 MW	24.3 %
Larger than 50 MW	9.0 %
Larger than 60 MW	2.7 %
Larger than 70 MW	0.7 %

CHAPTER IV

IV GEOTHERMAL FIELD DEVELOPMENT

IV.1 Well Productivity and Injectivity

Well productivity, which is a necessary factor in establishing the number of wells required to generate a power output of 20 MW for this project, was predicted using the wellbore simulator WELLFLOW that was developed at Kyushu University and modified by West JEC. West JEC has already applied the WELLFLOW in many geothermal fields so far to analyze the productivity of production wells, and their experience has confirmed its reliability and utility. The WELLFLOW program establishes the deliverability curve of a well based on the reservoir pressure, temperature, and permeability-thickness products (kh) at the feed depth. The relationship between wellhead pressure, steam mass flow rate and water mass flow rate with specific enthalpy can be calculated, and then the power output of the well can be estimated assuming the turbine inlet pressure.

As the Tulehu geothermal field is in an early stage of development, there is only one deep well TLU-01, and the information on the thermodynamic condition of the reservoir is not sufficient. Consequently the well productivity was estimated based on the assumptions listed in Table IV-1. The assumptions on reservoir conditions were made partly based on the results of the well testing of TLU-01. The “kh” value was assumed to be 2 (darcy-m), which corresponds to a rather low-productive well, in order to make the estimation to be somewhat conservative. The assumed casing program for production wells is shown in Fig. IV-1.

The result of simulation run is shown in Fig. IV-2. The figure indicates the production characteristics for a well with various well head pressure settings. From the result, it can be seen that the vapor/brine ratio in the Tulehu field is rather low (approximately steam 1 : brine 5). This result arouses an important issue that the design for reinjection wells have a great importance in planning the field development at Tulehu.

The result of simulation indicates that when a well head pressure was set to 0.2 MPaG, then 63 t/h steam and 280 t/h brine will be produced from the well. When the well head pressure would set to be 0.5 MPaG, then the steam flow rate will be 43 t/h, and the brine flow rate will be 239 t/h. The production characteristic will be utilized in estimating the required number of wells for 20 MW power generation.

Table IV-1 Input Parameters for WELLFLOW

Parameters	Values
Reservoir Pressure	11.5 (MPaA)
Reservoir Temperature	230 (^oC)
Permeability-Thickness (kh)	2 (darcy-m)
Production Casing Depth	850 (m)
Feed Point Depth	1200 (m)
Production Casing Diameter	0.342 (m) 13 3/8''
Liner Diameter	0.273 (m) 10 3/4"
Skin Factor	0.0

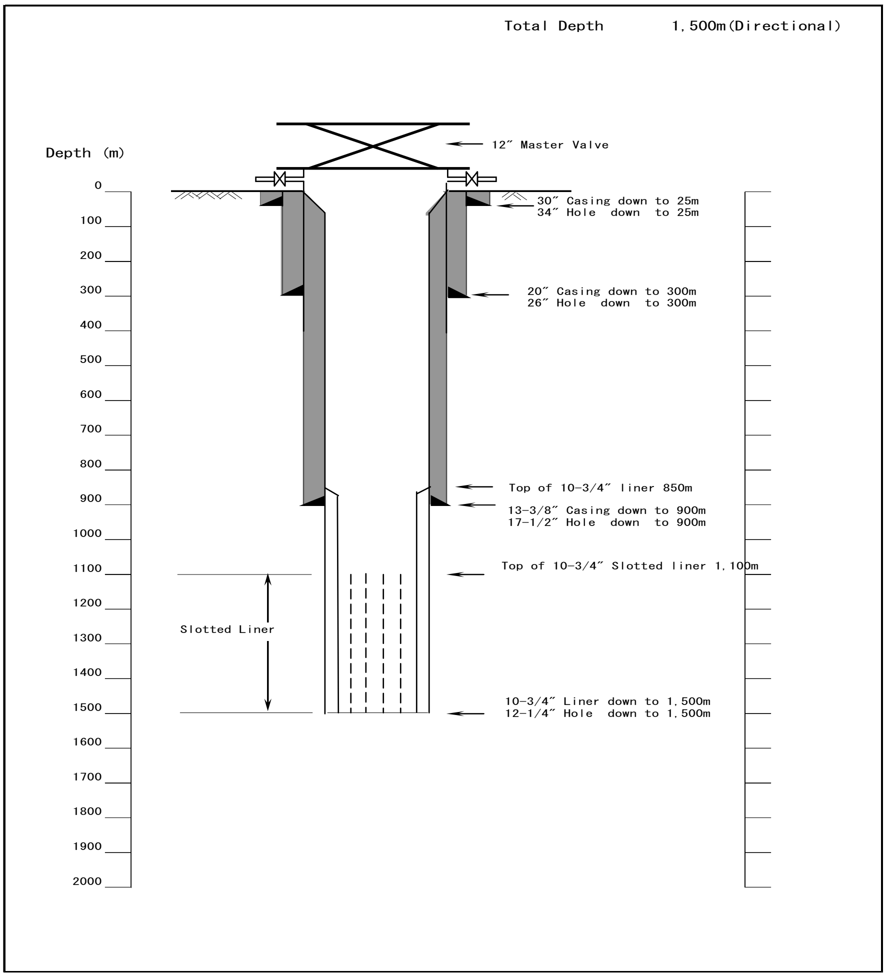


Fig. IV-1 Assumed Casing Program for Drilling of Production Wells

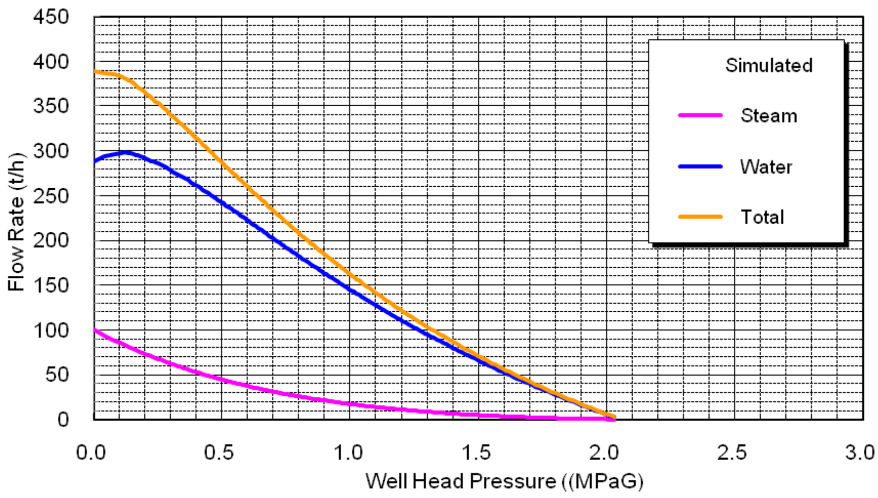


Fig. IV-2 Simulated Well Production Characteristics for a Production Well in Tulehu

IV.2 Number of Necessary Wells to Generate 20 MW Power

The result of well productivity esitmation was applied in evaluating the number of necessary wells for 20 MW power generation for 30 years.

For the evaluation, the productivity for the well head pressure 0.2 MPaG was adopted so that the estimate can be available to somewhat pessimistic case where the reservoir pressure was not high and the well head pressure should be kept low to be connected with production pipelines.

The steam consumption for generating one megawatt (1MW) was determined to be 10 t/h based on the catalogue specifications of turbines that are commercially available. If this is the case, the necessary amount of steam for 20 MW power generation is 200 t/h. As a single production well would produce 63 t/h steam and 280 t/h brine, the necessary number of production wells is calculated to be four (4). It is quite likely that some of the well drilling for production wells would fail. Assuming the success ratio for the production well drilling to be 80%, then the necessary number of production wells would be five (5) wells.

The total amount of brine that would be produced from the four production wells would be 1,120 t/h. Thus, approximately 1,200 t/h injection capacity would be necessary for stable 20 MW power generation in Tulehu field. Ideally, injectivities should be same with productivities, since both of them are controlled by the permeability of surrounding formations. As a single production well would produce 280 t/h brine, the injectivity of a well can be estimated to be around 280 t/h. However, to be more conservative, the injectivity of a single reinjection well was assumed to be 250 t/h. Thus the necessary reinjection wells would be six (6) wells.

As previously mentioned, the vapor-to-brine ratio in the Tulehu field is approximately five to one (vapor 1 : brine 5). This ratio suggested to utilizing what is known as “double flash” system that enhances the amount of steam production by 30 % through a further evaporation of the brine. Using this system, the steam productivity from a single well would increase to 82 t/h (63 x 1.3 = 81.9 t/h), and the brine flow rate would decrease down to 261 t/h (280 – (82-63) = 261 t/h) . The necessary number of production wells decreases to three (3) wells (82 x 3 = 246 t/h). The necessary reinjection capacity also decrease to four (4), because the total brine production from three production wells decrease to 783 t/h. In this case, four reinjection wells can process 1,000 t/h (250 x 4 = 1,000 t/h) of brine.

The results of the above-mentioned estimation are summarized in Table IV-2. For a single flash system , the necessary number of initial production well would be four (4), and for a double flash system, three (3) production wells would be necessary to commence generation of 20 MW of power.

Table IV-2 Necessary Number of Initial Wells

Type of Power Generation	Initial Production Wells	Initial Reinjection Wells
Single Flash Type	4 (+ 1 backup)	6
Double Flash Type	3 (+1 backup)	4

The productivity and/or injectivity of a well decline with time. When the total productivity declines below the rated power output or necessary injection capacity, make-up wells are drilled.

In evaluating the required number of make-up wells, same decline rate was adopted (3%/year). The estimate for the timing and the total number of make up wells are summarized in Fig. IV-3 and Table IV-3 for an ordinary single flash system. The same estimate for a double flash system are shown in Fig. IV-4 and Table IV-4.

For an ordinary single flash system, the initial number of production wells is four (4) wells with one back up well (taking into account the success ratio of 80%). After the drilling of five wells, four (4) wells would start producing steam in a total amount of 253 t/h. Then the production rate would decline at a rate of 3%/year. The production would decline below 200 t/h seven (7) years after the commencement of power generation. A make-up well for production will be introduced at this time, and the new well will produce 63 t/h of steam. The total steam production will recover to 261.8 t/h. Likewise, make-up wells would be necessary in the 16th year and 25th year of power generation. In total three (3) production wells would be necessary to sustain the 20 MW power generation. The power generation starts with six (6) reinjection wells that possess a 1,500 t/h reinjection capacity. The capacity decline at a rate of 3%/year. The necessary reinjection capacity is 1,200 t/h. The actual reinjection capability will decline below 1,200 t/h seven (7) years after the commencement of power generation. A reinjection well needs to be introduced at this time, and the total reinjection capability will recover to 1426 t/h. In the same manner, reinjection wells will be required at 14th year, 20th year, and 27th year of power generation. A total of four (4) make-up wells will be necessary for reinjection.

For a double flash system, the same estimation was made as that for the single flash system. Four (4) drilling operations will be attempted, and with a success ratio 80% will result in the commencement of power generation with three production wells. The total production capability will be 247 t/h. The production rate will decline at a rate of 3%/year. Make-up wells for production will be necessary in the 6th year, 19th year, and the final 30th year of power generation. For reinjection wells, the power generation starts with four (4) wells with a total reinjection capability of 1,000 t/h. Make-up wells for reinjection will decline at a rate of 3%/year and decline below the necessary 800 t/h injection capacity in the 7th year. Accordingly, make-up wells will be necessary in the 7th year, 16th year, and 25th year. In total three (3) make-up wells for production and three (3) wells for reinjection will be required to generate 20 MW power for 30 years.

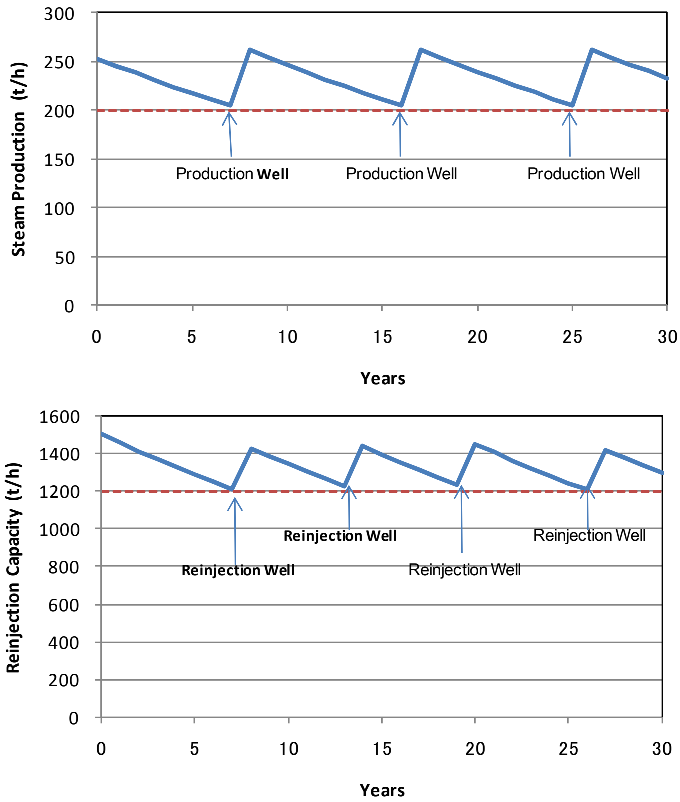


Fig. IV-3 Results of Estimation for Make-up Wells (Single Flash System)

Table IV-3 Results of Estimation for Make-up Wells (Single Flash System)

Years	Steam Production	Reinjection Capacity	Make Up Wells Production	Make Up Wells Reinjection
0	253	1500	0	0
1	246	1455	0	0
2	238	1411	0	0
3	231	1369	0	0
4	224	1328	0	0
5	218	1288	0	0
6	211	1249	0	0
7	205	1212	0	0
8	262	1426	1	1
9	254	1383	0	0
10	246	1341	0	0
11	239	1301	0	0
12	232	1262	0	0
13	225	1224	0	0
14	218	1437	0	1
15	212	1394	0	0
16	205	1353	0	0
17	262	1312	1	0
18	254	1273	0	0
19	247	1234	0	0
20	239	1447	0	1
21	232	1404	0	0
22	225	1362	0	0
23	219	1321	0	0
24	212	1281	0	0
25	206	1243	0	0
26	263	1206	1	0
27	255	1419	0	1
28	247	1377	0	0
29	240	1336	0	0
30	233	1296	0	0
		total	3	4

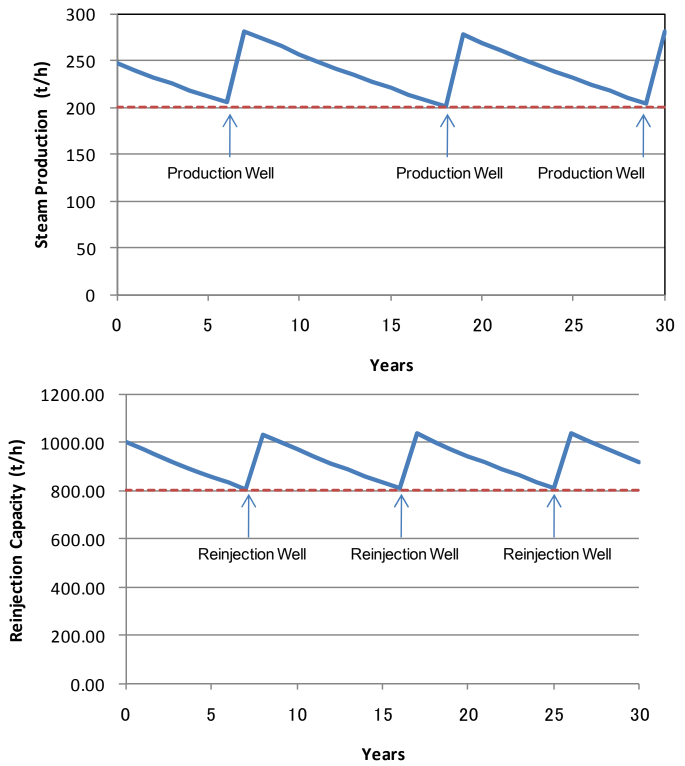


Fig. IV-4 Results of Estimation for Make-up Wells (Double Flash System)

Table IV-4 Results of Estimation for Make-up Wells (Double Flash System)

Years	Steam Production	Reinjection Capacity	Make Up Wells Production	Make Up Wells Reinjection
0	247	1000	0	0
1	240	970	0	0
2	232	941	0	0
3	225	913	0	0
4	219	885	0	0
5	212	859	0	0
6	206	833	0	0
7	282	808	1	0
8	273	1034	0	1
9	265	1003	0	0
10	257	973	0	0
11	250	943	0	0
12	242	915	0	0
13	235	888	0	0
14	228	861	0	0
15	221	835	0	0
16	214	810	0	0
17	208	1036	0	1
18	202	1005	0	0
19	278	975	1	0
20	270	945	0	0
21	261	917	0	0
22	254	890	0	0
23	246	863	0	0
24	239	837	0	0
25	231	812	0	0
26	225	1038	1	1
27	218	1006	0	0
28	211	976	0	0
29	205	947	0	0
30	281	919	0	0
		total	3	3

IV.3 Drilling Strategy

IV.3.1 Drilling Targets and Drilling Pads

The Tulehu geothermal field is located at Tulehu Village and Suli Village in Maluku province, Ambon Island and its topograghic condision is relatively flat. Based upon the field development scenario stated above (sustainable geothermal power generation of 20 MW for thirty (30) years, seven (7) production wells, four (4) start-up production wells and three (3) make-up production wells, will be required for single flash generating system. On the case of double flash generating system, six (6) production wells, three (3) start-up production wells and three (3) make-up production wells, will be required.

For reinjecrion wells, ten (10) wells will be required for single flash generating system, six (6) start-up wells and four (4) make-up wells. And it is required that six (6) reinjection wells are always on operating. On the case of double flash generating system, seven (7) wells will be required, four (4) start-up wells and three (3) make-up wells. And it is required that four (4) reinjection wells are always on operating. Assuming that the future make-up reinjection wells will be prepared by side trucking from original reinjection wells (previously drilled reinjection wells) as a rule, the following capacity of the drilling pad will be required; sufficient space to drill seven (7) reinjection wells for single flash generating system, or sufficient space to drill five (5) reinjection wells for double flash generating system.

The major drilling targets will be located along the Banda Hatuasa fault, Banda fault and R2 fault in the Tulehu field. The Hatuasa hot spa on the Banda Hatuasa fault is utilized as a hot spa resort but the hot springs on the Banda fault and R2 fault are not utilized. Judging from chemistry of hot waters, it is regarded that there is no direct connection between deep geothermal brine and hot water from the Hatuasa hot spa, as the hot water does not contain deep geothermal brine. However, impact from geothermal development along the Banda Hatuasa fault to the Hatuasa hot spa is not yet examined. On the other hand, every well will across the Banda fault on the way, when it will be drilled to the R2 fault at a possible pad (considering topographic condition). From these conditions, it is deduced, at the present, that the targets on the Banda fault have the first priority for geothermal development in the Tulehu field. Proposed drilling targets were selected under the following considerations.

1) All targets are located along the Banda fault.
2) Targets for production wells and for reinjection wells are respectively located on the western side and on the eastern side of the Sila hot spring, as an up-flow area is expected around the Sila hot spring from hot water chemistry.
3) Targets for production wells are located to keep spacing of more than 300 m, considering an interference problem (sufficient spacing must be examined through the future discharge test).
4) Targets for reinjection wells are located to keep spacing of more than 150 m, considering an interference problem (sufficient spacing must be examined through the future discharge test).

5) All of targets are located together with drilling pads to keep a drilling depth of less than 1500 m, as a rule.

Proposed locations of the drilling targets and drilling pads, based on the above considerations, are shown in Fig. IV-5. Seven (7) targets were proposed for the future production wells, excluding the drilled exploration well TLU-01. To keep a drilling depth of less than 1500 m, only three (3) targets are possible to drill for every pad. As the existing pad (TLU-0 pad) of the exploration well TLU-01 is close by the Banda fault, a possible target to drill at this pad is only one (TLU-02). Therefore, two (2) new pads are required for the future production wells. Proposed locations of the new pads (TLU-1 pad and TLU-2 pad) are shown in Fig. III-6. Considering topographic condition, the site for the future geothermal power plant will be located between the TLU-1 pad and the TLU-2 pad. Proposed drilling pad TLU-3 is for the future reinjection wells. For drilling to the proposed target TLU-37R, a drilling depth of about 1650 m is required, though drilling depths for the other targets are less than 1500 m. It is still uncertain whether the well TLU-01 can be used as a production well or not. The target TLU-11 is proposed as a target for an alternative well, when the well TLU-01 is not available for steam production. Tentative scope of proposed drilling pads and power plant site are summarized in Table IV-6. A typical layout of drilling pad, including a rig equipment arrangement is shown in Fig. IV-6.

The target TLU-12 will be proposed as a drilling target for the next well (production well). And targets following this will be TLU-13, TLU-21, TLU-22 and TLU-23, in order of priority. About a reinjection wells, the target TLU-31R will have the first priority. And targets following this will be TLU-32R, TLU-33R, TLU-34R, TLU-35R, TLU-36R and TLU-37R, in order of priority. It is recommended that long-term discharge test shall be done after drilling of three or four wells. Based on this discharge test, target locations and their must be reconsidered.

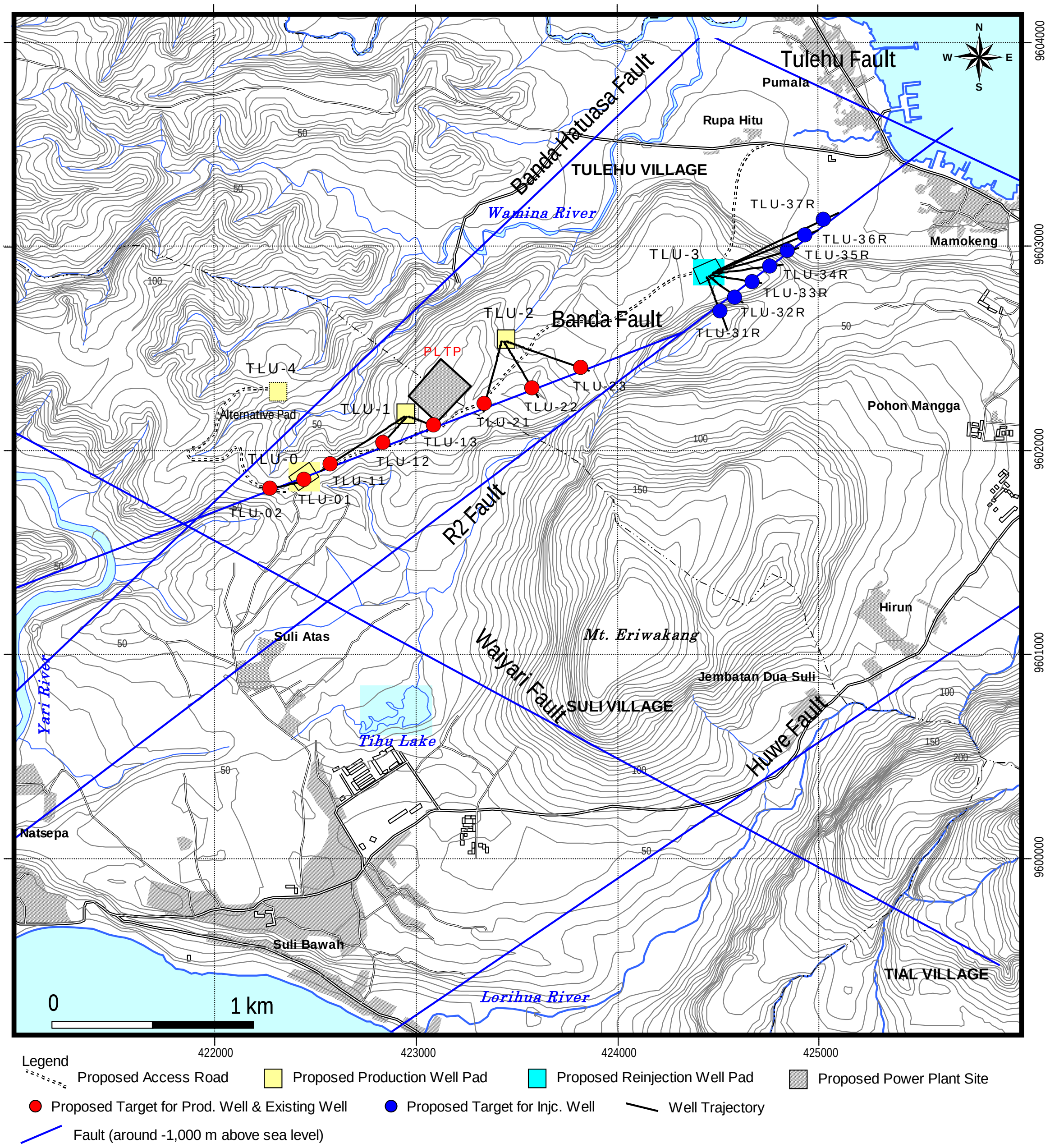


Fig. IV-5 Tentative Drilling Pads, P/P Location and Drilling Targets

Table IV-6 Required Size of Well Pads and Access Road

Item	Size	Note
Production Pad TLU-1	100m x 70m	3 Production Wells
Production Pad TLU-2	100m x 70m	3 Production Wells
Reinjection Pad TLU-3	130m x 80m	7 Reinjection Wells
Access Road	5m x 3,000m	Newly constructed

Note: (Start-up wells + *Make-up wells*)

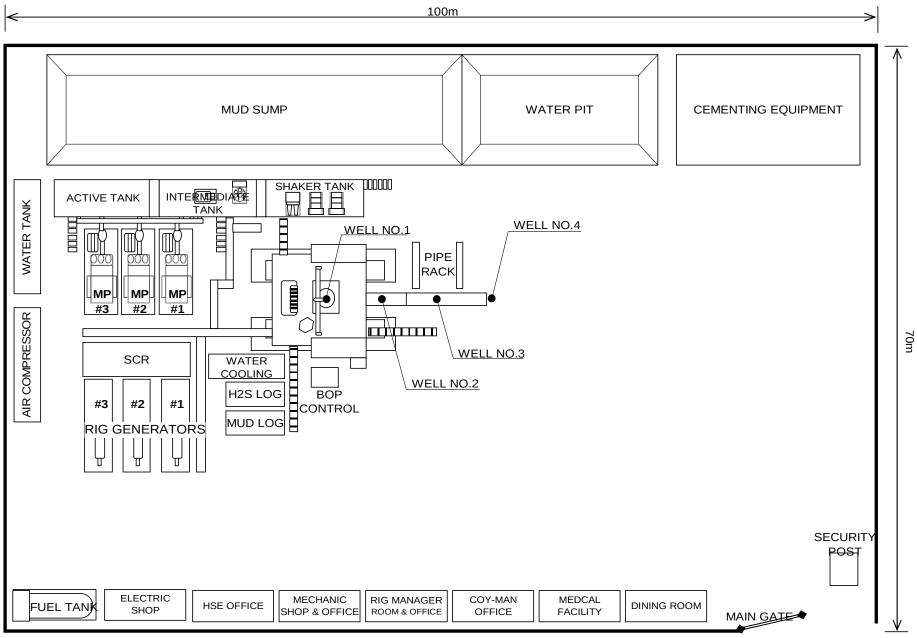


Fig IV-6 Typical Rig Layout (Not to Scale)

IV.3.2 Well Specifications

The location of drilling targets and the well trajectories to reach them are shown in Fig. IV-7, Fig. IV-8 and Fig. IV-9. Well specification to drill each target is given in Table III-7, Fig. IV-10, Fig. IV-11 and Fig. IV-12.

Production Wells

In Tulehu geothermal field, exploratory well TLU-1 has been drilled successfully to a depth of 927m and several well logging including Temperature/Pressure, Water Injection and Temperature Recovery have been completed. Based on the results of this drilling and logging, it is expected that well TLU-1 has sufficient formation temperature and permeability for production steam, even though the temperature recovery was not so fast due to the cooling effect of drilling mud and fresh water that was injected during drilling.

On another front, based upon the field development scenario and well-flow calculations stated above for geothermal power generation of 20MW, big-hole completion will be recommended for the production well. In other geothermal fields in Indonesia, big-hole completion (10-3/4" slotted liner completion) is currently a kind of standard for production well drilling and it such wells have been successfully drilled with a good production rate. Similar results will also be expected when production wells are drilled with a big-hole completion casing program in Tulehu geothermal field. However, on the other hand, the drilling cost for big-hole completion will be much more expensive than standard-hole completion (7" slotted liner completion). Therefore, whether big-hole completion will be much more economically effective than

standard-hole completion or not should be carefully examined.
A tentative production well casing program of both big-hole completion and standard-hole completion for Tulehu are shown in Fig. IV-9 and Fig. IV-10.

Reinjection Wells

In Tulehu geothermal field, reinjection wells will be provided to inject the separated brine and condensate into the reservoir to support reservoir pressure and mass production. A tentative reinjection well casing program for Tulehu is shown in Fig. IV-11. A 7” slotted liner standard completion program will be recommended. The depth at which the casings are set should be decided on the basis of the geo-scientific parameter set for each of the wells to be drilled.

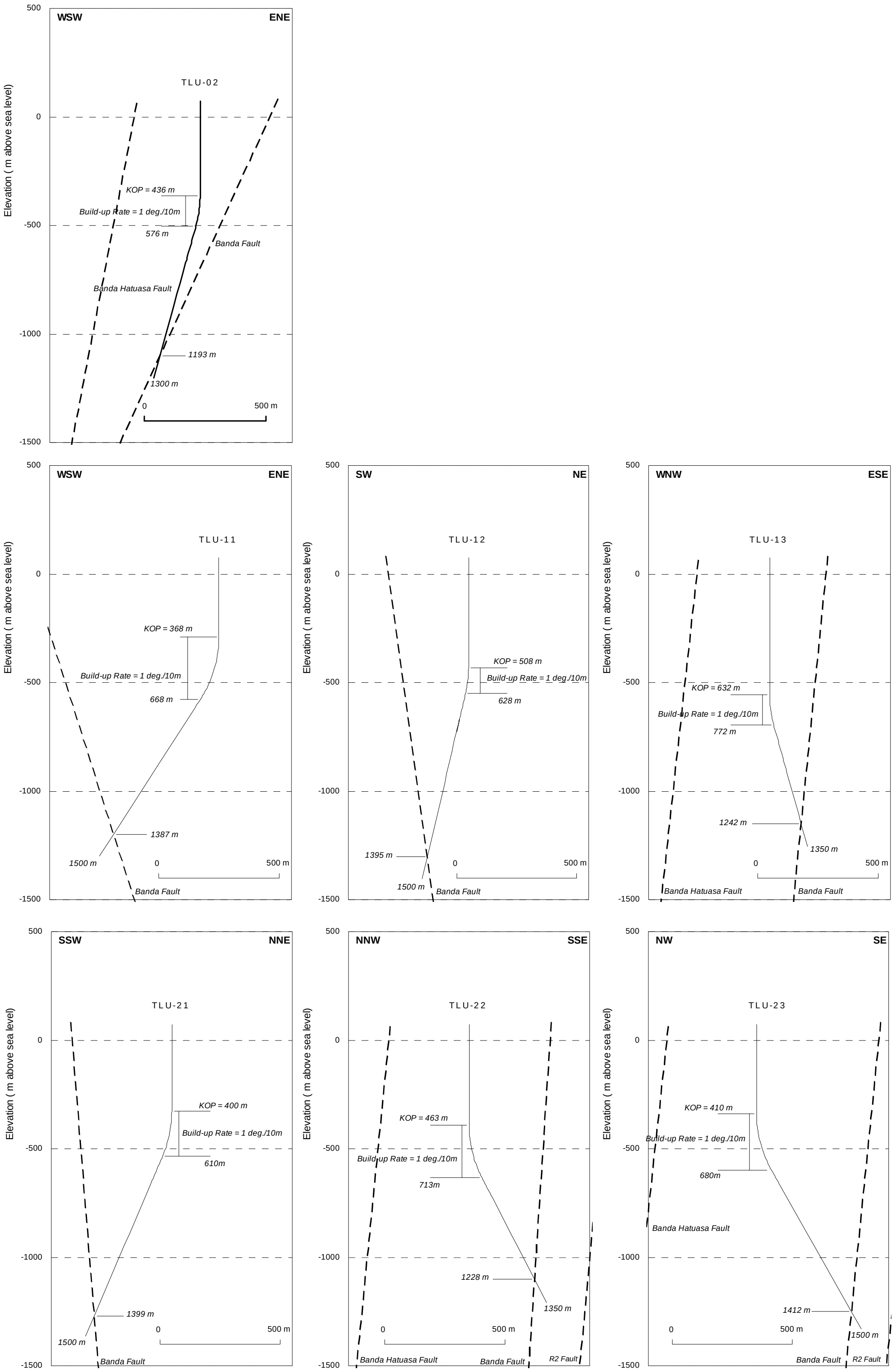


Fig. IV-7 Cross Sections along the Drilling Direction of Production Wells

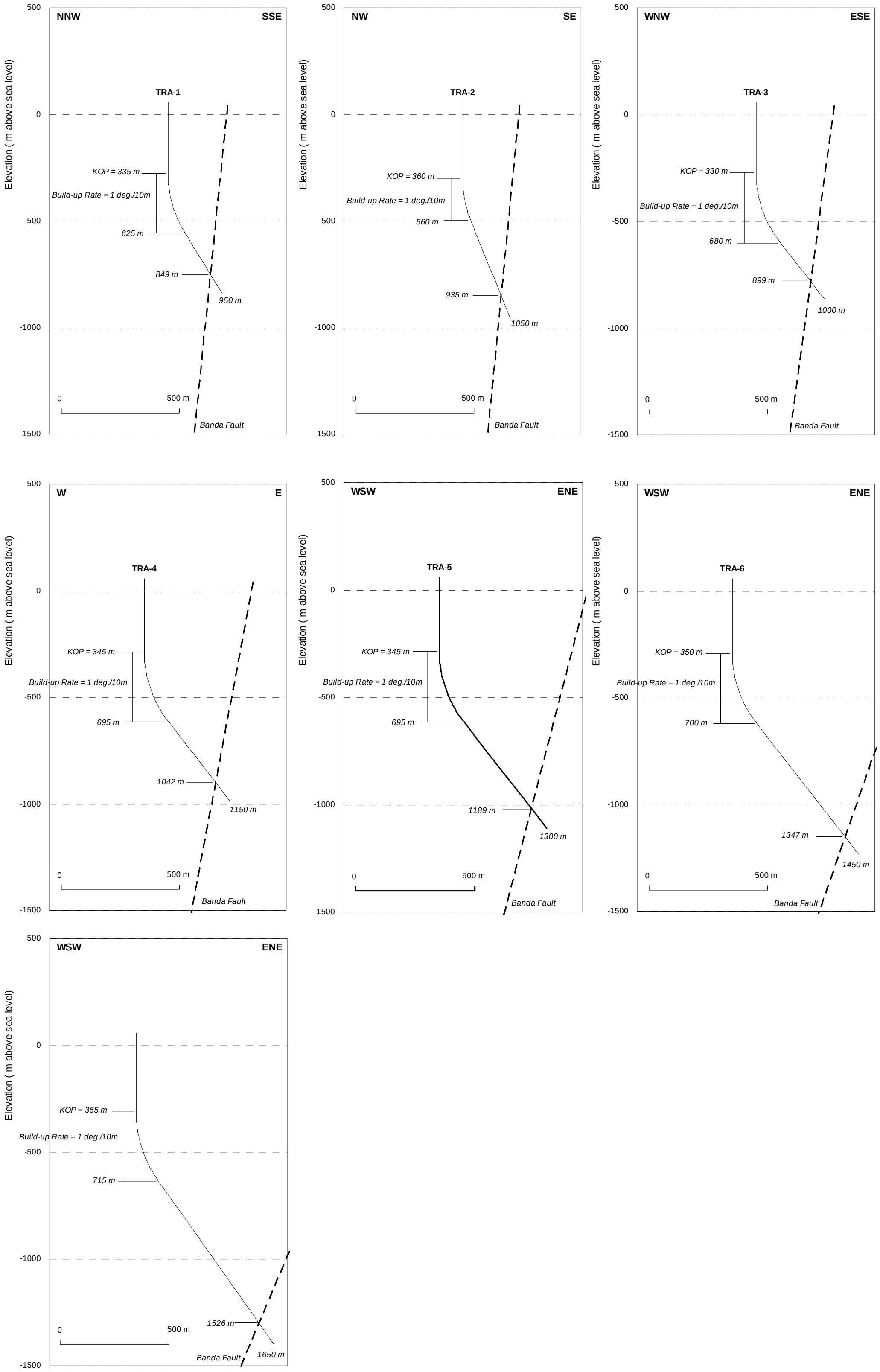


Fig. IV-8 Cross Sections along the Drilling Direction of Reinjection Wells

Total Depth	1250-1450m
Elevation	72-77m
KOP	310-410m
Drift Angle	Max.10-35deg.
Direction	

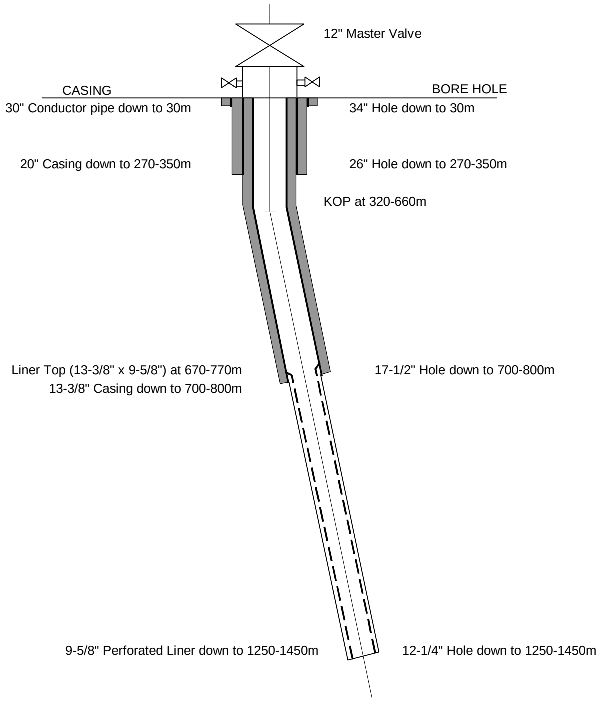


Fig. IV-9 Tentative Production Well Casing Program – Big Hole

Total Depth	1250-1450m
Elevation	72-77m
KOP	310-410m
Drift Angle	Max.10-35deg.
Direction	

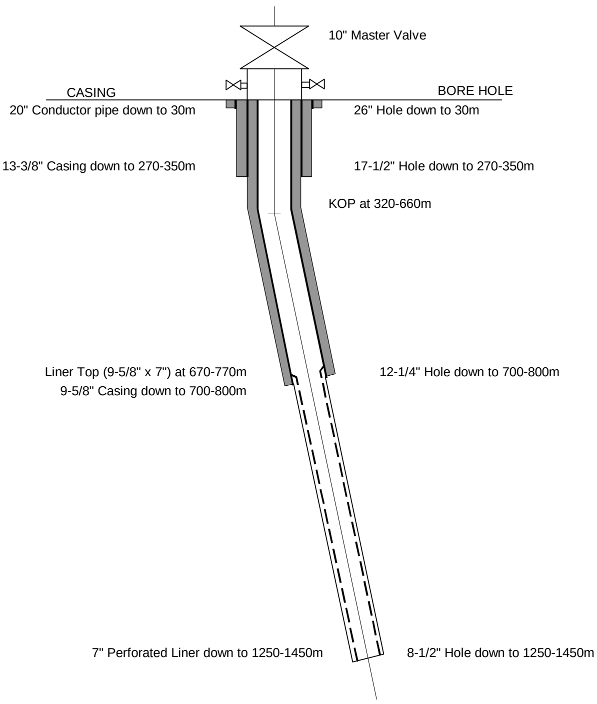


Fig. IV-10 Tentative Production Well Casing Program – Standard Hole

Total Depth	950-1450m
Elevation	58m
KOP	330-360m
Drift Angle	Max.20-35deg.
Direction	

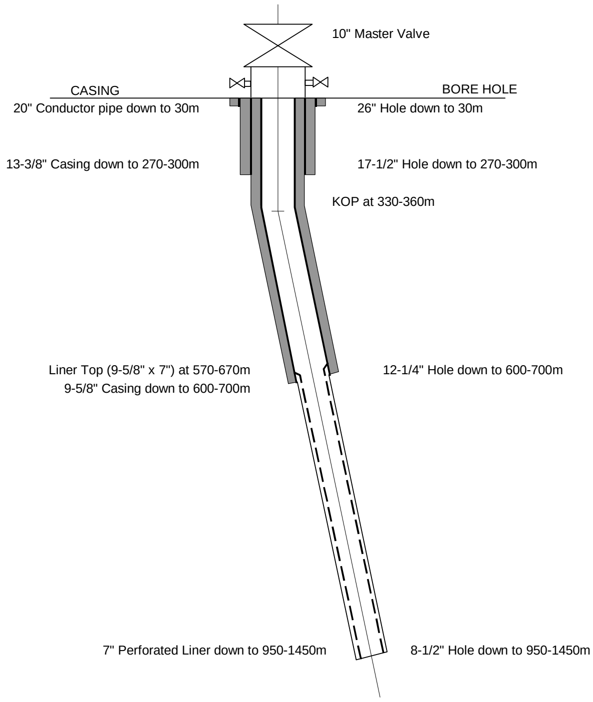


Fig. IV-11 Tentative Reinjection Well Casing Program

Table IV-7 Proposed Well Specifications

		TLU-01	TLU-02	TLU-11	TLU-12	TLU-13	TLU-21	TLU-22
Location	Easting (m)	422463.89	422456	422960	422970	422980	423440	423450
	Northing (m)	9601866.54	9601861	9602180	9602180	9602180	9602550	9602550
	Elevation (m)	72.78	72.78	77	77	77	72	72
Azimuth (deg. from true North)			257.32	237.27	221.27	109.93	194.84	148.26
KOP (m)			436	368	508	632	400	463
Build-up Rate (deg./10m)			1	1	1	1	1	1
Maximum Drift Angle (deg.)			14	30	12	14	21	25
Total Depth (m)			1300	1500	1500	1350	1500	1350
Vertical Depth (m)			1277.11	1375.02	1480.07	1331.44	1436.22	1282.46
Throw (m)			192.17	492.76	193.82	156.85	357.00	322.89
Target	Easting (m)		422294	422594	422857	423103	423358	423593
	Northing (m)		9601824	9601945	9602051	9602135	9602240	9602319
	Elevation (m)		-1100	-1200	-1300	-1150	-1270	-1100
Remarks			Banda Fault @1193 m	Banda Fault @1387 m	Banda Fault @1395 m	Banda Fault @1242 m	Banda Fault @1399.2 m	Banda Fault @1228 m

		TLU-23	TLU-31R	TLU-32R	TLU-33R	TLU-34R	TLU-35R	TLU-36R
Location	Easting (m)	423460	424455	424464	424472	424481	424489	424498
	Northing (m)	9602550	9602865	9602871	9602876	9602882	9602887	9602893
	Elevation (m)	72	58	58	58	58	58	58
Azimuth (deg. from true North)		109.25	158.74	128.29	99.21	82.71	73.64	68.16
KOP (m)		410	300	322	332	342	373	363
Build-up Rate (deg./10m)		1	1	1	1	1	1	1
Maximum Drift Angle (deg.)		27	36	22	23	27	32	34
Total Depth (m)		1500	950	1000	1100	1250	1350	1500
Vertical Depth (m)		1400.75	871.40	961.29	1051.11	1170.58	1233.79	1344.14
Throw (m)		434.72	279.88	213.29	255.76	352.10	435.22	543.63
Target	Easting (m)	423833	424520	424595	424681	424768	424855	424942
	Northing (m)	9602420	9602698	9602767	9602842	9602918	9602994	9603071
	Elevation (m)	-1250	-675	-790	-890	-990	-1090	-1190
Remarks		Banda Fault @1412 m	Banda Fault @779 m	Banda Fault @878 m	Banda Fault @988 m	Banda Fault @1113 m	Banda Fault @1248.9 m	Banda Fault @1384 m

		TLU-37R
Location	Easting (m)	424506
	Northing (m)	9602898
	Elevation (m)	58
Azimuth (deg. from true North)		64.53
KOP (m)		330
Build-up Rate (deg./10m)		1
Maximum Drift Angle (deg.)		35
Total Depth (m)		1650
Vertical Depth (m)		1453.22
Throw (m)		659.99
Target	Easting (m)	425032
	Northing (m)	9603149
	Elevation (m)	-1285
Remarks		Banda Fault @1516 m

IV.4 Plant Construction

IV.4.1 Overall Location Plan for Well Pads and Power Plant

The location plan for the Production Well Pads (TLU-0, TLU-1 and TLU-2), the Reinjection Well Pad (TLU-3), the Power Plant, and the Transmission Line is shown in Fig. IV-12. Production Well Pad TLU-0 currently being developed by PLN will be reserved as a spare pad, and new Production Well Pad TLU-1 will be located at approximately 600 m north-east of the existing TLU-0 and another Production Well Pad TLU-2 will be located at approximately 600 m north-east of TLU-1. Reinjection Well Pads TLU-3 will be located approximately 1000 m north-east form of TLU-2. The Tulehu Geothermal Power Plant will be located at between TLU-1 and TLU-2.

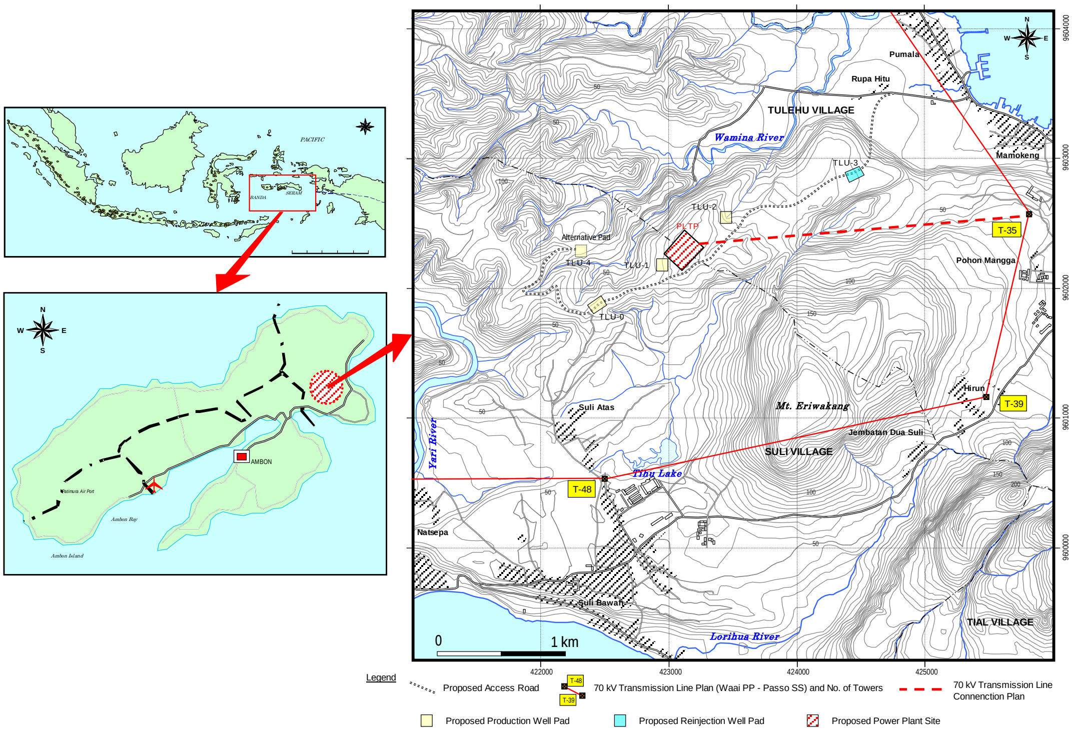


Fig. IV-12 Location Plan of Drilling Pads, Power Plant and Transmission Line

IV.4.2 FCRS Plan

The Fluid Collection and Reinjection System (FCRS) consists of (1) the pipeline of steam and hot water mixture from the production wells to the separator(s), (2) the separator(s), (3) the steam pipeline from the separator(s) to the power plant, (4) the brine pipeline from the separator(s) to the reinjection wells, and (5) the condensate reinjection pipeline from the power plant to the reinjection pipeline. For a double flash system, the flasher(s) will be additionally attached to the brine pipeline of the separator downstream. In the flasher(s), the brine temperature becomes lower (around 100°C), and the likelihood of a scaling problem increases. The scaling phenomenon will be carefully examined through geothermal fluid analysis in the production tests of the exploration wells in the near future, and the adequate flasher pressure will be determined. In addition, countermeasures against scaling problems will be taken, if necessary.

The conceptual process flow diagrams are presented for the double flash type of FCRS for reference.

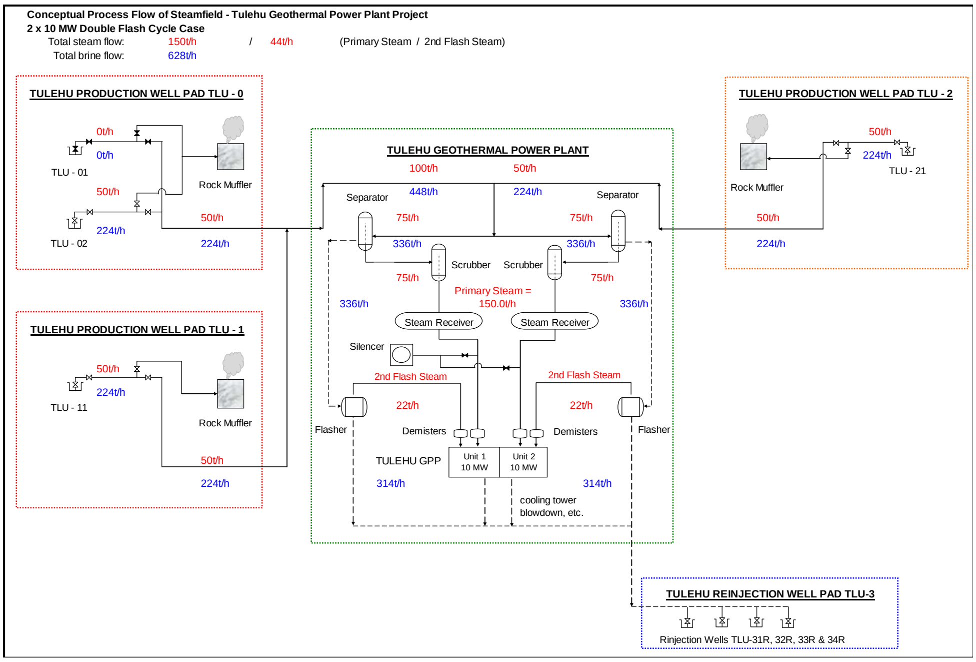


Fig. IV-13 Conceptual Process Flow of FCRS - 2 x 10 MW Double Flash Cycle Case

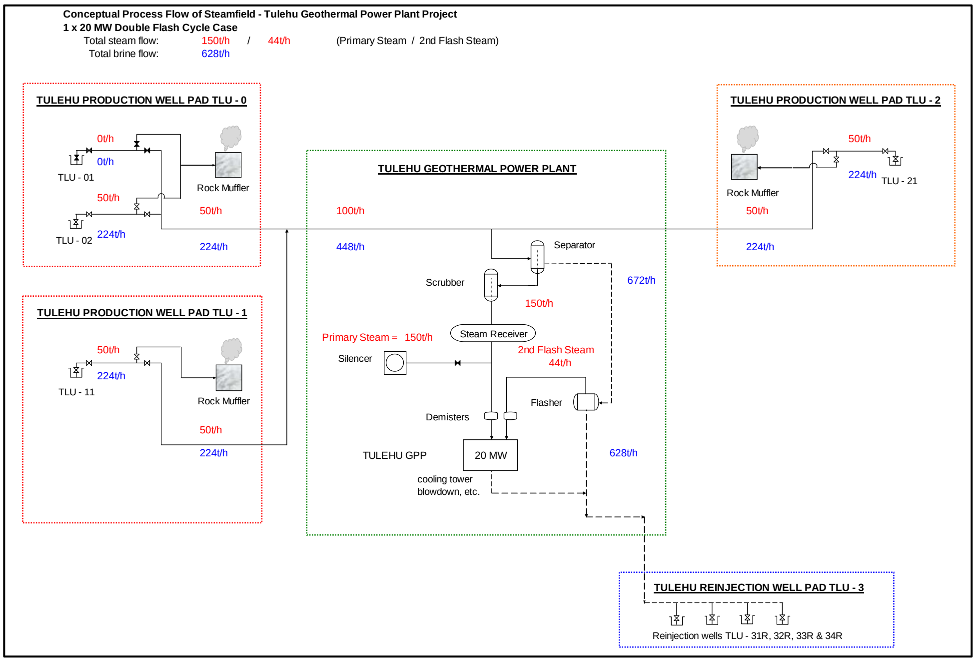


Fig. IV-14 Conceptual Process Flow of FCRS - 1 x 20 MW Double Flash Cycle Case

IV.4.3 Geothermal Power Plant Plan

Based on the geothermal resource study of the currently available data and the development plan explained in Chapter III and sections IV.1, IV.2, and IV.3, the plans for possible types of the geothermal power plant are studied.

The power plant systems (single flash system, double flash system, and binary system), the plant unit capacity, and the equipment and specifications for the mechanical, electrical, and instrumentation and control system of the power plant are studied in this section.

The current outputs of geothermal resource study and its development plan are enhanced with some assumptions based on knowledge and experience since the currently available data and information are limited. The geothermal resource evaluation should be re-examined in the light of additional data as more information on the drilling and testing of the further exploratory wells becomes available and in the light of meteorological observations at the project site. The geothermal resource development plan and the power plant plan will need to be reconsidered accordingly before starting project implementation.

1. Power Plant System

There are various types of geothermal power plant systems, such as the back pressure system, the single flash condensing system, the double flash condensing system, and the binary system, as presented in the Table IV-8. Based on the evaluation of the Tulehu geothermal resources, the single flash system and the double flash system, which are the most generally adopted systems for geothermal power plants, are studied in this feasibility study, and the features, merits and demerits of the both systems are compared.

The double flash system seems to be more suitable for the Tulehu geothermal project than the single flash system because of the following technical and economc considerations. The double flash system is recommendable because of its effective utilization of the geothermal energy and because it results in a more economically viable geothermal power plant project, as explained hereinafter.

The pressure and temperature of the Tulehu geothermal fluid is not so high (around 3 bara / 133 deg. C only), and the anticipated steam-hot water ratio will be approximately 1:4.5, meaning that a large volume of hot water will be contained in the fluid. In the case of the single flash system, the large volume of hot water separated as brine in the separator will be about 80 %wt of the total amount of the geothermal fluid. None of the separated brine will be utilized for power generation, but will be returned to the underground via reinjection wells. In the case of the double flash system, additional secondary steam will be extracted from the separator brine in the flasher, and this additional secondary steam will work to generate power, making the plant more efficient.

From the viewpoint of project costs, a single flash system project will cost approximately 40 % more (to drill large numbers of wells required) than a double flash system project.

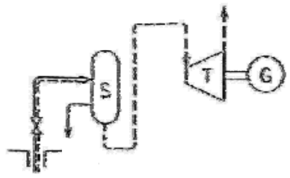
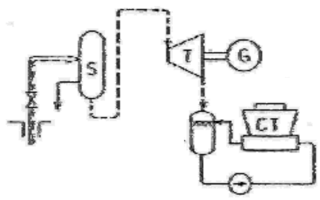
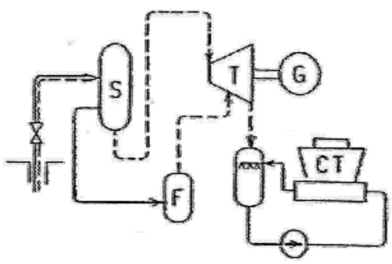
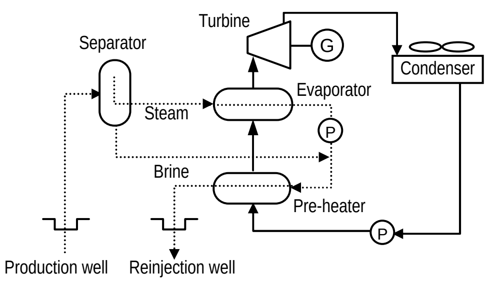
The single flash system project will need four (4) production wells and six (6) reinjection wells for operation of the 20 MW geothermal power plant, since there will be less usable steam and more brine to reinject. The double flash system project will require three (3) production wells and four (4) reinjection wells. It will require some additional investment, approximately a few per cent (%) increase, for the secondary steam facilities such as flasher(s), piping, valves, supports, etc., but this additional investment will be much lower than the cost of drilling additional wells for the single flash system project.

The chemical characteristics of the geothermal fluid are not available yet, and there could be a possibility of scaling problems arising in a low-temperature operation. Scaling problems would necessitate a limitation on the flashing pressure and temperature, which might restrict the double flash system to a limited utilization of the brine energy. The suitable geothermal power plant system should be re-studied in the next stage before implementation of the project on the basis of additional data, information, and the results of the further drilling of exploration wells, production tests, and chemical analysis of the geothermal fluid. If the geothermal fluid enthalpy proves be lower than estimated and the hot water quantity is much greater than anticipated, the possibility of a binary system may be considered.

Geothermal Binary System:

Since the geothermal fluid of Tulehu is anticipated to be not so high in temperature and to comprise a large quantity of hot water, a geothermal binary system could also be an attractive choice. A geothermal binary system can effectively utilize the geothermal energy, and the number of wells to drill can be reduced, as with the double flash system compared to the single flash system. The unique feature of the binary system is that power generation is possible with a secondary medium of low boiling temperature, even when the available geothermal fluid is relatively low in temperature. However, as in the case of the double flash system, a low limiting temperature due to the brine scaling problem will be a factor in geothermal fluid utilization. The in-house plant use of electric power with a geothermal binary system is as high as around 15 %, or double or triple the single flash and double flash system use of around 5 – 8 %. In order to secure the same net electric power generation as a single flash or double flash system, a larger gross generation capacity, approximately 10 % greater, will be required for a geothermal binary system. A geothermal binary system will also require alager plant compound area to accommodate a number of air-cooled condensers. In the technical study of a geothermal binary system, many design factors and conditions need to be clarified for secondary medium selection. Factors such as the pressure, temperature, and flow rate of the secondary medium, atmospheric design temperature, brine temperature, unit capacity, cooling methods, possible combination with a back-pressure steam turbine, and others need to be considered. Most of these factors and conditions can-not be confirmed at this stage in the feasibility study, and further consideration of a geothermal binary system is adjourned. It is recommended that further detailed studies of the geothermal binary system be resumed in the next engineering stage, when additional data and information on the characteristics of the geothermal fluid, steam, and brine will have been obtained through additional exploration well drilling and testing, and the atmospheric design conditions can be confirmed by meteorological observations at the project site.

Table IV-8 Geothermal Power Plant System

Type of Process	Features
1) Single Flash with Back Pressure System 	• Suitable for water-dominated resources. • Suitable for high NCG content. • Small capacity - Usually installed as a wellhead generating pilot plant. • Lower efficiency compared to condensing steam turbine. • Low construction cost. • High exhaust noise level.
2) Single Flash with Condensing System 	• Suitable for water-dominated resources. • Wide range of capacity from small to large. • System in most general use. • Lower efficiency in utilizing geothermal energy of geothermal fluid of low specific enthalpy compared to a double flash system.
3) Double Flash with Condensing System 	• Suitable for water-dominated resources • Wide range of capacity from small to large. • The 1st steam is separated in the separator and the additional 2nd steam is separated in the flasher. • Higher efficiency than single flash system. • Higher construction cost than for single flash. • Low temperature brine from flasher might cause silica scale problem in the reinjection line.
4) Two-phase (Biphase) Binary System 	• Suitable for water-dominated resources. • Suitable for resources of moderate to medium specific enthalpy. • Low temperature brine from separator and heat exchanger might cause silica scale problem in reinjection line. • Unit capacity is small, up to around 10 MW. • Station power use is considerable (approx. 15%).

2. Plant Unit Capacity

As mentioned in the geothermal resource study of chapter III, the development scale of the Tulehu geothermal field is 20 MW. The peak load demand of the Ambon electric power system will reach to 110 MW in the near future. The Tulehu geothermal power plant will be operated as a base load power plant, and as large a unit capacity as practicable would be desirable. The unit generating capacity of the power plants will have an impact on the stable operation of the Ambon electric power system. A unit capacity of 10 to 20 MW for Tulehu geothermal power plant could be still tolerable, considering the future scale of the Ambon electric power system.

For reference, the unit capacity of the Waai coal-fired thermal power plant is 15 MW x 2 units. The Waai power plant is currently under construction in the eastern part of Ambon Island and will start supplying power to the Ambon electric power system in 2012 through a 70 kV transmission line. The peal load demand in 2013 of the Ambon electric power system is anticipated to be 52.9 MW.

The two (2) cases of unit output capacity (2 x 10 MW and 1 x 20 MW) for the Tulehu geothermal power plant are studied, and the unit capacity of 20 MW seems to be a little advantageous in the construction cost, construction period, and procurement market competition.

3. Specifications of Major Mechanical Equipment

The specifications of the major mechanical equipment for the Tulehu geothermal power plant are studied for the following four (4) cases of plant system and unit capacity: 2 x 10 MW Single Flash Condensing System, 1 x 20 MW Single Flash Condensing System, 2 x 10 MW Double Flash Condensing System, and 1 x 20 MW Double Flash Condensing System. The equipment and specifications mentioned hereunder should be reconsidered at the beginning of the project implementation stage in light of to the test data from the additional exploration wells and the meteorological data observed at the project site.

For the above four (4) cases, the typical layout plans, the overall flow diagrams, and the specifications of the major mechanical equipment of the power plants are shown in section IV.4.3 of the main report.

In this summary report, the typical layout plans and the overall flow diagrams are introduced for the cases of double flash system in Figs. IV-15, IV-16, IV-17 and IV-18.

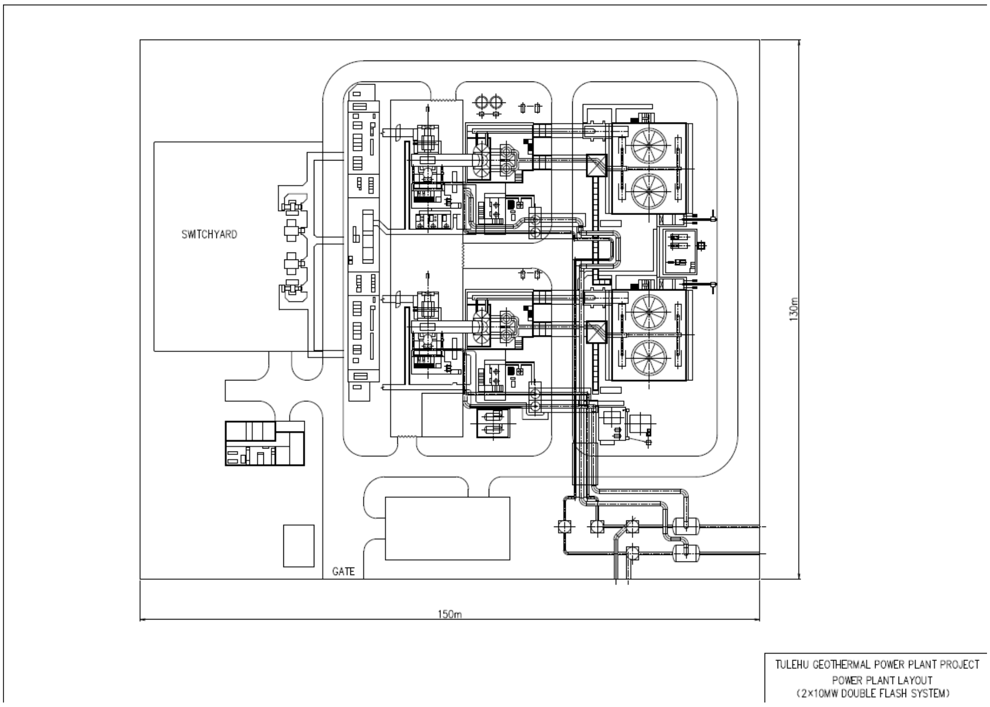


Fig. IV-15 Power Plant Layout (2 x 10 MW Double Flash System)

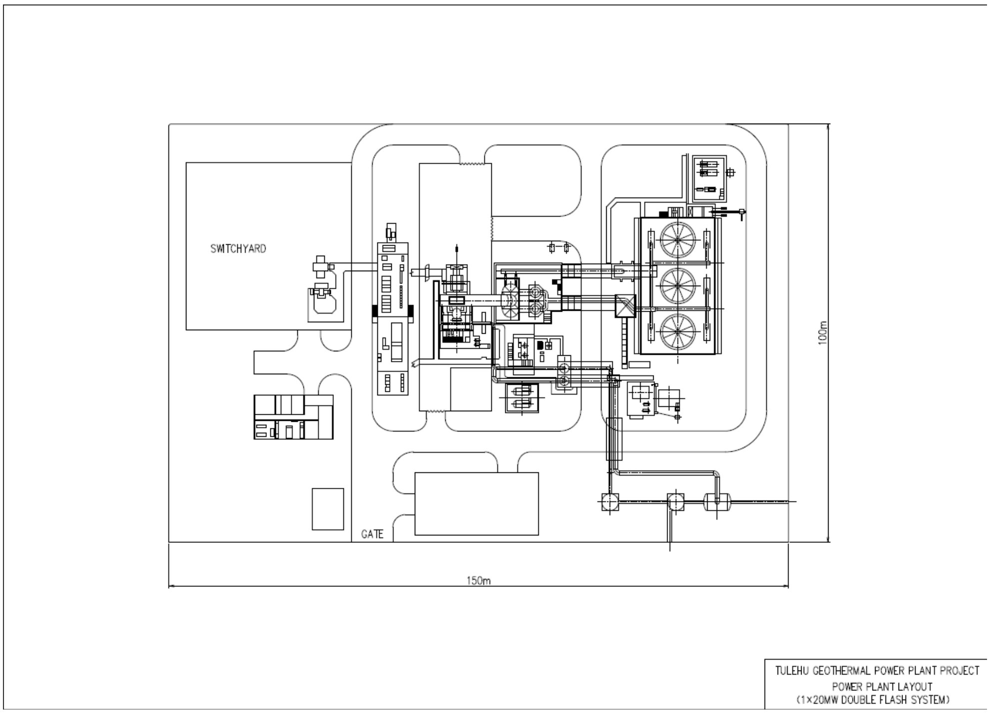


Fig. IV-16 Power Plant Layout (1 x 20 MW Double Flash System)

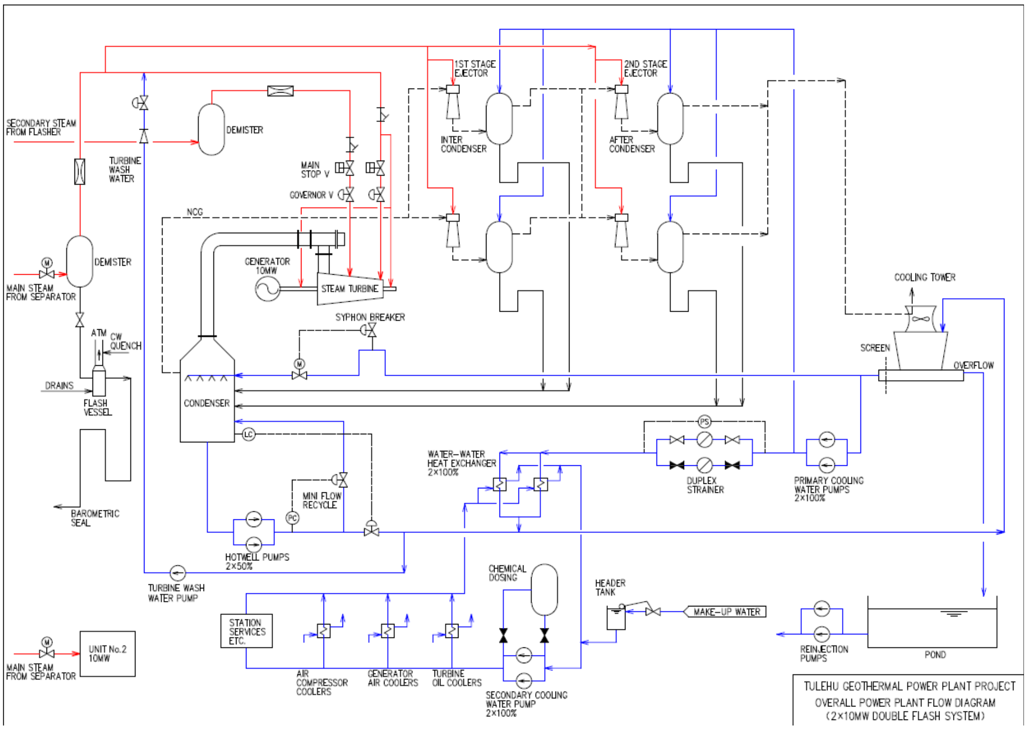


Fig. IV-17 Overall Power Plant Flow Diagram (2 x 10 MW Double Flash System)

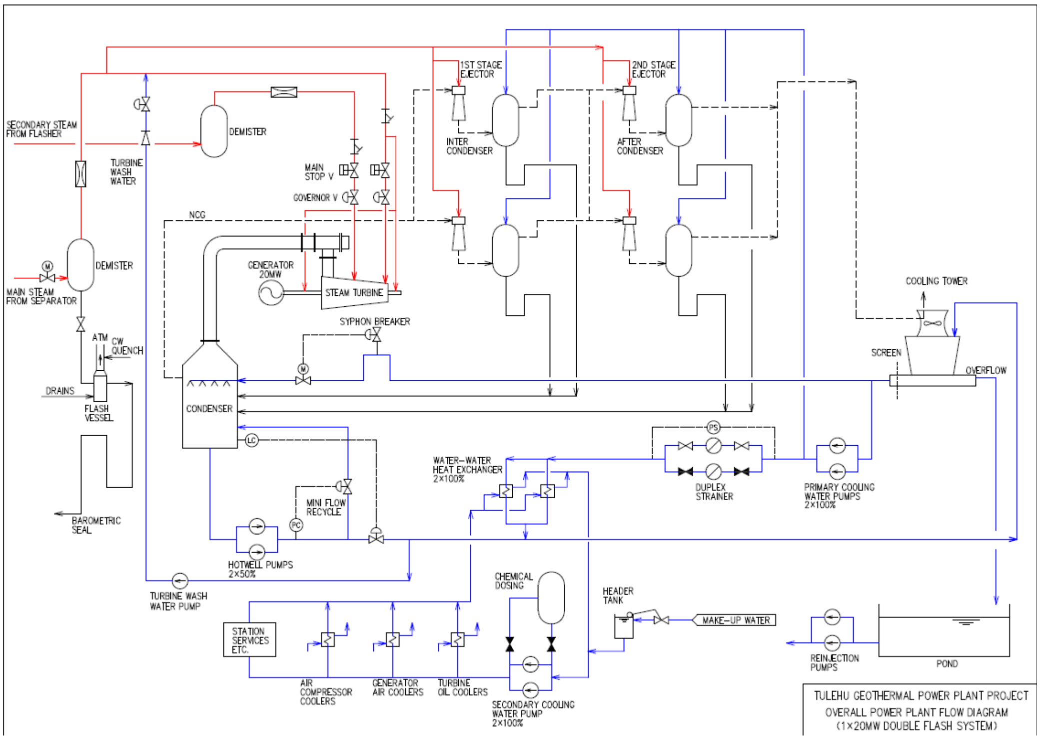


Fig. IV-18 Overall Power Plant Flow Diagram (1 x 20 MW Double Flash System)

4. Electrical, Instrumentation and Control System

a. General

Since there is no specific difference between single flush and double flush on electrical aspects at Feasibility study stage, only 2 cases (2 x 10 MW and 1 x 20 MW) are studied at this section.

The voltage of the generator output is stepped up to 70 kV by Main transformer(s) and connected to 70 kV transmission line between Waai coal fired thermal power plant and Passo substation through 70 kV switchgears in the power plant.

On the other hand, power for the auxiliary equipment in the power plant is supplied through Unit transformer(s) and auxiliary circuit is formed in the power plant, as shown in Fig. IV-4-19 and Fig. IV-4-20 “Single Line Diagram”. Medium voltage (MV) equipment might be applied in order to reduce large voltage drop at low voltage bus. Rules of voltage system for auxiliaries in the power plant should be defined at the time of the implementation stage.

The auxiliary power in the power plant will be supplied from the grid with the generator circuit breaker (CB) open at the time of start-up operation. As soon as the turbine is started, the generator is synchronized with the grid using the generator CB. Thus, auxiliary power is transferred with its own power. After the generator has reached its rated output, the start-up operation is complete. When the unit is shutdown, the auxiliary power must be fed from the grid again with the generator CB open.

b. Generators

Air-cooled, three-phase synchronous generator(s) will be applied. They are easy to operate, require less maintenance and are well-proven in a geothermal environment. Corrosive gas like H2S must be removed from the cooling air for the generator, utilizing oxidized catalytic filters etc., since the atmosphere around the geothermal field contains highly corrosive H2S gas. A brushless exciter system will be applied.

The main specifications of the generators are as follows:-

- Type : Cylindrical rotating field type, totally enclosed, air-cooled, three-phase synchronous generator(s)
- Rated Output : 2 x 10 MW or 1 x 20 MW
- Rated voltage : 11 kV (Manufacturer’s standard)
- Frequency : 50 Hz
- Speed : 3,000 rpm
- Power Factor : 0.8 (Lagging)
- Neutral Grounding : Transformer

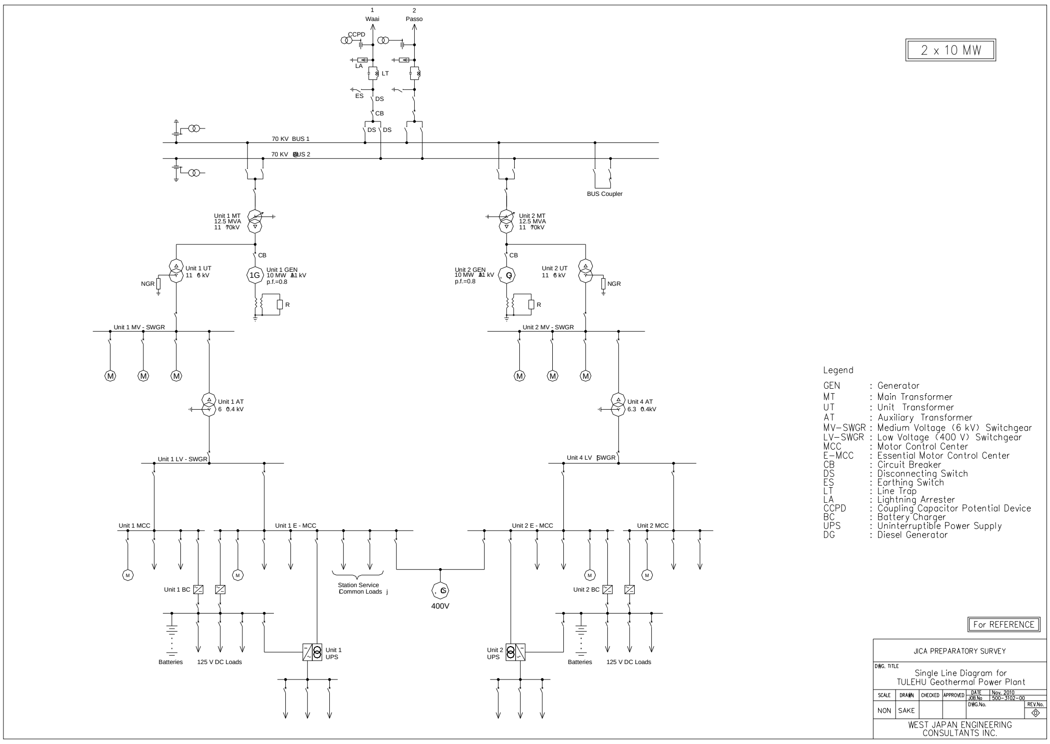


Fig. IV-19 Single Line Diagram (2 x 10 MW)

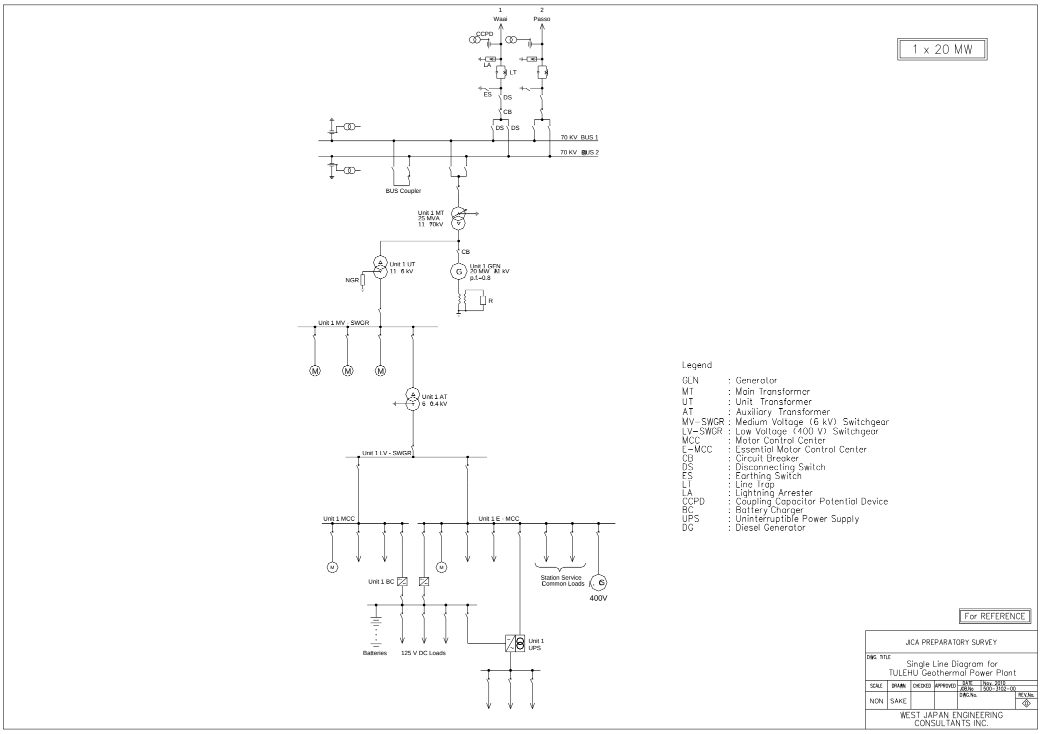


Fig. IV-20 Single Line Diagram (1 x 20 MW)

c. Control and Instrumentation Equipment

A micro-processor-based Distributed control system (DCS) will be installed to control the whole system and monitor various parameters of the geothermal power plant including FCRS. The DCS contributes to the highly reliable, fail-safe operation and productivity of the power plant.

The control systems in the geothermal power plant are mainly as follows:

i) Main steam supply
ii) Turbine and generator control
iii) Condenser level
iv) Electrical equipment control

In addition to the control system, a plant interlock system must be provided to protect the power plant equipment. For equipment operation, the software interlock systems are included in the DCS. For emergency tripping of the major equipment, however, a hard-wired interlock system should be provided in order to protect valuable equipment.

d. Communication System

The power plant must have communication equipment to communicate with Local control center in Ambon system.

e. Switchyard Equipment

The configuration of the switchyard will be of 70 kV, outdoor, conventional type, with a Double busbar system, which is the standard system of PLN. In order to protect the switchyard equipment and transmission lines from corrosion due to H_2S gas, the switchyard area will be located on the opposite side from the cooling tower facilities. The main specifications of the 70 kV switchgears are as follows:

- Switchyard type : Outdoor, conventional type
- Bus system : Double busbar system
- Rated voltage : 72.5 kV
- Rated current : 2,000 A
- Rated interrupting current : 25 kA or 31.5 kA (depending on the system)
- Rated insulation level
  - Lightning impulse withstand voltage : 325 kV
  - Power frequency withstand voltage : 140 kV
- Transmission line protection
  - Main protection : Impedance relay protection
  - Back-up protection : Directional earth fault protection and Overcurrent protection with Auto-reclose

IV.4.4 Equipment Transportation

Ambon port is equipped with a wharf for large ships and unloading facilities. The wharf is large enough to accomodate a large ship transporting well-drilling and power plant equipment. The wharf unloading facility has 32-ton lifting capacity and used especially for container handling. For the transportation and unloading of the power plant equipment for the project, it would be advisable to arrange for a ship equipped with its own lifting facilities.

The road from Ambon port up to the entrance to Rupa Hitu village is a well-paved national road, and there will be no difficulties transporting the necessary materials because of issues with road width, curves, and slopes in the road, or bridges (either concrete or steel framework). Power lines, however, cross the national road at many places at a height of a few meters, and appropriate measures will need to be taken for the transportation of large size equipment. After Ambon port, the road passes through the center of Ambon city, which has heavy traffic. Therefore, special measures will need to be considered for moving heavy and large equipment, such as advance application for permits from the local government, nighttime transportation, etc.

An access road will be constructed from Rupa Hitu village to the well pads and power plant. This access road will be approximately 4 km long with a gradual slope.

IV.5 Transmission Lines

Double circuits of 70 kV Transmission line will be constructed by PLN between 70 kV switchyard in Tulehu geothermal power plant and the 70 kV transmission line which is planned to construct for newly installed Waai thermal power plant. Fig. IV-21 shows Single Line Diagram of Ambon-Seram Interconnection system. (Source; PLN Wilayah Maluku dan Maluku utara)

As shown in the Diagram, double circuits of the transmission line from the plant will be cut-in (Pi connection) to the one circuit of 70 kV transmission line between PLTU Waai and GI Passo (Passo substation). According to the *document given by Cabang Ambon, T-35 tower is the and most suitable tensional tower for Pi connection of the transmission lines. (*Reference document; Survey Reconnaissance Jalur Transmisi 70 kV, PLTU Liang – Passo – Ambon, Augustus 2007) Please refer to Fig. IV-12. Appropriate design should be made for the tower (T-35 tower) to accept Pi connection of one line in future, in view of both physical connection and mechanical strength of the tower, even another line is in operation. Fig. IV-22 is a sample drawing for provision of Pi connection, for reference.

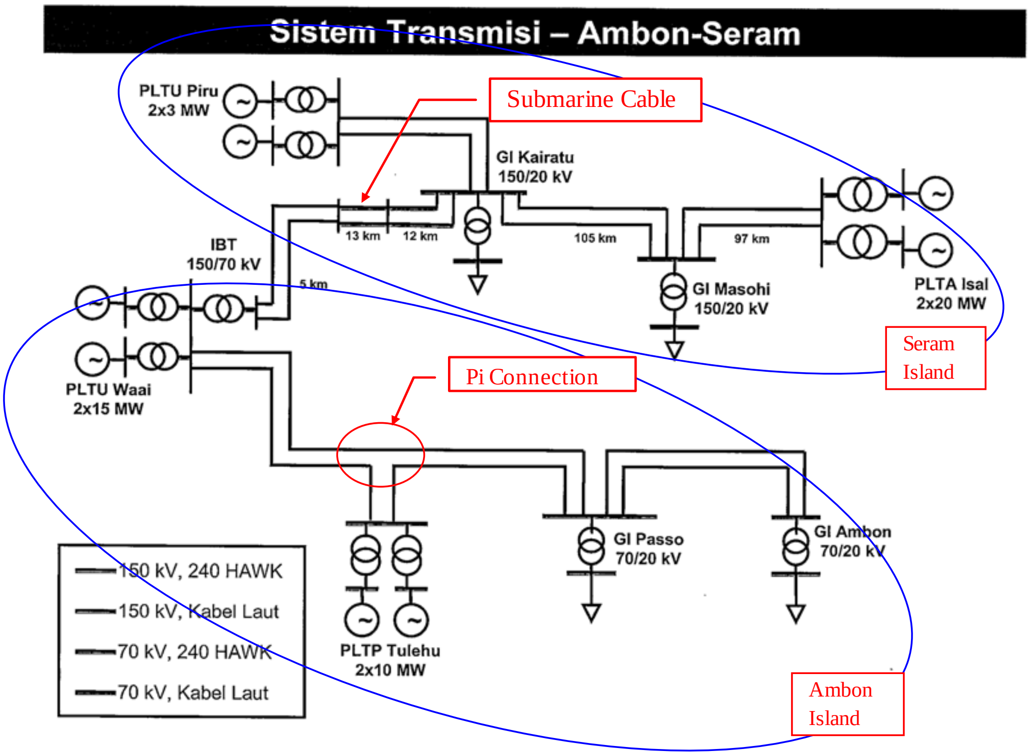


Fig. IV-21 Single Line Diagram of Ambon-Seram Interconnection System

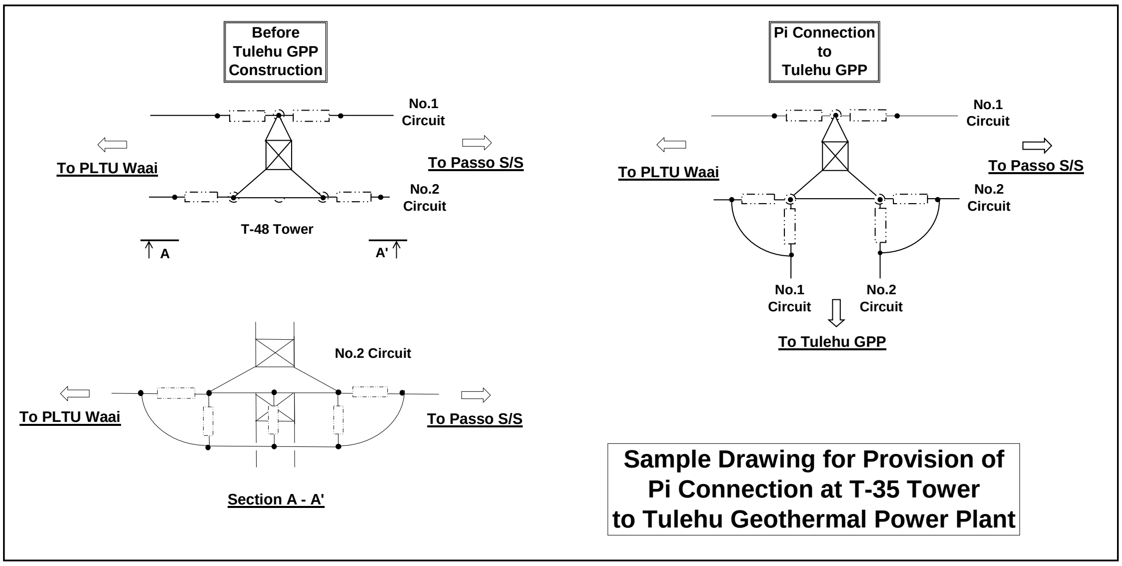


Fig. IV-22 Sample Drawing for Provision of Pi Connection

IV.6 Project Cost

IV.6.1 Resource Development Cost

The work categories and cost estimates including land acquisition are shown below in Table IV-9.
The necessary cost for each well estimated based on the recent market prices is shown in Table IV-10. The make-up well drilling cost and its distribution is shown in Table IV-11. A construction cost estimate for well pads and access roads is shown in Table V-12.

Table IV-9 Resource Development Cost

Work Category	Work Item	Cost Estimate (US$)
Single Flash		
Work done by PLN in preparation for the commencement of drilling work (Pre-construction Work)	Well Pad Construction (2 production and 1 reinjection)	1,320,000
	Access Road Construction (for new well pad)	360,000
	Water Line for Drilling	480,000
	Land Acquisition	373,800
	Sub-total	2,533,800
Construction Stage	Rig Mobilization/Demobilization	2,000,000
	Production Well Drilling including Testing (4 wells)	21,560,000
	Reinjection Well Drilling (6 wells)	23,100,000
	Sub-total	46,660,000
Grand Total		49,193,800
Double Flash		
Work done by PLN in preparation for the commencement of drilling work (Pre-construction Work)	Well Pad construction (2 production and 1 reinjection)	1,320,000
	Access road construction (for new well pad)	360,000
	Water Line for Drilling	480,000
	Land Acquisition	373,800
	Sub-total	2,533,800
Construction Stage	Rig Mobilization/Demobilization	2,000,000
	Production Well Drilling including Testing (3 wells)	16,170,000
	Reinjection Well Drilling (4 wells)	15,400,000
	Sub-total	33,570,000
Grand Total		36,103,800

Table IV-10 Drilling Cost Estimates

(Unit: US$)

Item	Production well Ave. Depth: 1,500m (Big hole) Ave. Drilling Days: 30	Reinjection well Ave. Depth: 1,500m (Standard hole) Ave. Drilling Days: 27
1. Rig Hire		
a. Drilling cost		
***Rig Operation ($30,000/day)**	**1,080,000**	**972,000**
***Air drilling package**	**600,000**	**N/A**
b. Rig Move (On location)	**240,000**	**240,000**
Sub-total	**1,920,000**	**1,212,000**
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	**360,000**	**300,000**
f. H2S Monitoring	**50,000**	**40,000**
g. Well logging	**90,000**	**60,000**
Sub-total	**1,330,000**	**1,090,000**
5. Drilling materials		
a. Bit and others	**160,000**	**120,000**
b. Casing and accessories	**700,000**	**500,000**
c. Well-head and valves	**240,000**	**180,000**
d. Mud materials	**90,000**	**75,000**
e. Cement and additives	**180,000**	**140,000**
f. Fuel and Oil supply	**360,000**	**300,000**
g. Drilling consumable-Foreign	**90,000**	**70,000**
h. Drilling consumable-Local	**20,000**	**18,000**
Sub-total	**1,840,000**	**1,403,000**
6. Drilling support		
a. Transport (on site)	**20,000**	**15,000**
b. Water supply	**40,000**	**30,000**
c. Others (Catering, etc.)	**60,000**	**50,000**
Sub-total	**120,000**	**95,000**
7. Well Testing	**180,000**	**50,000**
Grand Total for Drilling	**US$5,390,000/well**	**US$3,850,000/well**

Note: Excluding Rig Mob./Demob.

Table IV-11 Cost Estimates of Make-up Wells

(Unit: MUS$)

Single Flash

Drilling Schedule						Drilling Unit Cost			
						5.39	3.85	2.00	Mill US$
No.	Year	P-Well	R-Well	Rig Mob		P-Well	R-Well	Rig Mob	Total
-5	2010					0	0	0	0
-4	2011				JICA	0	0	0	0
-3	2012					0	0	0	0
-2	2013	4	1	1		21.56	3.85	2.00	27.41
-1	2014		5			0	19.25	0	19.25
Initial		4	6	1		21.56	23.1	2.00	46.66
1	2015					0	0	0	0
2	2016					0	0	0	0
3	2017					0	0	0	0
4	2018					0	0	0	0
5	2019					0	0	0	0
6	2020					0	0	0	0
7	2021					0	0	0	0
8	2022	1	1	1		5.39	3.85	2.00	11.24
9	2023					0	0	0	0
10	2024					0	0	0	0
11	2025					0	0	0	0
12	2026					0	0	0	0
13	2027					0	0	0	0
14	2028		1	1		0	3.85	2.00	5.85
15	2029					0	0	0	0
16	2030					0	0	0	0
17	2031	1		1		5.39	0	2.00	7.39
18	2032					0	0	0	0
19	2033					0	0	0	0
20	2034		1	1		0	3.85	2.00	5.85
21	2035					0	0	0	0
22	2036					0	0	0	0
23	2037					0	0	0	0
24	2038					0	0	0	0
25	2039					0	0	0	0
26	2040	1	1	1		5.39	3.85	2.00	11.24
27	2041					0	0	0	0
28	2042					0	0	0	0
29	2043					0	0	0	0
30	2044					0	0	0	0
Total		3	4	5		16.17	15.4	10.00	41.57
Grand Total			7						

Double Flash

Drilling Schedule						Drilling Unit Cost			
						5.39	3.85	2.00	Mill US$
No.	Year	P-Well	R-Well	Rig Mob		P-Well	R-Well	Rig Mob	Total
-5	2010					0	0	0	0
-4	2011				JICA	0	0	0	0
-3	2012					0	0	0	0
-2	2013	3	2	1		16.17	7.7	2.00	25.87
-1	2014		2			0	7.7	0	7.7
Initial		3	4	1		16.17	15.4	2.00	33.57
1	2015					0	0	0	0
2	2016					0	0	0	0
3	2017					0	0	0	0
4	2018					0	0	0	0
5	2019					0	0	0	0
6	2020					0	0	0	0
7	2021	1	1	1		5.39	3.85	2.00	11.24
8	2022					0	0	0	0
9	2023					0	0	0	0
10	2024					0	0	0	0
11	2025					0	0	0	0
12	2026					0	0	0	0
13	2027					0	0	0	0
14	2028					0	0	0	0
15	2029					0	0	0	0
16	2030					0	0	0	0
17	2031	1	1	1		5.39	3.85	2.00	11.24
18	2032					0	0	0	0
19	2033					0	0	0	0
20	2034					0	0	0	0
21	2035					0	0	0	0
22	2036					0	0	0	0
23	2037					0	0	0	0
24	2038					0	0	0	0
25	2039					0	0	0	0
26	2040	1	1	1		5.39	3.85	2.00	11.24
27	2041					0	0	0	0
28	2042					0	0	0	0
29	2043					0	0	0	0
30	2044					0	0	0	0
Total		3	3	3		16.17	11.55	6.00	33.72
Grand Total		6							

Table IV-12 Cost Estimates for Civil Work/Land Acquisition done by PLN

(Unit: MUS$)

ITEM		UNIT	QUANTITY	UNIT PRICE	PRICE	REMARKS
I	PRODUCTION WELL PAD	L.S.	1		740,000	
I-1	Production Pad No.1	m2	7,000	50	350,000	Size:70m x 100m
I-2	Production Pad No.2	m2	7,000	50	350,000	Size:70m x 100m
I-3	Cellar	nos	4	10,000	40,000	W2m x D3m x H2m x T0.3
II	REINJECTION WELL PAD	L.S.	1		580,000	
II-1	Reinjection Pad No.1	m2	10,400	50	520,000	Size:80m x 130m
II-3	Cellar	nos	6	10,000	60,000	W2m x D3m x H2m x T0.3
III	ACCESS ROAD	m	3,000	120	360,000	Width:5m, Unpaved
IV	WATER LINE	m	2,000	240	480,000	
V	LAND ACQUISITION	L.S.	1		373,800	
V-1	Well Pad	m2	29,400	7	205,800	(7,000 + 7,000 + 10,400) x 1.2
V-2	Access Road	m2	24,000	7	168,000	8m x 3,000m
GRAND TOTAL					**2,533,800**	I + II + III + IV + V

IV.6.2 Cost for Construction of Plant and Transmission Lines

1. Estimated Cost of Geothermal Power Plant

The cost for construction of plant and switch yards were estimated for four (4) cases (Single flash 2 x 10MW, Single flash 1 x 20 MW, Double flash 2 x 10MW, and Double flash 1 x 20MW Systems).

The construction costs of the Tulehu geothermal power plant including associated switch-yard were estimated on the basis of the actual cost of the similar Lahendong-3 geothermal power plant project in North Slawesi. The similarities between Lahendong-3 GPP and Tulehu GPP can be seen from the following: Lahendong-3 was a PLN geothermal power plant project carried out with a JICA ODA Loan. A 1unit x 20 MW single flash plant was newly constructed in North Sulawesi, a remote, isolated, Indonesian island. The EPC contract was concluded in April 2007, and the project was completed in February 2009. The contracted project cost of Lahendong-3 GPP was approximately 1,900 US$/kW. Based on this recent contracted cost record, the construction cost for each of the four types of plant design being considered for Tulehu GPP was estimated, taking into consideration the wide variation in the US$ exchange rate, the increased cost factor for a double flash system and the cost disadvantage factor for a smaller capacity scale of 10 MW. The currency allotment proportion in the foreign currency and the local currency was estimated in light of the actual contract details for Lahendon-3 GPP.

The FCRS costs were estimated on the basis of the unit costs (US$/inch-m) estimated for the FCRS piping system in the 2010 feasibility study for a geothermal power plant project in Sumatra Indonesia.

The costs of the geothermal power plant were shown in the following Table IV-13.

Table IV-13 Cost Estimate of Power Plant (4 cases)

(MUS$)

	Single Flash 2 x 10 MW	Single Flash 1 x 20 MW	Double Flash 2 x 10 MW	Double Flash 1 x 20 MW
FCRS:	8.38	7.94	6.62	6.62
Power Plant:	44.00	42.00	46.00	43.80
FCRS + Power Plant	52.38	49.94	52.62	50.42

2. Estimated Cost of Connecting Transmission Lines

The construction cost of about 3 km connecting transmission line with 70 kV transmission line is estimated at 0.3 Million US$. The study team confirmed that the connection work will be done by PLN's own equity aside from the Yen Loan.

IV.7 Project Implementation Plan

The executing agency of the project is PLN (PT. PLN (Persero)).

PLN will start procurement of a Consultant who has an ample experience not only in the planning, design and construction of geothermal power plants but also in the procurement and supervision of geothermal well drilling and FCRS construction. With the consultant's assistance, PLN will implement the work of planning, design, contractor selection & contracting, supervision and management of contractors' work, and project acceptance.

The project operation and maintenance organization has not yet been clearly decided at PLN. The following operation organization can be anticipated from the operation organization of the Lahendong geothermal power plants which are in operation in North Sulawesi.

Steam Supply:	PLN (PT PLN Geothermal)
Geothermal Power Generation:	PLN (PT PLN Geothermal)
Transmission and Distribution:	PLN (Wilayah Maluku & Maluku Utara at Ambon)

The Tulehu Geothermal Power Plant Project comprises the following work and services with financing from the sources indicated.

	Work & Services	Finance Source
1)	PLN Advance Work (land acquisition, well pad preparation, access road construction, meteorological observation at the Project site)	PLN Own Fund
2)-1	Exploratory Well Drilling & Testing for Tulehu (3 production wells and 1 reinjection well)	JICA ES Loan
2)-2	Additional Well Drilling & Testing for Tulehu	JICA Project Loan
3)	Construction of FCRS	JICA Project Loan
4)	Construction of Geothermal Power Plant (including associated switchyard)	JICA Project Loan
5)	70 kV Transmission Line Connecting Work	PLN Own Fund
6)	Engineering Consulting Services	JICA ES Loan
7)	Exploratory Well Drilling & Testing for future development site (2 production wells and 1 reinjection well)	JICA ES Loan

With due consideration of the JICA standard yen loan schedule, a tentative project implementation schedule has been prepared for the four cases of the project: 2 x 10 MW Single Flash, 1 x 20 MW Single Flash, 2 x 10 MW Double Flash, and 1 x 20 MW Double Flash. In this summary report, the standard project schedule for the 2 x 10 MW Double Flash case is shown in Fig. IV-23 as an example, and the project total period will be 60 months from the start until the plant completion. The accelerated version of the project implementation schedule for the 2 x 10 MW Double Flash case is shown in Fig. IV-24 as target schedule, in consideration of PLN's strong intention to complete the project as early as possible, and the project total period will become 52 months. The project schedules of the other cases are shown in section IV.7.4 of the main report.

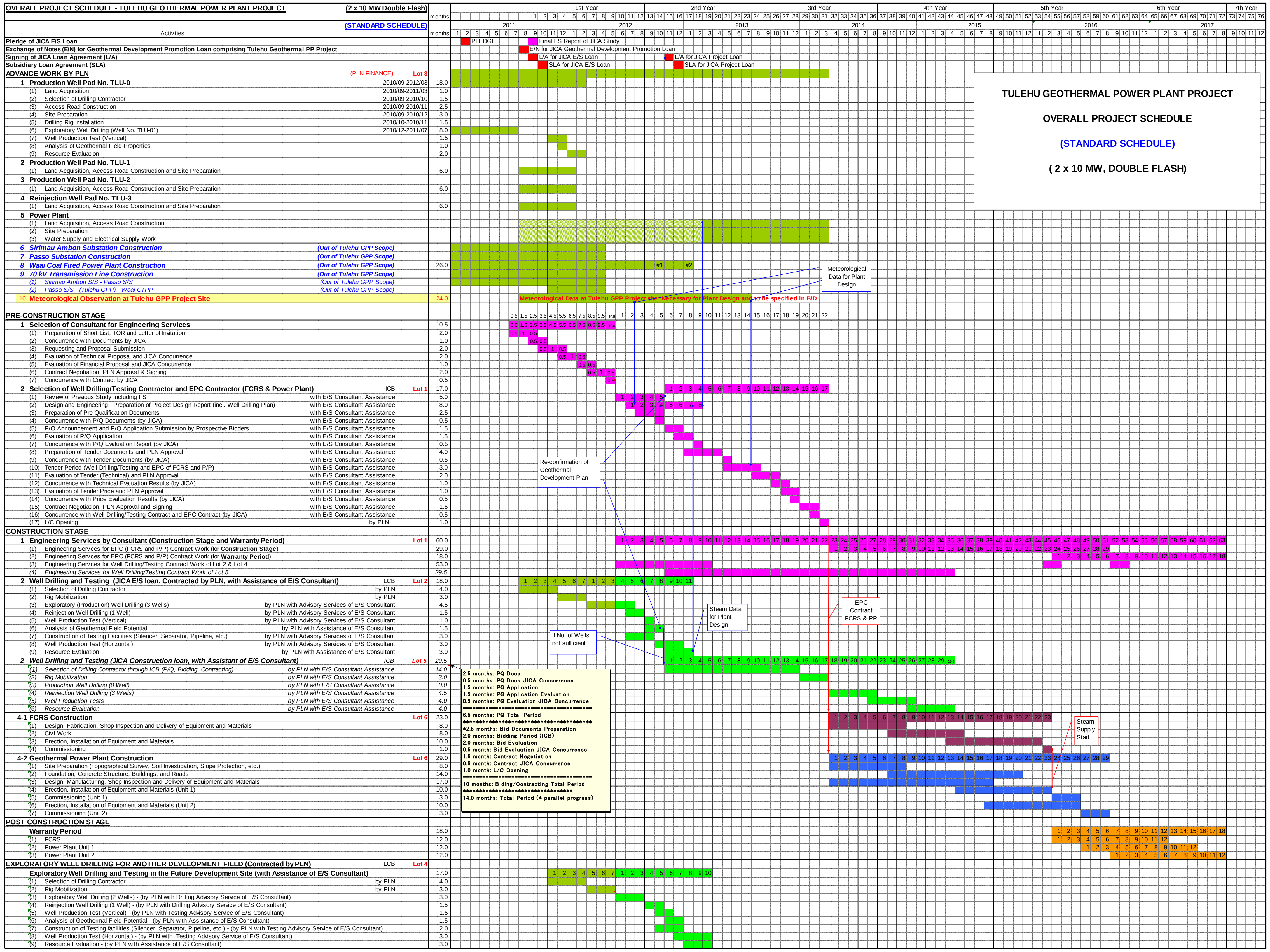


Fig. IV-23 Tentative Project Implementation Schedule (2 x 10MW Double Flash System) – Standard Schedule

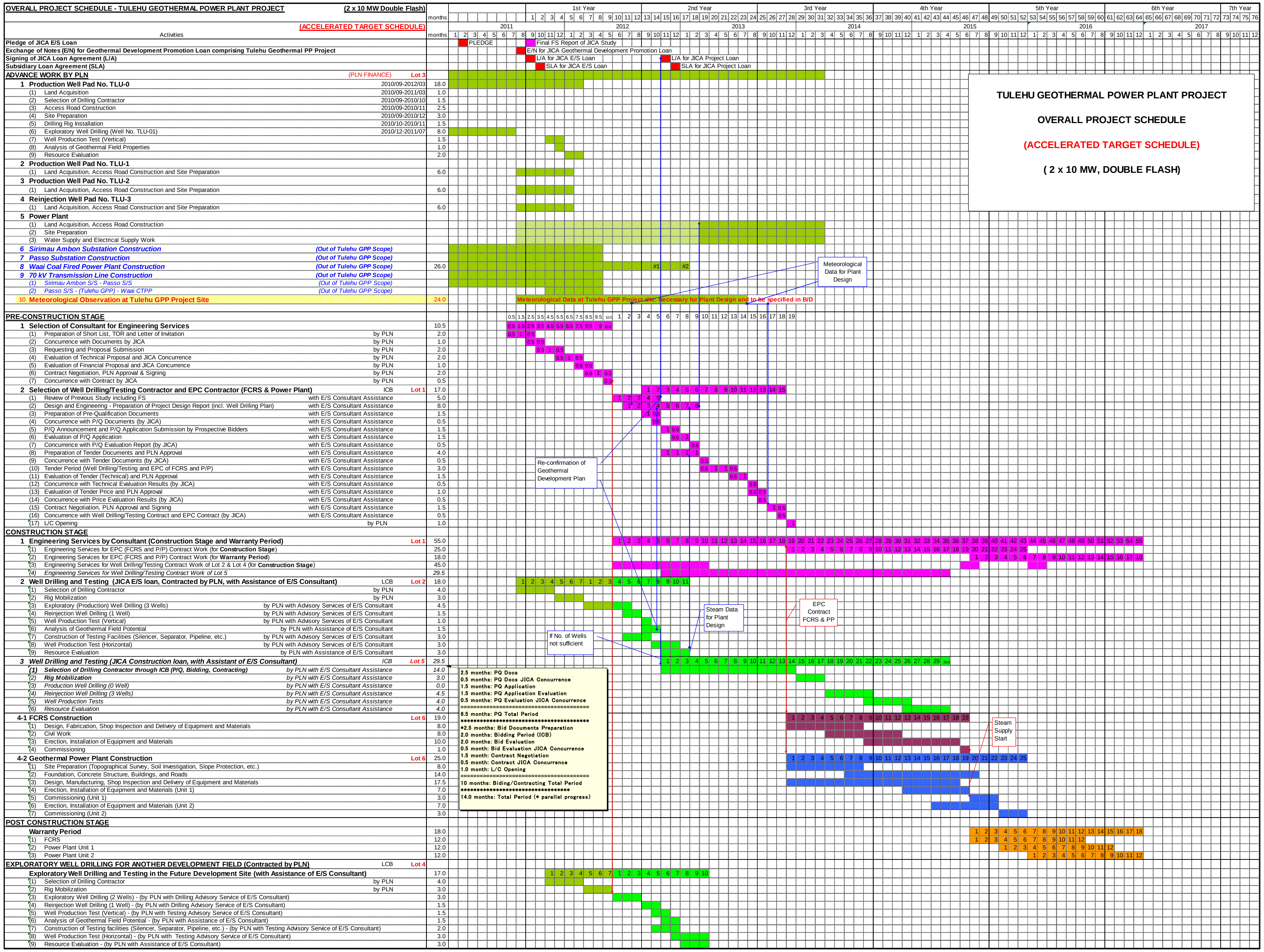


Fig. IV-24 Tentative Project Implementation Schedule (2 x 10MW Double Flash System) Accelerated Target Schedule

IV.8 Confirmation of Project Effect

IV.8.1 Project Cost Summary

With respect to the 4 types of power configuration, the respective project cost estimate is made on condition that the finance will be granted from the JICA Yen Loan, and these estimates are summarized in Table IV-14. In a double flash system, the cost for power plant is high-priced to some extent. However, the number of wells could be reduced in double flash systems because of higher efficiency in brine utilizations. Consequently, double flash systems are favorable in reducing total project cost.

Table IV-14 Summary of Project Cost Estimation

Unit: Million US$	**Single Flash**		**Double Flash**	
Item	10 x 2	20 x 1	10 x 2	20 x1
1 Project Up Stream Works				
1.1 Access Road/Civil Works (PLN portion)	2.53	2.53	2.53	2.53
1.2 Well drilling	46.66	46.66	33.57	33.57
Subtotal	49.19	49.19	36.10	36.10
2 Project Down Stream Works				
2.1 Power Plant	44.00	42.00	46.00	43.80
2.2 FCRS	8.38	7.94	6.62	6.62
2.3 Connecting T/L (PLN)	0.30	0.30	0.30	0.30
Subtotal	52.68	50.24	52.92	50.72
3 Total Project Cost	101.87	99.43	89.02	86.82
4 Administration Cost	4.07	3.98	3.56	3.47
5 Consulting Fee	10.51	10.51	10.51	10.51
6 Contingencies				
6.1 Price Conti. (FC:1.6%, LC:7.9%)	14.71	14.37	13.51	13.16
6.2 Physical Conti.	6.04	5.93	5.39	5.26
Subtotal	20.75	20.30	18.90	18.42
7 Grand Total	137.20	134.22	121.99	119.22
8 Implementation				
9.1 PLN Equity	25.82	25.28	22.96	22.45
9.2 JICA Project Loan, (less than 85%)	99.21	96.77	86.86	84.60
9.3 JICA Consultant Loan, 100%	12.17	12.17	12.17	12.17
Total	137.20	134.22	121.99	119.22
Yen equivalent (Million Yen)				
9.1 PLN Equity	2,053	2,010	1,825	1,785
9.2 JICA Project Loan, (less than 85%)	7,887	7,693	6,905	6,725
9.3 JICA Consultant Loan, 100%	968	968	968	968
Total	10,907	10,670	9,698	9,478
9 IDC+Commitment Charge	1.19	1.16	1.13	1.10

IV.8.2 Economic and Financial Evaluation

Economic and financial evaluations were attempted with respect to four types of system configurations. The results of evaluations are summarized in Table IV-15. The results indicated that the projects are financially feasible, except the case of 2 x 10MW single flash system. The project is highly expected to improve the financial condition of PLN Ambon. In the financial/economical evaluations, double flash systems were superior to single flash system because of superiority in investment, as shown in Fig. IV-25.

Table IV-15 Summary of Project Cost Estimation

Economic and Financial Evaluation Summary	Single F 10 MW x 2	Single F 20 MW x 1	Double F 10 MW x 2	Double F 20 MW x 1
Saving and Reduction Effects				
1 Annual Fuel Saving Volume	41.31 Mill/lit	41.31 Mill/lit	41.31 Mill/lit	41.31 Mill/lit
2 Annual Fuel Saving Amount	29.56 MM$	29.56 MM$	29.56 MM$	29.56 MM$
3 Subsidy Reduction	19.97 MM$	20.34 MM$	22.33 MM$	22.66 MM$
Economic Evaluation				
1 EIRR to diesel fuel oil saving	19.64% >12%	19.98% >12%	22.18% >12%	22.57% >12%
2 EIRR to subsidy reduction	13.42% >12%	13.96% >12%	17.17% >12%	17.76% >12%
3 EIRR to willingness to pay at 2500 Rp/kWh	17.47% >12%	17.78% >12%	19.61% >12%	19.97% >12%
4 EIRR to 15 MW x 2 Coal-fired	10.52% <12%	10.94% >12%	13.51% >12%	14.06% >12%
Financial Evaluation				
1 LEC at PP outlet (House service ratio at 5%)	14.89 cent/kWh	14.63 cent/kWh	13.23 cent/kWh	12.99 cent/kWh
2 LEC at Sending end (System loss at 10%)	16.55 cent/kWh	16.26 cent/kWh	14.70 cent/kWh	14.44 cent/kWh
3 WACC	2.56%	2.56%	2.56%	2.56%
4 FIRR at actual selling price at 7.93 cent/kWh	2.35% <2.56%	2.48% <2.56%	3.27% >2.56%	3.41% >2.56%
5 Project FIRR at LEC at sending end	8.90% >2.56%	8.90% >2.56%	8.85% >2.56%	8.86% >2.56%
6 Equity FIRR at LEC at sending end	30.46% >12%	30.43% >12%	29.55% >12%	29.53% >12%

LEC at sending end			
Dis Rate	LEC,$	ProjFIRR	Eqty FIRR
12.00%	**0.138**	**9.01%**	**29.24%**
3.00%	0.069	2.5%	#DIV/0!
4.00%	0.075	3.4%	#DIV/0!
5.00%	0.082	4.2%	#DIV/0!
6.00%	0.089	4.9%	#DIV/0!
7.00%	0.097	5.7%	#NUM!
8.00%	0.105	6.4%	8.5%
9.00%	0.113	7.1%	20.8%
10.00%	0.121	7.8%	24.3%
11.00%	0.130	8.4%	26.9%
12.00%	0.138	9.0%	29.2%
13.00%	0.147	9.6%	31.3%
14.00%	0.156	10.2%	33.2%
15.00%	0.165	10.7%	35.0%
16.00%	0.174	11.2%	36.6%

LEC at PP outlet			
Dis Rate	LEC, $	ProjFIRR	Eqty FIRR
12.00%	**0.124**	**9.01%**	**29.24%**
3.00%	0.062	2.5%	#DIV/0!
4.00%	0.068	3.4%	#DIV/0!
5.00%	0.074	4.2%	#DIV/0!
6.00%	0.080	4.9%	#DIV/0!
7.00%	0.087	5.7%	#NUM!
8.00%	0.094	6.4%	8.5%
9.00%	0.102	7.1%	20.8%
10.00%	0.109	7.8%	24.3%
11.00%	0.117	8.4%	26.9%
12.00%	0.124	9.0%	29.2%
13.00%	0.133	9.6%	31.3%
14.00%	0.141	10.2%	33.2%
15.00%	0.149	10.7%	35.0%
16.00%	0.157	11.2%	36.6%

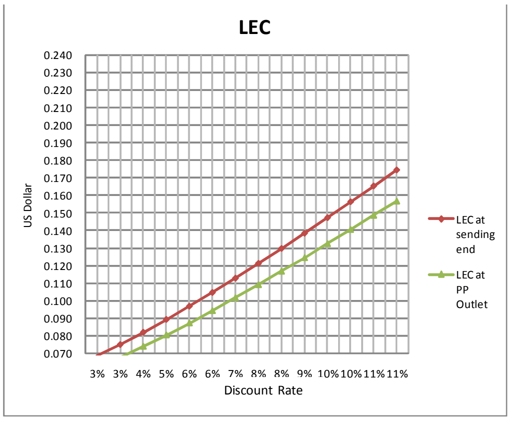


Fig. IV-25 Levelized Energy Cost (10 MW x 2 Double Flash)

Though the discount rate for LEC calculation used is 12%, if the WACC about 3% is the opportunity cost and discount rate, the generating cost at power plant becomes 6.2 cent/kWh and that at sending end (selling unit rate) 6.9 cent/kWh, less than the actual selling rate of 7.53

cent/kWh.

The result of sensitivity analysis of FIRR with respect to project cost is shown in Fig. IV-26. The FIRR of the base case for 10 MW x 2 Double Flash System recorded at 9% as shown in Fig. IV-26. Even the project cost should become 30% higher than the base case, the FIRR is still 6.6% and exceeds the WACC at 2.98%.

Project Cost Sensitivity		
Project Co	Pro FIRR	Eqty FIRR
100%	9.0%	29.2%
120%	6.6%	22.4%
118%	6.8%	22.8%
116%	6.9%	23.2%
114%	7.0%	23.6%
112%	7.2%	24.0%
110%	7.3%	24.4%
108%	7.5%	24.9%
106%	7.6%	25.3%
104%	7.8%	25.8%
102%	7.9%	26.2%
100%	8.1%	26.7%
98%	8.3%	27.2%
96%	8.5%	27.7%
94%	8.6%	28.2%
92%	8.8%	28.7%
90%	9.0%	29.2%
88%	9.2%	29.8%
86%	9.4%	30.3%
84%	9.6%	30.9%
82%	9.8%	31.5%
80%	10.1%	32.1%

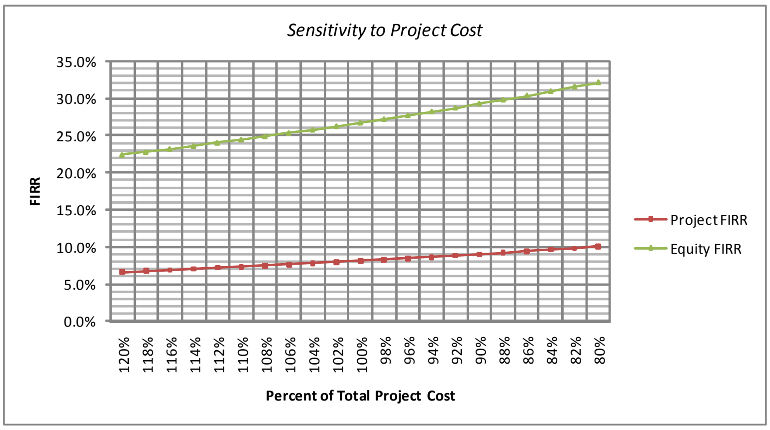


Fig. IV-26 Sensitivity to Project Costs (10 MW x 2 Double Flash)

If the Project should be completed without any expense of contingencies (97.1 Million US$ as against the base of 114.9 Million US$, or about 84% of the base), the project financial conditions should be as follows.

Financial Evaluation		With Contingencies	Without Contingencies
1 Levelized Energy Cost at PP outlet (House service ratio at 5%)		12.45 cent/kWh	10.89 cent/kWh
2 Levelized Energy Cost at Sending end (System loss at 10%)		13.84 cent/kWh	12.10 cent/kWh
3 WACC		2.98%	2.96%
4 FIRR at actual selling price at	7.53 cent/kWh	3.34% >2.98%	4.44% >2.96%
5 Project FIRR at LEC at sending end		9.01% >2.98%	9.10% >2.96%
6 Equity FIRR at LEC at sending end		29.24% >12%	29.22% >12%

IV.8.3 CDM Effects

The CO_2 reduction by this project is calculated with the CO_2 emission coefficient of the diesel power at 0.8 ton/MWh as the Ambon Power System is now totally relying on diesel power. Thus, the CO_2 reduction will be obtained with the following formula

20 MW x 8,760 hr x 85% (capacity factor) x 0.8 = 119,136 ton/year

While the steam in this field include non-condensable gasses containing the CO_2 at 98 vol% (or 0.87 wt%) as shown in a calculation based on the result of geochemical data analysis, the certified value for CO_2 transaction should deduct the CO_2 producing amount from the geothermal power operation.:

20 MW x 8,760 hr x 85% x 10 t/MWh (consumption) x 0.87CO_2wt%/100 =12,956 ton/year

Thus, annual CER CO_2 volume from this geothermal power project will be 119,136 – 12,956 = 106,180 ton/year.

In accordance with Nikkei-JBIC carbon quotation index as shown below, the CO_2 is currently transacted at the unit cost of 1,100 yen/t, or10 US$/t. If the CO_2 reduction from this project should be transacted, the annual CER value will be approximately 1.0 Million US$. It is said that the preparation for the Project Design Report for CER approval by an independent consultant costs around 300,000 US$/site, annual revenue increase of 1.0 million is worth to pursue even paying such a consulting fee.

CHAPTER V

V SOCIAL AND ENVIRONMENTAL CONSIDERATIONS

V.1 Permissions and Explanations

V.1.1 EIA and Environmental Permissions

UKL/UPL has been approved by Government of Central Maluku Regency (Approval letter No.660.21/PLH-III/2010, 12 March 2010).

V.1.2 Explanations to Local Stakeholders

A project briefing session for the local residents was held at the Suli village office on October 1, 2010, with the village head acting as the mediator. The main points of the project and predicted environmental impact during construction were explained, and the understanding and cooperation of the residents were obtained. ThePLN, the executing agency, is planned to have a stakeholders meeting at the Tulehu village in near future, too.

V.2 Social Environment

V.2.1 Resettlement

No involuntary resettlement is expected due to the project as the project site is located in the cultivated area.

V.2.2 Minorities and Indigenous Peoples

There is no indigenous people and minorities in the project area.

V.3 Natural Environment

V.3.1 Protected Area

The project area including the connecting transmission line is not located in protected areas, designated by the country's laws or international treaties and conventions.

V.3.2 Ecosystem

The existence of protected species, such as rare or indigenous species, has not been confirmed around the planned project site. The scheduled site is surrounded by fields with low trees and grass, and by groves of sago palm. With obvious human intervention already in place, the environment presents little in the way of unaltered nature. The effect of implementation of the project on the fauna, flora and ecosystem is considered to be insignificant.

V.4 Pollution Control

V.4.1 H_2S

There is no data available, as the project activity still in exploitation stage (drilling activities). H_2S in the geothermal steam will be extracted from the condensers using the gas extractor, and sent to the cooling tower and discharged into the atmosphere from the top where it is diluted and dispersed. This type of treating method is a standard practice employed in geothermal power plants around the world, and in most cases can sufficiently reduce the H_2S concentration at ground level. However, a detailed evaluation should be carried out based on the maximum ground concentration of H_2S calculated through diffusion simulation or wind tunnel experiments.

V.4.2 Noise

The predicted level of noise from operation of the power plant was 53 dB and 48 dB at the nearest hot spring and house of Suli village, and meets the environmental standards (Kep.48/MenLH/11/1996).

V.4.3 Water Quality

Geothermal hot water will be reinjected underground through the reinjection well.
Domestic sewage and wastewater from the power plant will be treated before draining and the effluent standards can be met. The effect by implementation of the project on the surrounding waters, groundwater, and ecosystem is considered to be insignificant.

V.5 Environmental Check List

Environmental checklist for Tulehu project is as follows.

Environmental Check List

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
1 Permits and Explanation	(1) EIA and Environmental Permits	(a) Have EIA reports been already prepared in official process? (b) Have EIA reports been approved by authorities of the host country's government? (c) Have EIA reports been unconditionally approved? If conditions are imposed on the approval of EIA reports, are the conditions satisfied? (d) In addition to the above approvals, have other required environmental permits been obtained from the appropriate regulatory authorities of the host country's government?	(a) Y (b) Y (c) N (d)	(a)UKL/UPL has been prepared. (b)UKL/UPL has been approved by Government of Central Maluku Regency (Approval letter No.660.21/PLH-III/2010, 12 March 2010). (c) The were 8 conditions on UKL/UPL approval letter. PT. PLN GE will take responsibility to follow these conditions (d)No other environmental permissions are required for this project.
	(2) Explanation to the Local Stakeholders	(a) Have contents of the project and the potential impacts been adequately explained to the Local stakeholders based on appropriate procedures, including information disclosure? Is understanding obtained from the Local stakeholders? (b) Have the comments from the stakeholders (such as local residents) been reflected to the project design?	(a) Y (b) Y	(a)A project briefing session for the local residents was held at the SULI village office on October 1, 2010, with the village head acting as the mediator. The main points of the project and predicted environmental impact during construction were explained, and the understanding and cooperation of the residents was obtained. (b)The residents' opinions will be closely considered, and will be reflected in the project as much as possible.
	(3) Examination of Alternatives	(a) Have alternative plans of the project been examined with social and environmental considerations?	(a) N	At the first stage we did not consider the other alternative such as the geothermal potential at Haruku Island located 7 km in front of Tulehu. Tulehu is the closest location from the load center (demand area, Ambon City) and the resource, and the project site of Tulehu was indicated, also there will be no significant negative impact of environmental and social there.
2 Pollution Control	(1) Air Quality	(a) Do air pollutants, such as hydrogen sulfide (H2S) emitted from geothermal power plants comply with the country's standards? Is there a possibility that the emitted hydrogen sulfide will have an impact on the surrounding areas, including vegetation? Are any mitigating measures taken? (b) Do air pollutants emitted from the other project facilities comply with the country's emission standards?	(a) Y (b)	(a)There is no data available. The project activity is still in the exploration stage (drilling activities, exploitation same as the above. 1) H_2S in the geothermal steam will be extracted from the condensers using a gas extractor, sent to the cooling tower and discharged into the atmosphere from the top where it is diluted and dispersed. This type of treatment method is a standard practice employed in geothermal power plants around the world, and in most cases can sufficiently reduce the H_2S concentration at ground level. However, a detailed evaluation should be carried out based on the maximum ground concentration of H_2S calculated through diffusion simulation. 2) Although H_2S level predictions were included in the UKL and UPL, the basis of the data used for the predictions is unknown. 3) In terms of H_2S, existing geothermal power plants meet the environmental standards with almost no impact on the environment around the plants. Therefore, although H_2S emission data for the present project is not available, H_2S is considered to be no particular problem as long as its emissions are within the levels of existing geothermal plants. (b)None of the geothermal power plant facilities output any air pollutant other than H_2S.
	(2) Water Quality	(a) Do effluents (including thermal effluent) from the project facilities, such as power generation facilities comply with the country's effluent standards? Is there any possibility that the effluents from the project will cause any areas not to comply with the country's ambient water quality standards? (b) In the case of geothermal power plants, is there any possibility that geothermal utilization will cause water pollution by toxicants, such as Arsenic (As) and Mercury (Hg) contained in geothermal fluids? If the water pollution is anticipated, are adequate measures considered? (c) Do leachates from the waste disposal sites comply with the country's effluent standards and ambient water quality standards? Are adequate measures taken to prevent contamination of soil, groundwater, and seawater by leachates? (d) Is there any possibility that effluent from well excavation would cause water contamination? If water pollution is anticipated, are adequate measures considered?	(a) Y (b) N (c) N (d) N	(a)Domestic sewage from the power plant facilities will be treated in a septic tank to be provided, while wastewater containing oil will be collected in a drainage tank to separate the oil from the water before draining. With these measures, the effluent standards can be met. (b) Geothermal hot water will not generate water pollution as it will be reinjected underground through reinjection wells. (c)There are no plans for a waste repository for the present project. (d)Effluent from well drilling will be stored in a reservoir provided with permeation prevention measures, and the effluent will be recycled for reuse.

Environmental Check List (Continued)

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
2 Pollution Control	(3) Wastes	(a) Are wastes generated by the plant operations properly treated and disposed of in accordance with the country's regulations? (b) Are wastes generated by the effluents from well-excavation properly treated and disposed of in accordance with the country's standards?	(a) Y (b) Y	(a)Sludge from the cooling tower and waste oil will be appropriately treated and disposed of in accordance with Government Regulation Number 74 Year 2001 concerning Hazardous and Toxic Material Waste Management. (b)Sludge generated by well drilling will be stored in a reservoir provided with permeation prevention measures, and will be appropriately treated and disposed of in accordance with Government Regulation Number 74 Year 2001 concerning Hazardous and Toxic Material Waste Management.
	(4) Noise and Vibration	(a) Do noise and vibrations comply with the country's standards?	(a) Y	(a)Monitoring of existing geothermal power plants of a scale (20 MW) identical to the present project indicates that the noise levels at neighboring villages meet the environmental standards. The predicted level of noise from operation of the power plant was 45 dB at the nearest village (Suli), and meets the environmental standards (Kep.48/MenLH/11/1996).
	(5) Subsidence	(a) Is there any possibility that the extraction of steam will cause subsidence?	(a)	(a)No ground subsidence has been reported in relation to existing geothermal power plants, though the impact of these plants on the ground is unknown. In order not to affect the shallow groundwater that could cause ground deformation, steel pipe (impervious tube) will be inserted deep underground in the production well and the gap between the pipe and the well wall will be cemented。 Consideration has been given to preventing ground deformation, and includes plans to reinject geothermal hot water deep underground via the reinjection wells.
	(6) Other	(a) Are there any odor sources such as H2S, and any anticipated effects? Are adequate odor control measures taken?	(a) Y	(a) See air quality (b)
3 Natural Environment	(1) Protected Areas	(a) Is the project site located in protected areas designated by the country's laws or international treaties and conventions? Is there a possibility that the project will affect the protected areas?	(a) N	(a)The project areas are not located in protected areas designated by the country's laws or international treaties and conventions.
	(2) Ecosystem	(a) Does the project site encompass primeval forests, tropical rain forests, ecologically valuable habitats (e.g., coral reefs, mangroves, or tidal flats)? (b) Does the project site encompass the protected habitats of endangered species designated by the country's laws or international treaties and conventions? (c) Is there a possibility that the project will adversely affect downstream aquatic organisms, animals, plants, and ecosystems? Are adequate protection measures taken to reduce the impacts on the ecosystem?	(a) N (b) N (c) N	(a)The project area is located in a traditional cultivated area that is privately owned. (b)We observed that there are no rare and endangered species defined by the Indonesian Laws and the International Union for Conservation of Nature and Natural Resources (IUCN's) Red List in or around the project area. (c)The mitigation of negative impacts on flora and fauna caused by the project will be done by minimizing the number of trees to be cut.There is no regulation governing trees after cutting in that area.
	(3) Topography and Geology	(a) Is there any possibility that the project will cause a large-scale alteration of the topographic features and geologic structures in the surrounding areas?	(a)	(a)The project will not cause large-scale alteration of topographic features and geologic structures.

Environmental Check List (Continued)

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
4 Social Environment	(1) Resettlement	(a) Is involuntary resettlement caused by project implementation? If involuntary resettlement is caused, are efforts made to minimize the impacts caused by the resettlement? (b) Is adequate explanation of compensation and resettlement assistance given to affected people prior to resettlement? (c) Is the resettlement plan, including compensation with full replacement costs, restoration of livelihoods and living standards developed based on socioeconomic studies on resettlement? (d) Is the compensation going to be paid prior to the resettlement? (e) Are the compensation policies prepared in document form? (f) Does the resettlement plan pay particular attention to vulnerable groups or people, including women, children, the elderly, people below the poverty line, ethnic minorities, and indigenous peoples? (g) Are agreements with the affected people obtained prior to resettlement? (h) Is the organizational framework established to properly implement resettlement? Are the capacity and budget secured to implement the plan? (i) Are any plans developed to monitor the impacts of resettlement? (j) Is a grievance redress mechanism established?	(a) N (b) N (c) N (d) N (e) N (f) N (g) N (h) N (i) N (j) N	No involuntary resettlement is expected due to the project, as the project is located in a cultivated area. (a) (b) (c) (d) (e) (f) (g) (h) (i) (j)
	(2) Living and Livelihood	(a) Is there a possibility that the project will adversely affect the living conditions of inhabitants? Are adequate measures considered to reduce the impacts, if necessary? (b) Is there a possibility that the amount of water (e.g., surface water, groundwater) used and the discharge of effluents by the project will adversely affect the existing water uses and water area uses?	(a) Y (b) Y	(a)the livelihood of the local residents will be affected adversely due to the construction and operation of the project. Compensation plans will follow the government regulations. Additionally, a Community Development Program of PLN (as part of the Corporate Social Responsibility/ CSR program of PLN) will be considered in our compensation plans in order to smooth the land acquisition process. (b)The project will not use much surface water in the operation stage compared with the construction stage. The amount of water used during operation by PLN GE will be in accordance with the standards. So there should not be a severe
	(3) Heritage	(a) Is there a possibility that the project will damage the local archeological, historical, cultural, and religious heritage? Are adequate measures considered to protect these sites in accordance with the country's laws?	(a) N	(a)There are no local instances of archeological, historical, cultural, and religious heritage that would be at risk.
	(4) Landscape	(a) Is there a possibility that the project will adversely affect the local landscape? Are necessary measures taken?	(a) N	(a)There are not any special landscapes, touristic places or scenic spots in or around the project site
	(5) Ethnic Minorities and Indigenous Peoples	(a) Are considerations given to reducing impacts on the culture and lifestyle of ethnic minorities and indigenous peoples? (b) Are all of the rights of ethnic minorities and indigenous peoples in relation to land and resources respected?	(a) N (b) N	There are no indigenous people or minorites in the project area. (a) (b)

Environmental Check List (Continued)

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
4 Social Environment	(6) Working Conditions	(a) Is the project proponent respecting any laws and ordinances associated with the working conditions of the country which the project proponent should observe in the project? (b) Are tangible safety considerations in place for individuals involved in the project, such as the installation of safety equipment which prevents industrial accidents, and the management of hazardous materials? (c) Are intangible measures being planned and implemented for individuals involved in the project, such as the establishment of a safety and health program, and safety training (including traffic safety and public health) for workers etc.? (d) Are appropriate measures taken to ensure that security guards involved in the project do not threaten the safety of other individuals involved, or local residents?	(a) Y (b) Y (c) Y (d) Y	(a)In the Bid Documents, PLN GE plans to include requirements for the contractors to comply with all laws and regulations on working conditions, and to present a compliance plan to this end. (b)The installation of safety facilities will be added to the design after the final plans for the project have been decided. (c)The requirements in the Bid Documents will include the formulation of safety and health plans and implementation of safety education for the workers and other people involved in the project. (d)The requirements in the Bid Documents will also include compliance with public morality and the maintenance of good community relations. In addition, PLN GE means to instruct the contractors to take appropriate measures toward these ends.
5 Others	(1) Impacts during Construction	(a) Are adequate measures considered to reduce impacts during construction (e.g., noise, vibration, turbid water, dust, exhaust gases, and wastes)? (b) If construction activities adversely affect the natural environment (ecosystem), are adequate measures considered to reduce the impacts? (c) If construction activities adversely affect the social environment, are adequate measures considered to reduce the impacts?	(a) Y (b) Y (c) Y	(a)The main impact during construction is air pollution, especially construction dust, and damage to roads due to heavy equipment transportation. Another impact is river water turbidity caused by soil erosion. All of the impacts can be reduced by several mitigation measures (based on UKL/UPL). (b)The project area is located in a traditional cultivated area where there are no rare and endangered species. No important effects on the ecosystem are anticipated. (c)The main impact during construction will be in the form of jobs and business opportunities and disappearance of calm environment. All of the impacts can be reduced by several mitigation measures (based on UKL/UPL).
	(2) Accident Prevention Measures	(a) Does the project have any accident prevention equipment and scheme to store, emit and transport toxic and hazardous materials? Are any measures taken to prevent the pollution of drinking water, for example when the facilities discharge liquid wastes into the rivers in an emergency?	(a) Y	(a)The requirements in the Bid Documents will include the establishment of accident prevention measures. It is common practice in geothermal power plants for kerosene (for use in the emergency generators) and chemicals such as NaOH and H_2SO_4 to be placed at designated locations. In transporting and storing the kerosene and chemicals, measures to prevent accidents will be required, including such means as using appropriate transport routes and the provision of dikes, in
	(3) Monitoring	(a) Does the proponent develop and implement a monitoring program for the environmental items that are considered to suffer potential impacts? (b) What are the items, methods and frequencies of the monitoring program? (c) Does the proponent establish an adequate monitoring framework (organization, personnel, equipment, and adequate budget to sustain the monitoring framework)? (d) Are any regulatory requirements pertaining to the monitoring report system identified, such as the format and frequency of reports from the proponent to the regulatory authorities?	(a) Y (b) Y (c) Y (d) Y	(a) PLN GE has developed a monitoring program (UPL). The program requires additional monitoring of the nearby hot spring and residential wells. (b)In the monitoring program, monitoring is conducted periodically in each phase. For example, water monitoring is done quarterly, air monitoring biannually etc. (c) A HSE team is stationed in the project area, under a supervision of HSE manager who is supported with adequate budget and personnels. The HSE team is in charge of monitoring safety controls and implementing mitigation measures when the results of monitoring exceed the standard. (d)PT PLN Geothermal will conduct monitoring and report every six (6) months to the Environmental Protection Office of Central Maluku Regency, as mentioned in the approval of the UKL-UPL Report.
6 Note	Reference to Checklist of Other Sectors	(a) Where necessary, pertinent items described in the Power Transmission and Distribution Lines checklist should also be checked (e.g., projects including installation of electric transmission lines and/or electric distribution facilities).	(a)	(a)Construction of the transmission line does not involve resettlement of residents, as there are no houses on the planned route. There is no large-bird habitat around the planned transmission line route, and the area is not confirmed to be on the migratory routes of large birds. The existence of a transmission line is thus not expected to affect birds.
	Note on Using Environmental Checklist	(a) If necessary, the impacts to transboundary or global issues should be confirmed (e.g., the project includes factors that may cause problems, such as transboundary waste treatment, acid rain, destruction of the ozone layer, or global warming).	(a) N	(a) Not Necessary

1) Regarding the term "Country's Standards" mentioned in the above table, in the event that environmental standards in the country where the project is located diverge significantly from international standards, appropriate environmental considerations are required to be taken.
In cases where local environmental regulations are yet to be established in some areas, measures should be taken based on comparisons with appropriate standards of other countries (including Japan's experience).
2) The environmental checklist provides general environmental items to be checked. It may be necessary to add or delete an item taking into account the characteristics of the project and the particular circumstances of the country and locality in which it is located.

CHAPTER VI

VI CONCLUSIONS AND RECOMMENDATIONS

VI.1 Summary of Study Results

A feasibility study for construction of 20 MW geothermal power plant in Tulehu geothermal field has been conducted. The results of the current study can be summarized as follows.

- The geothermal resource potential in Tulehu area is sufficient for a development of 20 MW geothermal power plant.
- Banda-Hatuasa fault, Banda fault, and R2 fault are promising development targets.
- The drilling results of TLU-01 confirmed the existence of high-permeability reservoir. Besides, many data indicated that the reservoir temperature exceeds 200°C from relatively shallow region to deep region.
- It was confirmed that the bottom depth of cap rock layer is approximately -300m a.s.l in the vicinity of TLU-01 drilling site.
- The number of necessary wells for 20 MW power generation was estimated, and the results are shown in the following table.

Power Generation Type	Initial Wells (Production)	Initial Wells (Reinjection)	Makeup Wells (Production)	Makeup Wells (Reinjection)
Single Flash	4 (+ 1backup)	6	3	4
Double Flash	3 (+ 1backup)	4	3	3

- Based on the geothermal resource study of the currently available data and the development plan, the four (4) sets of plans for the four possible types of geothermal power plant are studied: 2 x 10 MW Single Flash Condensing System, 1 x 20 MW Single Flash Condensing System, 2 x 10 MW Double Flash Condensing System, and 1 x 20 MW Double Flash Condensing System.
- As for the possible use of a geothermal binary system, this is considered only in general terms at this very initial stage of the project study. Most of the factors and conditions for the detailed study of the geothermal binary system cannot be confirmed at this stage in the feasibility study, and further consideration of a geothermal binary system is adjourned until the next Engineering Service stage.
- The double flash system and binary system are more suitable for the Tulehu geothermal project than the single flash system because of effective utilization of the geothermal energy for the Tulehu geothermal fluid which is anticipated to contain a large volume of hot water (anticipated steam-hot water ratio 1:4.5).
- A unit capacity of 10 to 20 MW for Tulehu geothermal power plant could be still tolerable, considering the future scale of the Ambon electric power system.
- The current outputs of geothermal resource study and its development plan are enhanced with some assumptions based on knowledge and experience, since the currently available data and

information are limited. The geothermal resource evaluation should be re-examined in the light of additional data as more information on the drilling and testing of the further exploratory wells becomes available and in the light of meteorological observations at the project site. The geothermal resource development plan and the power plant plan will need to be reconsidered accordingly before starting project implementation.

- The project cost estimation was attempted for the four cases of power plant design, and each case was examined by economical and financial evaluations. The results indicated that double flash system would be advantageous for 20 MW power generation in Tulehu field. For the unit capacity of the power plant, the results indicated that both of 2 x 10 MW and 1 x 20MW might be feasible. However, a comprehensive investigation suggested that 1 x 20MW configuration was advantageous for the project implementation.

VI.2 Recommendations

The issues yet to be clarified in the current study are summarized in what follows.

- The intrinsic reservoir temperature of TLU-01 is uncertain due to remarkable cooling effect by drilling mud.
- TLU-01 encountered Banda fault at a depth of 927m, which is much smaller than initially planned drilling depth, 1,500m. It is likely that TLU-01 tapped just an upper-most portion of the reservoir. Consequently, the reservoir characteristics at deep portion of Banda fault is not clearly delineated.
- Due to the lack of production tests, the data for delineating the characteristics of steam/brine in the vicinity of Band fault are missing.
- The natural water level of TLU-01 was approximately 70m below its well head. If the water level in (future) reinjection area would be the same, reinjection strategies must be carefully studied in order to maintain the necessary reinjection capacity.

For clarifying the issues listed in above, the Study team recommends to conduct the following investigations in the near future.

- Drill an exploratory well of approximately 1,500m deep (preferably from a drilling pad which is different from TLU-0 pad), and conduct a production test using TLU-01 and the newly drilled well.
- In the production test, the chemical composition of geothermal fluid and the concentration of non-condensable gas should be clarified.
- Run static temperature loggings in TLU-01 once in a month in order to monitor its temperature recovery. The temperature recovery data can be utilized in assessing the possibility of spontaneous fluid production in TLU-01.
- Though the additional exploration well drilling and production testing recommended above, the steam conditions (pressure, temperature, and NCG volume and composition) hot water

quantity and scaling characteristics of geothermal fluid will need to be clarified for the power plant basic planning and design for the project implementation.

- The meteorological observation at the project site for two (2) years should be commenced immediately, and the meteorological conditions (temperature, atmospheric pressure, wet bulb temperature, wind direction, wind speed, rainfall, etc,) for the project design should be determined.
- The geothermal power plant plan will need to be reconsidered according to the abovementioned steam conditions, geothermal fluid characteristics, and meteorological conditions, and the optimum plan of power plant system (double flash, single flash or binary) and unit generation capacity should be determined in the process of basic plan and design of the geothermal power plant before starting project implementation.
- Evaluate the environmental impacts of H_2S gas by conducting a diffusion simulation or a wind tunnel experiments based on H_2S concentration and power plant design.